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## Review Article

# DYNAMICS OF INSECT-PLANT RELATIONSHIPS AND ITS APPLICATIONS IN CROP PRODUCTION

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**Abstract-** Plants and insects have coexisted for at least four hundred million years, and have evolved a variety of antagonistic and mutualistic relationships. As plants are attached by insect herbivores, they have evolved different defense mechanisms to reduce insect attack. Constitutive defenses are present continuously in the plant, but the induced defenses are activated only after the insect attack. The activation of induced defenses is result of highly sophisticated signaling system. In course of time, insect have also evolved several mechanisms to overcome plant defense barriers. In pollination, insects pollinate the plant in exchange of nectar and pollen, thus both are mutually benefitted. In addition, various carnivorous plants are known that have developed mechanisms to trap and digest insects in order to supplement their food requirement. Thorough knowledge of insect plant relationship can be exploited for sustainable crop production.

**Keywords**- Antagonistic, Mutualistic, Constitutive, Pollination, Carnivorous.

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### Introduction

Long term coexistence had led to the evolution of different kinds of relationships between insects and plants. Insects are known to damage the plants in different ways either by feeding on them or transmitting harmful plant pathogens [11]. In order to reduce insect attack, plants have evolved various defense mechanisms. Plant can differentiate physical damage and insect damage by recognizing their feeding pattern; chemicals present in their saliva and oviposition fluids [13, 27]. After recognition of insect pest attack, the information is conveyed through various signaling systems [26]. In counter response, insects have also evolved different strategies to overcome plant defense mechanism by detoxification of toxic plant chemicals or sequestering them and utilizing them for their own defense [30, 31]. Plants have also developed mutualism relationship with insects, as majority of the flowering plants are pollinated by insects. In return for pollen transfer, plants provide food to its pollinators in the form of nectar and pollen [16]. Carnivorous have evolved the mechanism to trap the insects to fulfill their nutrient requirement, as the soil in which they are growing is deficient in nutrient [44].

### Concept of Co-evolution

Co-evolution is a change in the genetic composition of one species in response to a genetic change in another species. Ehrlich and Raven were the first to apply the term in the context of insect-host plant co-evolution based on their study of Monarch butterfly-milkweed plant interactions [17]. From their observations, they proposed a scenario that they called co-evolution, as follows.

1. Mutations that provide a plant with a new defensive chemical are fixed in the species by the natural selection that various species of herbivorous insects collectively impose.
2. Because of the new defense, the plant becomes resistant against insects, previously known to attack on them.
3. Over the generations, this defense passes to its progeny and shared by various taxons of this plant.
4. In the course of time various species of herbivorous insects, from diverse groups not necessarily closely related to those that had formerly fed on the ancestral plant, become adapted to one or more members of the plant clade, which provide underutilized resources, or 'empty niches'. The insects' adaptation consists partly of tolerating the plants' characteristic chemical defense, or even using it as a stimulant to feeding or egg-laying.
5. Each such insect species gives rise to a clade of descendants that feed on different species in the plant clade. Thus related species of insects feed on related species of plants, although the diversification of the insects that came to be associated with them.
6. Over the period, the evolution may restart as some plants may acquire new defenses.

### Insect Herbivore

Herbivorous insects cause injury to plants either directly or indirectly in their attempts to secure food. Direct injury either by Chewing the leaf tissue *e. g.*, Defoliator, Leaf miner, Borers, *etc.* or by piercing and sucking from various plant parts *e. g.,* Aphids, Jassids, *etc*. Indirect damage either by disseminating plant diseases *e. g.,* Whitefly is vector of cotton leaf curl virus either by transporting the harmful insects from one plant to another. Ant carries aphids, mealy bugs, *etc.* from one plant to another. They care for and protect these insects in exchange to feed on the honey dew excretion of these pests [11]. Knowledge of insect plant relationship led to discovery of certain botanical insecticides [38]. Also efficiency of pollination can be increased by attracting pollinator using artificial attractant [39]. In this review various insect-plant relationships are discussed which can be used manipulated for insect pest management and efficient utilization of pollinator.

### Type of insect herbivore based on their feeding specialization

Generalists (Polyphagous) herbivore are those, which feed on various hosts plants belonging to different plant families. Specialist's herbivores are those, which feed on one (monophagous), or few (oligo-phagous) plant species belong to the same family. The generalists can tolerate a various forms of defenses mechanism of most host plants, while they are unable to feed on plants having more advanced defense mechanisms. Host plant defense chemicals act as cues to search host plant and also as feeding stimulant for specialist's herbivore insects [9].

**Plant reaction to insect feeding**

During the process of co-evolution plants have evolved defense mechanism to reduce herbivore pressure on them. These defense mechanisms may be present constitutively or they may be induced only after the herbivore feeding. The constitutive defenses are continuously present in the plant, but the induced defenses come into action after the recognition of the insect herbivore.

**Recognition of insect feeding**

Plants can distinguish between insect feeding and mechanical damage by recognizing, feeding pattern of insects, chemical present in insect oral secretion and oviposition fluids.

**Recognition of insect feeding pattern**

Plants can determine the quality and quantity of leaf tissue damage. For example, insects while feeding remove similarly size bits of the leaf tissue in a highly definite mannere. g., Simulation of caterpillar feeding by mechanical wounding of *Phaseolus lunatus* (lima bean) resulted in the emission of plant volatiles of same quantity as released when by an actual caterpillar feeding [27].

**Recognition of insect feeding by chemical compounds present in insect oral secretions**

Plants can also recognize insect attack based on the chemical compounds present in the insect oral secretion [Table-1][5].

**Table-1** *Herbivore associated elicitors in insect oral secretions*

| Elicitors | Insect species | Plant species |
|---|---|---|
| Glucose oxidase (GOX) | *Helicoverpa zea* | *Nicotiana tabacum* (tobacco) |
| b-Glucosidase | *Pieris brassicae* | *Brassica oleracea* (cabbage) |
| N-Acyl-amino acids (FACs), Volicitin | *Spodoptera exigua* | *Zea mays* |
| Caeliferins | *Schistocerca americana* | *Zea mays* |
| Inceptin | Produced by degradation of a plant ATP synthase during folivory by *Spodoptera frugiperda* | *Vigna unguiculata* (cowpea) |

**Recognition of insect by chemical present in oviposition fluids**

Chemical compounds present in insect oviposition fluids can also recognize by plant, which lead to activation of plant defense mechanisms *e.g.,* oviposition fluid of Pea weevil, *Bruchus pisorum, containing bruchin, induce* tumour-like growths beneath the egg, which prevent the larval entry into the pod of Pea, *Pisum sativum* [13].

**Events after recognition of insect feeding**

After the recognition of insect herbivore, there is occurrence of certain events at insect feeding site. They perform two functions at plant-insect interface: activation of defense genes at wounding site, after this activation of genes that generate systemic signaling compound to activate defense genes in undamaged tissues [26] early events and their mechanisms are describe as follow:

**Electrical signaling**

The plant plasma membrane can recognize environment stimulant as it is in direct contact with the environment and lead to the initiation of cascade events resulting in a possible plant response. Biotic and abiotic stress will lead to an alteration in ion movement across the cell plasma membrane. The change in membrane potential lead to generation of action potential (electric signal), which travels through the entire plant from the point where the signal was induced and activate plant defense mechanisms [15, 26].

**$Ca^{2+}$ Homeostasis**

In healthy cells the cytoplasm $Ca^{2+}$ concentration is lower than in the cellular organelles, herbivore attack induce various $Ca^{2+}$ channels, leading to increase in cytoplasm $Ca^{2+}$ concentration. This increase in the cytoplasmic $Ca^{2+}$ triggers: The activation of various ions channels, which leads to plasma membrane depolarization; The activation of protein kinase ($Ca^{2+}$-binding protein kinases (CDPKs) that lead to the expression of defense genes; The activation of production of $H_2O_2$; The activation of protein kinase that lead to the formation of the jasmonic acid [25, 36].

**Hydrogen peroxide ($H_2O_2$)**

Production of the hydrogen peroxide is called oxidative burst. It performs the following functions; it is itself toxic to the herbivore, activation of defense genes locally and systemically and activation of synthesis of jasmonic acid [4, 23].

**Systemic signaling**

Information of insect herbivore attack is conveyed from point of attack to the other undamaged plant parts through systemic signaling, resulting in the expression of the defense genes in the undamaged plant parts. Various compounds are known that are involved in systemic signaling: systemin, jasmonic acid and oligo-galacturonides.

**Oligo-galacturonides**

Oligo-galacturonic acid is formed by the action of Polygalacturonase (PG) on plant cell wall pectin, which is constitutively present in plants. Insect feeding causes mixing of PG with plant cell wall content and generation of oligo-galacturonic acid [3].

**Systemin**

It is present in phloem parenchyma cell in the form of pro-system in. As a result of wounding by the insect herbivore, the system in peptide is released from the *C*-terminal end of its precursor pro-system in by the activity of proteolytic enzymes. After this, system in enters the apoplast, where it binds to a membrane-bound receptor (SR160) and lead to an intracellular signaling cascade. This involves the activities of a MAP kinase (MAPK), leading to the release of polyunsaturated fatty acids (PUFAs) by phospholipases, from the membranes. This acid act as a precursor for the biosynthesis of JA. The biosynthesis takes place in the chloroplast and peroxisome within the companion cell through hexadecanoid pathway, after which it transported long distances via the phloem and activates the defense genes in the undamaged plant parts [28, 35, 42].

**Plant defense mechanism against insect attack**

Plants have evolved direct defenses and indirect defense mechanism against insect herbivore

**Direct Defense Response**

In the direct defense mechanism, plants rely on their own physical barriers or produce chemical compounds to repel or kill the insect. Direct defense mechanisms are described below.

**Secondary metabolites**

The secondary metabolites are used by the plant against insect herbivore and microbial pathogen infection, to attract pollinators and as a mediator in plant-plant communication. They are present constitutively or induced upon plant organism interaction. Various secondary metabolites are known which impart resistance in plants to its insect herbivore [Table-2][19].

**Defense proteins**

Plants produce a number of defense proteins that decrease the insect herbivores ability to successfully utilization of the host plant. Anti-digestive proteins reduce the enzymatic digestion of the food, whereas anti-nutritive proteins reduce the utilization of digested food by modifying the chemical structure. Various types of defense proteins are known to be present in the plant such as protease inhibitors, α-amylase inhibitors, lectins and polyphenol oxidases, which are described as follow:

**Table-2** *Secondary metabolites in defense against insect herbivore*

| Compound | Group | Crop | Insect Pest |
|---|---|---|---|
| DIMBOA | Benzoxazinoide | Maize | *Ostrinia nubilalis* |
| Dhurrin | Cyanogenic glucosides | Sorghum | Southwestern corn borer, *Diatraea grandiosella* |
| Isothiocyanates | Glucosinolates | White mustard, *Sinapis alba* | Flee beetle, *Phyllotretacruciferae* |
| Demissine | Alkaloids | Nightshade potato, *Solanum demissum* | Colorado beetle, *Leptinotarsa decemlineata* |
| Gossypol | Phenolics | Cotton | Bollworms |

### Protease inhibitors
They inhibit the proteolytic activity of midgut enzymes and there by decrease the availability of amino acids. The first gene of plant origin to be used in transgenic crop protection was that isolated from cowpea encoding a double-headed trypsin inhibitor (CpTi) and transferred in tobacco. The expression of CpTi in tobacco afforded significant protection against *Heliothis virescens* [12].

### Alpha-amylase inhibitors
They inhibit the activity of insect gut alpha-amylases, which are required for the digestion of starch. Transgenic pea seeds expressing alpha-amylase inhibitor derived from common beans were found to exhibit increased resistance against the pea weevil, *Bruchu spisorum* [12].

### Lectins
They are plant derived sugar binding proteins, they bind to glycoprotein lining of the intestine of the insect herbivores and inhibits nutrient absorption. Lectins from wheat (wheat germ agglutinin, WGA) and the snowdrop plant (*Galanthus nivalis* agglutinin, GNA) are inhibitory to the sap-sucking homopteran pests such as aphids, leafhoppers and plant hoppers. Wheat germ agglutinin is anti-metablolic, anti-feedant and insecticidal to the mustard aphid, *Lipaphis erysimi* [14].

### Polyphenol oxidases
They cause oxidative conversation of phenolic compounds into quinines, which cause cross-linking of dietary proteins during feeding; thereby decreasing the proteins' digestibility in the herbivores' gut [8].

### Alarm pheromone
Scientists at Rothemsted Research (UK) have made genetically modified wheat, by transferring (E)-*b*-farnesene synthase gene from peppermint (*Mentha peperita*), which repel the aphids from the plant instead to killing them [12].

### Reallocation of nutrient
Plants are known to reallocates valuable nutrient resources away from herbivore feeding site to other safe site. Spotted knapweed (*Centaurea macuosa*) allocates more nitrogen to the shoots upon attack by root borer, Knapweed moth (*Agapetazoegana*) [29].

### Morphological characters
Plants have also evolved certain morphological and anatomical barriers against its herbivores, which are described below.

### Trichomes
Plant surfaces are covered by trichomes (hairs), which impart resistance against insect herbivore. Non-glandular trichomes on cotton varieties impart resistant to jassids as their proboscis and ovipositor are not able to reach leaf surface. In contrast to this, they are more preferred by *Helicoverpa armigera* as adult female use them as foothold while laying eggs. Glandular trichomes have glands at their base, upon mechanical injury by inset feeding, they exudates gummy substances which entrap the insect and lead to starvation [30]. Trichomes production also induced after insect herbivory *e.g.,* there is increase in trichome number on the leaf of *Salix cinerea* in response to feeding by adult leaf beetle, *Phratoria vulgatissima* [10].

### Waxes
Waxes covering on plant surface prevent insect feeding. *e. g.,* bloom cultivars of sorghum, having wax covered stem are resistant to stem borer, *Chilopartellus.* Because the neonate larvae experience difficulty in climbing and their prolegs get stuck in the wax [30].

### Nutrient imbalance
Many plant exert nutritional hurdle to its insect herbivore *e.g.,* Mudgo variety of rice is resistant to Brown plant hopper, *Nilaparvata lugens* due to deficient in essential amino acid such as asparagine [41].

### Hypersensitive Response (HRs)
Hypersensitive response is a common resistance mechanism against microbial pathogens.It is a localized cell death in the host plant at the site of infection by a pathogen. In plant-insect interactions, this form of resistance has received less attention. *Brassicnigra*is known to kill eggs of the *Pierisrapae* by producing a necrotic zone at the base of the eggs, thereby apparently desiccating it [42].

### Latex and resins
Several plants like Rubber wine, *Cryptostegia grandiflora* and Ponderosa pine, *Pinus ponderosa* store latex and resins in specific ducts within vascular tissue. Their secretion is induced by herbivore feeding, may trap or intoxicate the herbivore.

However, specialist insects such as fir engraver beetle, *Scolytus ventralis* overcome the defense of Ponderosa pine, *Pinus ponderosa* by cutting across resin ducts and in that way prevent the movement of toxic resin to the feeding site [33].

### Indirect Defense Response
In “indirect defense” plants rely on other organisms to reduce enemy pressure. This is achieved by producing volatiles, extra floral nectar, food bodies and nesting or refuge sites.

### Plant Volatiles
Chemically these are aldehydes, alcohols, esters and various terpenoids. They are released from various plant parts. These are used by the plant to attract pollinators and predators or repel herbivores. They are also involved in communication within or between plants.

### Volatile organic compound in Tritrophic interactions
*Z. mays* when attacked by Armyworm, *S. littoralis* release terpenoids (*(E)-β-farnesene* and *(E)-α-bergamotene*) which attracts its parasitoid *Cotesia marginiventris* [37].

### Volatile organic compound in below ground Tritrophic interactions

Maize roots release sesqui-terpene, (E)-b caryophyllene in response to feeding by larvae of the beetle, *Diabrotica virgifera* which attracts its entomopathogenic nematode, *Heterorhabditis megidis* [34].

### Volatile organic compound in Fourth trophic interaction

Hyper-parasitoids use herbivore-induced plant volatiles to locate their parasitoid host e. g., *Lysibia nana* (Ichneumonidae) that is hyperparasitoid of primary parasitoids in the genus *Cotesia* (Hymenoptera: Braconidae), uses volatile plant cues induced by *C. glomerata*-parasitized caterpillars, *Pieris rapae* to locate pupae of [32].

### Domatia

Plants can offer predators like ants, mites and bugs small chambers in the juncture of the midrib and the vein used as domatia.

A strong relationship is found between Ant, *Technomyrmex albipes* and Plant, *Humboltia spp*. Removal of ant domatia of *Technomyrmex albepes* increase herbivory, but there is no significant difference when they removed the domatia of other ants [18].

### Food bodies (FBs)

Food bodies (FBs) are cellular structures containing mainly carbohydrates, proteins and lipids. They serve as food for ants and are thereby used to attract predators *e.g.,* Acacia plants use obligate Ant mutualists as a constitutive indirect defense mechanism. Ants completely rely of food bodies provided by their hosts [20].

### Extra-floral nectar (EFN)

EFN is secreted on vegetative plant parts such as leaves, shoots *etc.* to attract predators and parasitoids. Presence of insect herbivore can increase EFN production*e. g.*, feeding by *Spodoptera littoralis* increase extra-floral nectar production on the leaf of Cotton and Castor [45]

### Insect mechanism to overcome the plant defense mechanism

Phytophagous insects have evolved mechanisms to overcome multiple hurdles posed by host plants, which are described below.

### Overcoming the nutritional hurdle

#### Increasing the feeding rate

Several insects species are known to increase feeding rate of food having low nutrient levels *e. g.,* when larvae of the *Pierisrapae* are fed plants with different nitrogen levels; they are able to adjust their food intake and assimilation rate to stabilize the rate of nitrogen accumulation [40].

#### Modifying the nutritive quality of host tissues

Hemipteran insects, while feeding, inject their saliva into the plant. In the process, cell tissues are broken down and the nutrient flow is diverted to the infested leaves, thus improving their nutritional quality [30].

#### Establishing associations with microorganisms

Insects which feed on nutritionally deficient plant part harbor extra-cellularly or intra-cellularly symbionts, which modify the food resource prior to ingestion by the insects e. g., Ambrosia beetles ( Scolytidae) which feed on the nutrient deficient xylem of woody plants carry the spore of fungus (*Ambrosiella*) in special cuticle structure known as mycangia. They spread the spore of the fungus, when they bore into the xylem tissue. Fungus helps in digestion of the cellulose [7].

### Overcoming the Secondary plant metabolites

Insects have evolved different mechanisms to overcome secondary plant metabolites, which are described as follow:

#### Rapid excretion

Tobacco horn worm, *Manducasexta*, which feeds on tobacco containing a toxic alkaloid that is nicotine, insect has developed mechanism to rapidly excrete nicotine before a toxic dose can accumulate in the body [38].

#### Enzymatic detoxification

Insects possess various enzyme systems, which can detoxify any foreign chemical compounds *e.g.,* cytochrome P450-dependent monooxygenases, reductases, esterases, epoxide hydrolase, glutathione S-transferases *etc.* Their activity gets increase when insect feeds on plant containing secondary plant metabolites *e. g.,* glutathione S-transferases activity increase in *Helicoverpa armigera*, when fed on Tomato and Tobacco treated with phytohormone [31].

#### Detoxification of inducible defense chemicals

The squash beetle, *Epilachna tredecimnotata*, make a circular trench in a leaf, before feeding on the leaves of the squash, *Cucurbita moschata* and feed on the encircled materials. It has been shown that the induced chemical (cucurbitacin) is rapidly mobilized to the damaged leaf tissues of *C. moschata*. This behavior of the *Epilachna* prior to feeding is, therefore, an effective adaptation to overcome the mobilization of the feeding inhibitor [30].

#### Use as pheromone

But some insects, instead of detoxifying plant poisonous chemicals, sequester and deploy the poison for their own pheromone system *e. g.,* the female of the western pine beetle, *Dendroctonus brevicornis* is attracted to its host by the terpene mixture of pine (oleoresin). The female attracts the male by a pheromone, one of whose chemical constituents, myrcene, has been sequestered from the tree's oleoresin [30].

#### Use in defense

Larvae of the monarch butterfly, *Danaus plexippus* sequester and store cardiac glycoside, while feeding on milkweed, *Asclepias humistrata*. It is stored in various body parts and passed up to adult stage, and provide defense against avian predators such as the blue jay, *Cyanocitta cristata*. In one study, soon after eating the monarch butterfly, the bird predator became violently ill and vomited. The jay rapidly learned to refuse these larvae [30].

### Avoidance

Insects exhibit an array of avoidance behaviors, such as minimizing direct exposure to plant secondary metabolites and, in certain instances, blocking inducible pheromonal plant-plant communication and avoiding physical plant defenses, which are described below.

#### Avoiding plant secondary metabolites

The mode of insect feeding can reduce exposure of the insect to plant allele-chemicals *e.g.* furano-coumarins in the plant family, apiaceae, are localized in seeds, within storage structures called vittae. The tarnished plant bug, *Lyguslineo laris* sucks fluids from seeds without contacting the vittae [30].

#### Avoiding pheromonal communication between plants

Some insect herbivores evolve strategies to suppress pheromonal communication between damaged plants through the herbivore secretions that block the release of communication substances from the wound *e.g.,* when potato plant, *Solanumly copersicum* was mechanical wounded and subsequently treated with gut regurgitant of colorado potato beetle, *Leptinotarsa decemlineata* there was decrease in relative expression of protease inhibitor gene [24].

#### Avoiding Physical defense

Larvae of the nymphalid butterfly, *Heliconius charithonia* develop mechanism to feed on a host plant, *Passiflora lobata* that is presumably protected by hooked trichomes. The larvae before feeding on the leaf lay silk mats on the trichomes and remove their tips by biting [6].

### Insect pollination

Insects have also evolved mutualistic relationship with plants. Majority of the flowering plants are pollinated by insects and in return for pollen transfer; plants provide food to its pollinators in the form of nectar and pollen [16].

**Adaptations in insect-plant pollination system**

Insect pollinated plants have pollens with sculptured structure and are covered with sticky substances, so they can easily adhere to insect body. Likewise hairs on the insect body aid in carrying the pollen from one flower to the next [16].

**Attractants for insect pollinator**

Attractants for pollinator can be categories into two groups: Primary attractants - which satisfies the demands for foods e. g., pollen and nectar. Secondary attractants - they advertise the presence of the primary attractants *e. g.,* color, scent and shape of the flowers.

**Flower colors**

A particular flower color is associated with its pollinator *e. g.,* Bees can recognize four color groups as yellow, blue-green, blue and ultraviolet, but are not attracted toward red color flowers. Also different species of a plant with different flower color are pollinated by different pollinator *e. g.*, *Aquilegia formosea* has red flowers and is pollinated by humming-bird but, *A. pubescens* has whitish flowers and is pollinated by the hawk moths [16].

**Flower shapes**

The flowers which are pollinated by bumble bee as in plant, *Digitatis purpurea* the flowers are sufficiently wide (bell shaped) so insect can easily creep into it. In contrast to this, the flowers which are pollinated by butterfly like in *Calopheria spp.,* the corolla islong narrow tube, as adapted to its long proboscis [16].

**Sex pheromone**

Flowers of *Ophrys speculum*, an orchid imitate the female wasp, *Campsoscolia ciliata* by producing sex pheromone to attract male wasps. Male wasps are attracted to the flowers and carry out pseudocopulation, in doing so they visit numbers of flower and aid in pollination [2].

**Obligate relationships**

**Fig - wasp pollination mutualism**

The pollination in *Ficuscarica*is carried out by Fig wasp, *Blastophaga psenes.* The female of this wasp lays eggs inside ovules of the flowers, which develop into the galls. The wingless male wasps emerge first and fertilize the female, which is still inside the galls. The females when emerge from galls between newly open anthers are loaded with pollen and carry it to the next flowers [16].

**Darwin's Madagascan Hawk Moth prediction**

In 1862, Darwin found that one orchid, *Angraecum sesquipedale* with long green nectary of eleven and a-half inches long. Because this orchids is moth pollinated, so Darwin predicted that there may be a moth with proboscis capable of extension to a length of between ten and eleven inches and in 1903, Rothschild and Jordan described a large Madagascan moth, *Xanthopan morgani* with proboscis of about 12 inches [22].

**Reward strategy for the pollinator**

As in nectar production, plant expense energy in term of carbon. Plants overcome this by reducing nectar and directing the energy saved to the seed production. Some plants do this by cheating their con specifics and save energy by secreting little or no nectar at all *e.g.,* In *Cerinthe major*, about 25% of the flowers produced copious amounts of the nectar but the remaining flowers secreted only small quantities [38].

Some plant species, *Commelina tuberosa* produce flowers with two kinds of stamen: some with reproductive anthers that produce normal pollen, and some with reward anthers. Reward anthers are brightly colored to attract potential pollinators, and produce limited quantities of nector [38].

**Signaling to the pollinator**

In order to increase pollination efficiency plant signal to its pollinators which flowers had already been pollinated by previous visitors. Many plants do this by changing flower colors, scent production, and even geometric outline *e. g.,* a spectacular color change from white to purple takes place in *Viola cornuta* in response to pollination. Flowers of the orchid, *Catasetum maculatum* cease odour production entirely within minutes after pollination [38].

**Carnivorous Plants**

The soils in which these plants are growing are lack in nutrient. In order to supplement their food requirement, they can trap and digest other organisms. For this, they possess traps with special cells for digesting the prey and absorbing the resulting food [Table-3][44].

**Table-3** *Examples of carnivorous plants*

| Family | Genus | Popular name |
|---|---|---|
| Byblidaceae | *Byblis* | Rainbow plant |
| Cephalotaceae | *Cephalotus* | Albany pitcher plant |
| Droseraceae | *Dionaea* | Venus fly trap |
| Lentibulariaceae | *Pinguecula* | Butterwort |
| Sarraceniaceae | *Darlingtonia* | Cobra lily |
| Nepenthaceae | *Nepenthes* | Monkey cup |

**Application of knowledge of insect-plant relationships**

**Host plant resistance**

Knowledge of insect-plant relationships lead to discovery of plant traits imparting resistance to its insect herbivore. These traits can be utilized in breeding for insect resistance and making transgenic. *e.g.,* high level of resistance to BPH and WBPH has been transferred from wild rice, *Oryza officinalis* to cultivated rice, *Oryza sativa* through wide hybridization [30]. Transgenic pea seeds expressing alpha-amylase inhibitor derived from common beans were found to exhibit increased resistance against the pea weevil, *Bruchu spisorum* [12].

**Delay in biotype development**

Cultivation of resistant variety year after year on large area leads to selection of insect population which can survive on resistant variety. Vertical (monogenic) resistance can be easily overcome by biotype than horizontal (polygenic) resistance. The durability of vertical resistance can be increased by sequential release of cultivar, gene pyramiding or stacking and gene rotation [1].

**Crop diversity**

Increasing crop diversity by planting different crops intermingled is one type of cultural control strategy that can make agro ecosystems less favorable to insect pests / and or more favorable to natural enemies. This can be explained with following theories

**The disruptive crop hypothesis**

According to this theory volatiles emitted from non-hosts intercrops may mask the odour of the host plants, thereby disrupting host finding behavior of the pest insects *e. g.,* Brussels sprouts when intercropped with the herbs sage (*Salvia officinalis*) and thyme (*Thymus vulgaris*) reduces egg laying of the diamondback moth *Plutella xylostella* than pure stands [38].

**Natural enemies hypothesis**

Natural enemies of insect pest species are expected to be more abundant in diverse cropping systems than in monoculture *e. g.*, intercropping of molasses grass, *Melinis minutiflora* in maize reduced damage by armyworm, *Spodoptera littoralis.* Because the grass constitutively emits a compound similar to the one released by maize in response to caterpillar damage to attract its parasitoid [21].

**Trap cropping systems**

Trap crops are plant stands around or in certain parts of a main field that attract pest insects so that the main crop escapes pest infestation *e. g.,* planting of Sudan grass, *Sorghum vulgare* Sudanese around maize fields reduced infestation on maize by *Chilopartellus* [12].

**Plant derived insecticides**

It is evident that most herbivorous insects are inhibited from feeding by secondary compounds in non-host plants. they can be extracted and utilize against insect pests. Nicotine, rotenone and pyrethrins have been used extensively and are effective insecticides that, because they degrade rapidly, do not accumulate in the food chain [38].

**Boosting the crop production by manipulating pollinators**

Pollinators are attracted by specific odour from the flowers. So, pollinators can be attracted by application of artificial scent on the crop to increase pollination e.g., application of bee attractants (Bee-Q and Fruit Boost™) increased the numbers of bee foragers on Niger and enhanced the seed set, seed weigh and germination of Niger [39].

**Conclusion**

Relationships between insect and plant are very complex and dynamic. Early events in insect-plant interactions are poorly studied. From a biotechnological and breeding point of view, understanding the defense systems of plants and learning how to apply the knowledge is of course of huge interest. Hypersensitive response in some plant-herbivore interaction, show the presence of R-genes, they should be identified in other plants. Behavior of pollinators can be modified in order to increase crop production.

**Abbreviations:** GOX-Glucose Oxidase; CDPKs-$Ca^{2+}$-Binding Protein Kinases; MAPKMAP Kinase; PUFAs-Polyunsaturated Fatty Acids; SR160-Systemin Receptor 60; DIMBOA-2,4-Dihydroxy-7-Benzoxazolinone; CpTi-Cowpea Trypsin Inhibitor, WGA-Wheat Germ Agglutinin; GNA-GalanthusNivalis Agglutinin, BPH-Brown Plant Hopper; WBPH-White Backed Plant Hopper.

**Author contributions**: literature related to insect-plant relationships was reviewed in the context of crop production.

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