OPEN ACCESS

Middle East Research Journal of Agriculture and Food Science
ISSN: 2789-7729 (Print) & ISSN: 2958-2105 (Online)
Frequency: Bi-Monthly
DOI: 10.36348/merjafs.2024.v04i02.005

KUWAIT SCHOLARS PUBLISHER
Website: http://www.kspublisher.com/
Email: office@kspublisher.com

Mechanism of Plant Resistance to Insects, Weeds and Pathogens

Esuyawkal Demis[1*]

[1]Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center, Woreta, Ethiopia

Abstract: Plants are primary producers and a food source for many heterotrophic phytophagous organisms. They are affected by different biotic and abiotic environmental stress. Insects, fungi, bacteria, viruses, nematodes, and other pests are biotic factors that significantly reduce crop productivity. Naturally, plants protect themselves from pest attacks by developing different morphological, structural, and biochemical defense mechanisms. However, our understanding of these defensive mechanisms is still limited. Hence, the objective of this paper is to review the mechanism of plant resistance to insects, weeds, and pathogens to know the relevant defense or resistance mechanisms of plants against pests. Many morphological characteristics contribute to plant resistance to insect pests. These include trichomes, surface waxes and hardness of plant tissues, thickening of cell walls and cuticles, the rapid proliferation of tissues, anatomical changes in plant organs, and color and shape of plant parts. The chemical composition of the host plant affects the behavior and adaptation of the herbivore and the host plant. These chemicals can be physiological inhibitors or nutritional deficiencies. Secondary metabolites are compounds that decrease the palatability of the plant tissues in which they are produced but have no effect on a plant's regular growth and development. Plants defend themselves against pathogens by a combination of weapons termed host resistance which is a structural and biochemical defense mechanism and they also defend from weeds by producing allelochemicals. Thus, plants have developed multiple resistance mechanisms to protect against pests. These resistance mechanisms could be an important tool for pest management by reducing the dose of chemicals used in pest control, resulting in a minimal effect of the chemicals on the environment. Also, these resistance mechanisms are compatible with other control methods that act as one of the components of integrated pest management methods to reduce the damage caused by pests.

Keywords: Allelopathy, Biochemical, Defense mechanisms, Morphological, Pests, Resistance, Structural.

Review Paper

***Corresponding Author:**
Esuyawkal Demis
Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center, Woreta, Ethiopia

How to cite this paper:
Esuyawkal Demis (2024). Mechanism of Plant Resistance to Insects, Weeds and Pathogens. *Middle East Res J. Agri Food Sci.*, 4(2): 76-85.

Article History:
| Submit: 26.01.2024 |
| Accepted: 28.02.2024 |
| Published: 06.03.2024 |

1. INTRODUCTION

Plants are a rich source of nutrients for numerous organisms, including fungi, bacteria, protists, insects, and vertebrates. They have developed an amazing array of structural, chemical, and protein-based defense mechanisms to identify and stop invading organisms before they can cause significant harm, despite lacking an immune system comparable to animals. Plants are nearly the only source of food for humans, and they also provide a wide range of essential non-food products, such as wood, textiles, dyes, pharmaceuticals, makeups, soaps, rubber, plastics, inks, and industrial chemicals. Understanding how plants defend themselves from pathogens and herbivores is essential to protecting our food supply and developing highly disease-resistant plant species (Freeman and Beattie, 2008).

Plants are primary producers and therefore a food source for a wide range of heterotrophic phytophagous organisms. From the plants' point of view, they require effective mechanisms to avoid herbivory and to defend themselves against pests such as nematodes, mollusks, most vertebrates, and arthropods (Mithofer and Maffei, 2016).

Plants have developed a wide range of morphological and chemical defense mechanisms that can effectively and drastically reduce insect feeding (Harborne, 1993). Plant resistance represents the inherent ability of a certain crop variety or cultivar to resist, retard, or overcome pest infestations. Host plant resistance includes those characteristics that enable a plant to avoid, tolerate, or recover from attacks of insects under conditions that would cause serious injury to other plants of the same species. The final extent of the insect's damage is determined by the proportion of heritable traits that the plant possesses. In practical agriculture, it represents the ability of a certain variety to produce a larger crop of good quality than ordinary varieties at the same level of insect populations. Plants are equipped with a waxy cuticle that prevents the evaporation of water but also forms an efficient barrier against phytopathogens (Eigenbrode and Espelie, 1995).

Moreover, many species have epidermal leaf hairs (trichomes), some of which carry a special gland at the tip, and for which a broad diversity of functions have been reported. For example, they form structural barriers that hinder small arthropods in their mobility (Simmons and Gurr, 2005), but also guide light to the leaf surface of the leaf so that it can be used optimally for photosynthesis (Wagner *et al*., 2004). Moreover, glandular hairs also secrete protective coatings that prevent fungal spores from germinating (Shepherd *et al*., 2005) and contain glues and toxins that obstruct and intoxicate plant surface-dwelling arthropods when ruptured (Glas *et al*., 2012).

Plant characteristics that adversely affect an insect's preference (host plant selection, oviposition, feeding behavior) or performance (growth rate, development, reproductive success) and lead to increased plant fitness in a hostile environment are considered resistance factors for direct plant defense against herbivorous insects. Numerous factors can contribute to a plant's defense against pathogens and herbivores, including the texture and composition of the plant's surface, the presence of anatomical structures like thorns or resin ducts, the lack of nutrients the pest requires, the presence of hormone-like substances that affect insect development, an improper pH or osmotic pressure, or the accumulation of secondary products (Dell and McComb, 1975).

Generally, plants are attacked by many pathogens, weeds, and insect pests due to this effect plants are resisting against their attacker by developing many resistance mechanisms such as morphological resistance, biochemical resistance, structural characteristics, and also by producing allelochemicals. These resistant mechanisms are important for managing pests by reducing the amounts of chemicals in the management of plant pests which has resulted in the minimal impact of chemicals on the environment and the ecosystems maintained without deterioration. These mechanisms of resistance are also compatible with other control methods for pest management strategies. However, our understanding of these resistance mechanisms is still limited. Therefore, the objective of this paper is to review the mechanism of plant resistance to insects, weeds, and pathogens to know the relevant resistance mechanisms of plants against pests.

2. MECHANISM OF PLANT RESISTANCE TO INSECTS

Plant resistance to insects involves the application of principles of insect-plant interactions to pest management. Resistance of a plant to an insect is defined as the relative amount of heritable qualities possessed by the plant which influences the ultimate degree of damage done by the insect. Plant resistance as an approach to pest management offers many advantages. Crop varieties that are resistant to insect pests offer an inherent control that is generally compatible with other insect control methods and doesn't require any additional costs or environmental pollution. Insect-resistant varieties are more valuable where crops are low in value, particularly in developing countries, and also in situations where lack of technical knowledge limits the proper use of costly insecticides. Growing insect-resistant crops is now highly valued in pest management programs. Depending on the level of resistance, it can be used either as the principal method or as a supplement to other measures of pest management. It also serves as a safeguard against the release of varieties that may be more susceptible than the existing ones (Jayaraj and Uthamasamy, 1990).

Plants have developed certain ways and means to defend themselves from insect attacks. These include tolerance, avoidance, and physical or chemical defense (Kennedy and Barbour, 1992). The defense may be passive/constitutive or dynamic/induced (Horsfall and Cowling, 1980). The defense has also been divided into three categories which are constitutive defense, induced defense, and crosstalk between plant defense signaling pathways. The induced defense may be due to nutrient removal, cell lignifications, controlled chemical biosynthesis, and uncontrolled chemical biosynthesis (Singh and Dhaliwal, 2005). Constitutive defense can deter, repel, intoxicate, or interfere with the development or reproduction of herbivores. Such resistance may be attributed to the texture and composition of the plant surface, the presence of anatomical structures, the absence of nutrients required by the insects, and the presence of allelochemicals (Duffey and Stout, 1996). Plants may tie up nitrogen in forms unavailable to herbivores (White, 1978).

Induced defense involves the production of chemicals or physical structures or the removal of nutrients essential to insects, in response to the attack by insects, diseases, or other herbivores (Wold and Marquis, 1997). After an attack, the plant produces a tough cell wall and less digestible food or produces certain chemicals (McCloud and Baldwin, 1997). In certain cases, plants defend themselves by promoting the effectiveness of natural enemies of insect pests through the provision of shelter, alternate food, or the production of signals that enable natural enemies to locate insect pests. Plants have established associations with certain organisms which play an important role in defending plants from insects. Some species of Acacia are protected from the attack of insects by ants living on them (Janzen, 1975).

Plants produce and release complex mixtures of volatile chemicals to suppress insect herbivory. Some of these compounds provide important host-location cues to predator insects or parasites that are natural enemies of insect herbivores. Synthesis and release of these chemical signals by attacked plants are active physiological processes, triggered by chemical elicitors or substances contained in the oral secretion of attacking herbivores. Certain chemicals contained in the saliva of grazing insects (herbivores) activate the synthesis and release of plant volatiles. The process of attracting predatory insects involves the interaction of specific blends of plant volatiles, with highly sensitive receptor molecules of the predators (De Moraes *et al*., 2001).

2.1. Morphological Resistance

Many morphological characteristics contribute to the resistance of plants to insect pests. These include trichomes, surface waxes, and hardness of plant tissues, thickening of cell walls and cuticles, the rapid proliferation of tissues, anatomical modifications of plant organs, color and shape of plant parts. Some morphological structures additionally contain allomones that affect the behavior and metabolism of phytophagous insects. Herbivorous insects of all feeding guilds must come into contact with the plant surface to establish on the host plant. It follows that the chemical and physical characteristics of the plant surface are significant factors in determining resistance. Every part of the plant provides some defense against the herbivore. They vary from tissue hardness to very complex glandular trichomes and spines. Structural defenses include morphological and anatomical features that give the plant an advantage by preventing direct feeding by insects, and range from visible plant protrusions to microscopic changes in cell wall thickness as a result of lignification and suberization (Tibebu, 2018).

Plant defense against insect pests is primarily mediated by structural features like trichomes, toughened or hardened leaves, divaricated branching (branches with wiry stems produced at wide axillary angles), spines and thorns, and incorporation of granular minerals into plant tissues. Sclerophyll refers to hardened leaves and plays an active role in plant defense against herbivores by reducing the palatability and digestibility of tissues, thus reducing herbivore damage (Tibebu, 2018). Spinescence includes plant structures like spines, thorns, and prickles. It has been reported to protect plants from many insects. Pubescence consists of a layer of hairs (trichomes) that extend from the epidermis of above-ground plant parts, including stems, leaves, and even fruit and occurs in a variety of forms, including straight, spiral, stellate, hooked, and glandular. Leaf glossiness, plumule, and leaf sheath pigmentation caused resistance to sorghum shoot fly, *Atherigona soccata* (Chamarthi *et al*., 2011).

2.1.1. Thorns and trichomes

A thorn is a loose term for any sharp, pointed appendage coming off a plant for defensive purposes. Botanically, thorns can also be called spines, prickles, or trichomes based on their location on the plant. These sharp appendages come in a variety of shapes, lengths, and colors. Trichomes are one of the most important morphological adaptations of plants against insect pests. Plant trichomes are of several kinds and have physiological and ecological functions. The trichomes are glandular hairs and are abundant on the leaves of many species of plants (Jayaraj and Uthamasamy, 1990). The pubescence may affect the locomotion, attachment, shelter, feeding, digestion, and oviposition of insects. Mechanical effects of pubescence depend on the density, erectness, length, and shape of trichomes (Norris and Kogan, 1980).

Figure 1: Resistance or defense mechanism of plants by thorns

Trichomes are found in all major groups of terrestrial plants. They originate from epidermal tissue and then develop and differentiate to produce hair-like structures (Johnson, 1975). They play an imperative role in plant defense against many insect pests and involve both toxic and deterrent effects. Trichomes density negatively affects the ovipositional behavior, feeding, and larval nutrition of insect pests. In addition, dense trichomes affect the insect mechanically and interfere with the movement of insects and other arthropods on the plant surface, thereby, reducing their access to the leaf epidermis. These can be, straight, spiral, hooked, branched, or un-branched and can be glandular or non-glandular. Non-glandular trichomes affect the locomotion, attachment, shelter, feeding, and survival of insects. To provide a combination of chemical and structural defense mechanisms, glandular trichomes secrete secondary metabolites such as flavonoids, terpenoids, and alkaloids which can be toxic, repellent, or trap insects and other organisms (Tibebu, 2018).

Figure 2: Resistance or defense mechanism of plants by trichomes

2.1.2. Surface waxes

All substances of a waxy nature isolated from a plant are considered under the term wax. Chemically wax refers to an ester formed of a long-chain fatty acid and a high molecular weight aliphatic alcohol. Plant waxes vary from a fraction of a percent to several percent of the dry weight of a plant. Most vascular plants have a thin layer of mostly hydrophobic constituents covering their cuticles. Plant waxes have the primary function of maintaining the water balance but also contain substances that interfere with insect attacks (Norris and Kogan, 1980).

Surface waxes over the epicuticle; protects the plant surface from drying out, feeding insects, and diseases. Epicuticular waxes influence the feeding behavior of insect pests by acting as phagostimulants or feeding deterrents. Due to the existence of waxes on the surface of the plant, the sensory organs of the insect tarsi and mouth parts receive negative chemical and tactile stimuli from the plant surface, resulting in resistance of the plant to insect attack (Ram *et al*., 2005).

2.1.3. Tissue hardness

The plant tissue hardness is related to insect resistance. The texture of plant tissues varies greatly, ranging from extremely soft to extremely hard. Plant tissue hardness is determined by the properties of the epidermis and any thick-walled cells immediately beneath it (Grubb, 1986). Tissue texture may prevent herbivore feeding. Successful stylet penetration of *Parabemisia myricae* (Homoptera, Aleyrodidae) in its host plant leaves is decreased with increasing host tissue hardness and age (Walker, 1988). The hardening of gall wal1s prevents penetration of the ovipositor of parasitoid wasps that would reach the larva and inhibits feeding on the gal1 tissue by herbivores (Craig *et al*., 1990).

2.1.4. Leaf and root toughness

The tough leaves prevent the mouthparts of piercing-sucking insects from penetrating plant tissues and increase mandibular wear in biting-chewing herbivores (Raupp, 1985). Leaf cell walls are also strengthened during feeding using various macromolecules like lignin, cellulose, suberin, and callose, as well as small organic molecules like phenolics and even inorganic silica particles. Roots eaten by herbivorous insects show significant regrowth and development. Furthermore, compared to genotypes with short and thick roots, genotypes with long, fine roots suffered less from herbivory (Tibebu, 2018).

2.1.5. Color and shape

Host selection behavior of phytophagous insects is associated with the color and shape of plants. The color and shape of plants remotely affect the plant host selection behavior of phytophagous insects and thus are associated with resistance. Color-related insect resistance in plants does not exist but genetic manipulation of plant color usually affects some fundamental physical plant processes (Norris and Kogan, 1980). Foliage color and tree shape and size play a role in discrimination between hosts and non-hosts by Rhagoletis fly (Boller and Prokopy, 1976). Yellow-green plants were preferred to green plants by the pea aphid, *Acyrthosiphon pisum* (Cartier, 1993). The color of cabbage leaves affected host selection by *Brevicoryne brassicae*. Red-leaved cabbage varieties were less susceptible to *Pieris brassicae* (Verma *et al*., 1981).

2.1.6. Thickening of cell walls

The thickening of cell walls results from the deposition of cellulose and lignin. As a consequence, the tissue becomes tougher or more resistant to the tearing action of mandibles or the penetration of the proboscis or ovipositor of insects. Thicker hypodermal layers of rice were considered a resistance factor to stripe stem borer, *Chilo suppressalis* (Patanakamjorn and Pathak, 1967). Resistance in sorghum to the sorghum shoot fly, *Atherigona soccata* was attributed to the presence of cells with distant lignifications and thicker walls enclosing the vascular bundle sheaths within the central whorl of young leaves (Blum, 1968). Seed damage due to alfalfa seed chalcid, Bruchophagus raddi was less in Medicago species which had highly lignified pod-walls (Springer *et al*., 1990).

2.2. Biochemical Resistance

Plants' ability to withstand insects is also a result of their chemical makeup, which can be quantitative or qualitative. These chemicals occur within certain parts of the plant or in specific stages of plant growth. The herbivore's behavior and adaptation to the host plant are influenced by the chemical composition of the host plant. These chemicals may be physiological inhibitors or nutritional deficiencies. Plants produce a large and wide range of organic compounds that do not seem to play a direct role in growth and development i.e. they do not have a generally recognized role in photosynthesis, respiration, solute transport, translocation, nutrient assimilation, and differentiation processes. These compounds or chemicals play an important role in direct defense and impair the performance of herbivores through one of two general mechanisms: these chemicals can reduce the nutritional value of plant food or act as feeding deterrents or toxins. Secondary metabolites are compounds that lessen the palatability of the plant tissues in which they are produced but have no effect on a plant's regular growth and development. In response to an insect or microbial attack, the defensive (secondary) metabolites can be generated or constitutively stored as dormant forms (Tibebu, 2018).

Plants and insects have intricate interactions with each other based on plant characteristics and biological parameters of insect pests. Plants remain surrounded by an external environment of volatile compounds that emanate from the outer layers of different parts of plants. Many allelochemicals reduce insect growth. The allelochemicals can be considered ecological and chemical requirements of plants since these serve to tie the insects to their hosts and protect plants from other insects, pathogens, and general herbivores that have not broken the chemical defenses of these plants. An allelochemical is dominant in insect or plant interactions. The allelochemicals are principally shared between two groups of interspecifically active chemicals known as allomones and kairomones. In general, allelochemicals occur in plants in diverse ways to protect them from their enemies (Whittaker, 1970).

2.2.1. Plant phenolic compounds

Plant phenols are one of the most common groups of defensive compounds among secondary metabolites, and they are important for the host plant's resistance against insect pests. They act as a defense mechanism not only against insect pests but also against microbes and rival plants. In addition to protecting plants from insects, phenols also serve as a defensive mechanism against microbes and rival plants. The phenolic heteropolymer lignin is essential to plants' defense mechanisms against diseases and insects. It restricts the entry of pathogens by physically obstructing them or by making the leaf tougher, which lessens insect feeding and lowers the leaf's nutritional value. Lignin synthesis is induced by insect or pathogen attack and its rapid deposition reduces further growth of the pathogen or insect fecundity (Tibebu, 2018).

2.2.2. Plant lectins

Lectins are carbohydrate-binding glycoproteins that have a protective function against a range of pests. They are found in a wide range of plant species mainly in the family *Leguminosae*. Lectins are also found in the *Graminaceous* and *Solanaceous* plants. They are synthesized at high molecular weight precursors and serve as plant defense compounds. Different plant lectins have been used as naturally occurring insecticides against insect pests because of their insecticidal properties. The ability of lectins to survive in insects' digestive systems and thus have a potent insecticidal potential is one of their most significant characteristics. They act as anti-nutritional or toxic agents by attaching to membrane glycosyl groups lining the digestive tract, causing a variety of detrimental systemic reactions (Tibebu, 2018).

2.2.3. Flavonoids

Flavonoids are cytotoxic and use complexation to interact with various enzymes. By affecting the behavior, growth, and development of insects, flavonoids, and isoflavonoids both shield the plant from insect pests (Tibebu, 2018).

2.2.4. Tannins

Tannins have a strong deleterious effect on phytophagous insects and affect insect growth and development by binding to the proteins, reducing nutrient absorption efficiency, and causing mid-gut lesions. Tannins are mouth-puckeringly bitter, polyphenols that prevent many insect pests from feeding.

Tannins decrease the digestibility of proteins when consumed, which lowers the nutritional value of plants and plant parts for insects. The function of tannins in plant defense against different stresses and their induction in response to insect damage has been studied in numerous plants (Tibebu, 2018).

Tannins are phenolic polymers and most of the phenolic groups in tannins are free and can bind proteins. The most common effects of tannins on insects are reduced food consumption, decreased weight gain, and decreased efficiency of food utilization. The population of white flies was low on cotton varieties with high tannin content. It indicates that tannins impart resistance in cotton against this insect (Butter *et al*., 1992).

2.2.5. Enzymes

Enzymes are also one of the most important aspects of the host plant's resistance to insects, which disrupt the insect's diet. The enzymes peroxidases, polyphenol oxidases, ascorbate peroxidases, and other peroxidases that oxidize mono- or dihydroxyphenols are the ones that hinder insects' ability to absorb nutrients by forming electrophiles (Tibebu, 2018).

2.3. Induced Resistance

The plant-induced response is one of the most important components of insect pest management in agriculture and has been used to regulate insect herbivore populations (Tibebu, 2018). This is a non-heritable resistance where the host plants are induced to impart resistance to tide over the pest infestation. This is possible by manipulation of fertilizer application, biofertilizers, organic amendments, etc. Such manipulations also bring about changes in the biochemicals of the host plants. The application of higher amounts of potassium confers resistance to some pests that reduce the infestations of insects (Jayaraj and Uthamasamy, 1990).

Induced defenses are often subdivided into direct and indirect defenses. Direct defense includes the activation or production of antifeedants, such as toxins and inhibitors of digestion, which negatively affect the growth or survival of herbivores (Howe and Jander, 2008). Defenses may also be induced in the phloem (Will *et al*., 2013). For instance, feeding on rice by the brown plant hopper (*Nilaparvata lugens*) induces the deposition of callose on the plant’s sieve plates to block further transport of sap through the attacked phloem tissues (Hao *et al*., 2008). Indirect defense refers to plant traits that enhance attraction or arrestment of natural enemies of the herbivore, such as predators and parasitoids (Sabelis *et al*., 2001).

Induced defenses make plants phenotypically plastic and thus reduce the possibility of insect attack adapting to the induced chemicals. Plant defenses against insects can change as a result of an attack, creating an unpredictable environment for insect herbivores. This can have an impact on the insects' behavior and fitness. In addition to increasing the plant's overall fitness, an early-onset-induced response is very beneficial to the plant and lessens the subsequent herbivore and pathogen attack (Tibebu, 2018).

Induced resistance means an increase in resistance temporarily as a result of some changed conditions in plants or environment (Singh and Agarwal, 1983). Certain environmental changes or conditions and disease infections may alter the physiology of a plant to the extent that it becomes unsuitable as a host for an insect pest. The application of growth regulators to host plants reduced the fecundity and growth of aphids. Growth regulators may have a direct effect on the insects or indirectly by causing certain physical or biochemical changes in host plants. Growth regulators can also alter the timings of plant development in a way that susceptible material is not available for the infestation at the time of pest attack. There are various other approaches by which resistance in crop plants may be induced such as balanced use of fertilizers, optimal use of water, proper sowing times, and others (Salim, 1988).

3. MECHANISM OF PLANT RESISTANCE TO WEEDS

Weeds are a major constraint to agricultural crop production. In conventional agriculture, the main management strategy is the application of herbicides to control weeds. However, complementary approaches to herbicides are becoming increasingly important, to decrease the reliance on chemical control and to lessen the negative impacts that these compounds impose on the environment. Knowledge of allelopathy might constitute an important asset to boost the acceptance of agricultural products in today’s demanding consumer markets (Trezzi *et al*., 2016).

Allelopathy

Allelopathy is a type of interaction between organisms that can be both positive and negative and is caused by the action of chemical compounds called allelochemicals. These compounds are mostly produced as a result of the secondary metabolism of plants and microbes and they can affect many processes in ecosystems and agro-ecosystems (Olofsdotter *et al*., 2002). In plants, allelochemicals can cause a variety of mechanisms of action. Allelopathic effects are mostly referred to as a type of negative interaction (Radosevich *et al*., 2007; De Albuquerque *et al*., 2011), but depending on the allelochemical considered, target plant, and concentration tested, positive interactions have also been reported (Eichenberg *et al*., 2014).

In the context of agriculture, allelochemicals can be produced by cultivated crops or non-cultivated plants, many of which are regarded as weeds. In agricultural ecosystems, allelopathy can affect weed control, plant reproduction, species association, the mulching effect on crops, and the succession and rotation of cultivated species (Chon *et al*., 2006). Some allelochemicals, such as benzoxazinones and their derivatives, which can suppress weeds suppression, have already been characterized from their production in the donor plant (*Secale cereale* L.) to their effects on the target plant (*Avena fatua* L.) (Macias *et al*., 2014). Furthermore, several techniques and knowledge that appear to take advantage of allelopathy have already been empirically applied in agriculture to exploit the suppressive effect on weeds by some crop species (Trezzi *et al*., 2016).

Allelopathy can also be a key part of supporting organic farming where weed control is a major problem. The use of cover crops is probably the most common form of allelopathy information used for weed suppression in organic agroecosystems (Wortman *et al*., 2013). Organic farming may involve reducing weed infestation by intercropping plant species with an allelopathic potential or using plant extracts (Wortman *et al*., 2013; Bajwa *et al*., 2015). Allelopathic effects occur when certain crop species that release allelochemicals are intercropped like intercropping corn and *Urochloa* spp. (*Brachiaria* spp.) increases crop and forage yield improves soil quality and decreases weed infestation (Borges *et al*., 2015). The allelopathic effects explain the reduced infestation by the parasitic weed *Striga hermonthica* (Del.) Benth. when *Desmodium* spp. is intercropped with corn (Khan *et al*., 2002).

Plant extracts are an additional method to use allelochemicals for weed management in agricultural ecosystems, as they have already been used as natural post-emergence herbicides in some countries. For instance, in Pakistan, an aqueous extract derived from a 10% concentration of sorghum shoots is allowed to ferment for several weeks and is subsequently sprayed post-emergence for control of weeds. This fermented water extract, called “Sorgaab”, decreased weed density and weed dry weight by up to 50% in field trials, depending on the weed species (Cheema and Khaliq, 2000; Cheema *et al*., 2002).

Crop species that produce useful allelochemicals in agro-ecosystems include sorghum (*Sorghum bicolor* L.), which exudes sorgoleone from its roots and inhibits the emergence and growth of different weed species (Trezzi and Vidal, 2004). Mucuna species (*Mucuna* spp.) are very beneficial in decreasing the infestation of the world’s worst weed, nutsedge (*Cyperus rotundus* L.) (Zanuncio *et al*., 2013). Many other annual crop species are known for their allelochemical production, such as rye (*Secale cereale* L.), rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), sunflower (*Helianthus annus* L.), and alfalfa (*Medicago sativa* L.) (De Albuquerque *et al*., 2011).

Crop cultivars with increased production of allelochemicals may be another technological application to lessen weed infestation. Nonetheless, in certain cases, there is no relationship between the production of allelopathic compounds and the competitive ability of the crop (Worthington *et al*., 2015). Allelopathic varieties can be obtained by traditional breeding or genetic engineering. In general, the development of allelopathic varieties has not been a focus of most conventional crop breeding programs. Instead, the focus of attention has been directed to increasing the crop yield; thus, there is a tendency to decrease the allelopathic potential in modern varieties (Bertholdsson, 2004). An alternative to this approach is the use of molecular markers linked to allelopathic traits, such as genes encoding the synthesis of allelochemicals (Macias *et al*., 2007).

4. MECHANISM OF PLANT RESISTANCE TO PATHOGENS

Plants use a combination of defense mechanisms, termed host resistance, including structural and biochemical defenses, to defend themselves against a pathogen. Structural mechanisms act as physical barriers and biochemical defense mechanisms by taking place a biochemical reaction in the cells and tissues of the plant that produce substances either toxic to the pathogen or inhibit the growth of the pathogen in the plant. Combinations of structural features and biochemical reactions used in the plant defense are different host-pathogen systems (Jibril *et al*., 2016).

4.1. Structural Characteristics

The structural features act as physical barriers and prevent or inhibit the pathogen from entering and proliferating throughout the plant. Some structural defense mechanisms are already present on the plant before the pathogen comes into contact with the plant. Such structures include the amount and quality of wax and cuticles that cover the epidermal cells, the structure of the epidermal cell walls, the size, location, and shapes of stomata and lenticels, and the presence of tissues made of thick-walled cells that hinder the advance of the pathogen on the plant. The waxes on the surface of the leaves and fruits form a waterproof surface and thus prevent the formation of a water film on which pathogens can settle and germinate (fungi) or reproduce (bacteria). Plant structures such as tough and thick epidermal cells also play a role in defense against pathogens. Only via stomata do numerous pathogenic bacteria and fungi enter the plants. The structure of different somata may confer resistance to some varieties against certain bacterial pathogens. Cell walls contain proteins and enzymes that actively modify the wall during cell growth, but thicken and strengthen the wall during induced defense (Jibril *et al*., 2016).

A thick cuticle could increase resistance to infection in diseases where the pathogen can only enter the host by direct penetration. The cuticle thickness and toughness of the outer wall of epidermal cells are important factors in the resistance of some plants to certain pathogens. Thick, tough walls of epidermal cells make direct penetration by fungal pathogens difficult or impossible. The significance of the cuticle as a barrier to penetration has been demonstrated by the dependence of numerous pathogens on attachment and the succeeding release of cutin-degrading enzymes during penetration (Jibril *et al*., 2016). Many saprophytic fungi and bacteria also secrete cutin-degrading enzymes, but their main function is to allow access to cellulose in plant cell walls so that it can be used as a nutritional substrate. Pathogens use different forms of cutin-degrading enzymes to puncture the cell wall. The activity of this type of chitinolytic enzyme in isolates of *Fusarrum solani*, *F*. sp. pisi is directly associated with their aggressiveness on pea stems, showing that pathogens incapable of dissolving the cuticle at the site of penetration are excluded (David and John, 1997).

Enzymes catalyze an oxidative burst when a plant cell senses the presence of a possible pathogen. This burst creates extremely reactive oxygen molecules that can harm the cells of invasive organisms. By catalyzing cross-linkages among cell wall polymers, it also contributes to the strength of the cell wall and alerts nearby cells to an impending attack. In response to microbial invasion, plant cells also quickly synthesize and deposit callose between the cell wall and cell membrane surrounding the pathogen. Callose deposits, also known as papillae, are polysaccharide polymers that obstruct cellular penetration at the injection site and are frequently produced as a component of the induced basal defense response (Freeman and Beattie, 2008).

4.2. Biochemical

Biochemical reactions occur in the cells and tissues of the plant and produce substances that are either toxic to the pathogen or create conditions that inhibit or prevent the growth of the pathogen in the plant. Exudates on plant surfaces or compounds in plant cells can stimulate or inhibit pathogen development. Plants can occasionally resist infections because they do not provide the pathogen with the necessary nutrients (Jibril *et al*., 2016). Resting spores of pathogens, for example, *Spongospora subterranea* (powdery scab of potato), *Urocgstls agropgri* (flag or leaf smut of wheat), and *Plasmodtophora brassicae* (club root of crucifers) and eggs of the potato cyst nematode, *Globodera rostochiensis*, need precise substances to stimulate germination or hatching. They are found in the secretions of certain plants, including potential hosts. Plants that do not secrete these stimulants are resistant by default (David and John, 1997).

Phytochemicals are classified into primary and secondary metabolites. Primary metabolites are substances produced by all plant cells that are directly related to growth, development, or reproduction. Nucleic acids, proteins, sugars, and amino acids are examples of primary metabolites. Secondary metabolites are not directly involved in growth or reproduction but are frequently involved in plant defense. These compounds typically fall into one of three major chemical classes; terpenoids, phenolics, and alkaloids (Freeman and Beattie, 2008).

Phenolics are the most significant class of compounds in both constitutive and induced disease resistance. Tannins, which are phenolic polymers, have been implicated in disease resistance, and have long been used to retard wood deterioration. Tannins are toxic to several pathogenic fungi at the concentrations found in bark, cork, and heartwood; fungal attacks occur if the tannins are removed. The resistance of chestnut species to the chestnut blight fungus *Endothia parasitica* is due in part to qualitative differences in the structure and differential solubility of their tannins. The presence of tannin in fruit is responsible for reducing the spread of infection by the brown rot fungus *Sclerotinia fruitigena* (Whittaker, 1969).

5. CONCLUSION

Plants are surrounded by a large number of enemies such as fungi, bacteria, viruses, nematodes, insects, mites, and other herbivorous animals. These biotic factors are found in almost all ecosystems, and they are largely to blame for the significant decline in crop production and productivity. Usually, plants are attacked by pathogens, weeds, and insect pests. Plants defend these pests by developing different defensive or resistance mechanisms using morphological, biochemical, and structural characteristics, and by producing secondary metabolites. These resistant mechanisms could be exploited as an important method for pest management to minimize the amounts of chemicals used for pest control and these resistance mechanisms are also important to be compatible with other control strategies. Therefore, these mechanisms of resistance are used for the management of plant pests and study attempts should be directed towards the resistance mechanisms of plants against pests.

REFERENCES

- Bajwa, A. A., Mahajan, G., & Chauhan, B. S. (2015). Nonconventional weed management strategies for modern agriculture. *Weed Science*, 63, 723-747.
- Bertholdsson, N. O. (2004). Variation in allelopathic activity over 100 years of barley selection and breeding. *Weed Research*, 44, 78-86.
- Blum, A. (1968). Anatomical phenomenons in seedlings of sorghum varieties resistant to the sorghum shoot fly (*Atherigona varia soccata*). *Crop Science*, 8, 388-391.
- Boller, E. F., & Prokopy, R. J. (1976). Bionomics and management of Rhagoletis. *Annual Review of Entomology*, 21, 223-246.
- Borges, W. L. B., de Freitas, R. S., Mateus, G. P., de Sa, M. E., & Alves, M. C. (2015). Cover crops for the northwest region from Sao Paulo State, Brazil. *Ciencia Rural*, 45(5), 799-806.

- Butter, N. S., Brar, A. S., Kular, J. S., & Singh, T. H. (1992). Effect of agronomic practices on incidence on key pests of cotton under unsprayed conditions. *Indian Journal of Entomology*, 54, 115-123.
- Cartier, J. J. (1993). Varietal resistance of peas to pea aphid biotypes under field and greenhouse conditions. *Journal of Economic Entomology*, 56, 205-213.
- Chamarthi, S. K., Sharma, H. C., Vijay, P. M., & Narasu, L. M. (2011). Leaf surface chemistry of sorghum seedlings influencing expression of resistance to sorghum shoot fly (*Atherigona soccata*). *Journal of Plant Biochemistry and Biotechnology*, 20(2), 211-216.
- Cheema, Z. A., & Khaliq, A. (2000). Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agriculture, Ecosystems & Environment*, 79(2-3), 105-112.
- Cheema, Z. A., Khaliq, A., & Ali, K. (2002). Efficacy of sorgaab for weed control in wheat grown at different fertility levels. *Pakistan Journal of Weed Science Research*, 8, 33-38.
- Chon, S. U., Jennings, J. A., & Nelson, C. J. (2006). Alfalfa (*Medicago sativa* L.) autotoxicity: Current status. *Allelopathy Journal*, 18, 57-80.
- Craig, T. P., Itami, J. K., & Price, P. W. (1990). The window of vulnerability of a shoot-galling sawfly to attack by a parasitoid. *Ecology*, 71, 1471-1482.
- David, G., & John, B. (1997). Plant pathogens and plant diseases. Rockvale Publications National Library of Australia, 263-260.
- De Albuquerque, M. B., dos Santos, R. C., Lima, L. M., Melo Filho, P. D. A., Nogueira, R. J. M. C., Da Camara, C. A. G., & de Rezende Ramos, A. (2011). Allelopathy, an alternative tool to improve cropping systems. A review. *Agronomy for Sustainable Development*, 31, 379-395.
- De Moraes, C. M., Mescher, M. C., & Tumlinson, J. H. (2001). Caterpillar-induced nocturnal plant volatiles repel conspecific females. *Nature*, 410, 577-580.
- Dell, B., & McComb, A. J. (1975). Glandular hairs, resin production and habitat of Newcastelia viscida E. Pritzel (Dierastylidaceae). *Australian Journal of Botany*, 23(3), 373-390.
- Duffey, S. S., & Stout, M. J. (1996). Antinutritive and toxic components of plant defense against insects. *Archives of Insect Biochemistry and Physiology*, 32(1), 3-37.
- Eichenberg, D., Ristok, C., Kroeber, W., & Bruelheide, H. (2014). Plant polyphenols implications of different sampling, storage, and sample processing in biodiversity ecosystem functioning experiments. *Chemistry and Ecology*, 30(7), 676-692.
- Eigenbrode, S. D., & Espelie, K. E. (1995). Effects of plant epicuticular lipids on insect herbivores. *Annual Review of Entomology*, 49, 171-194.
- Freeman, B., & Beattie, G. (2008). An overview of plant defenses against pathogens and herbivores. The Plant Health Instructor.
- Glas, J. J., Schimmel, B. C., Alba, J. M., Escobar-Bravo, R., Schuurink, R. C., & Kant, M. R. (2012). Plant glandular trichomes as targets for breeding or engineering of resistance to herbivores. *International Journal of Molecular Sciences*, 13(12), 17077-17103.
- Grubb, P. J. (1986). Sclerophylls, pachyphylls, and pycnophylls: The nature and significance of hard leaf surface. *Insects and the Plant Surface*, 137-150.
- Hao, P., Liu, C., & Wang, Y. (2008). Herbivore-induced callose deposition on the sieve plates of rice: an important mechanism for host resistance. *Plant Physiology*, 146, 1810-1820.
- Harborne, D. J. (1993). Emergency treatment of adder bites: Case reports and literature review. *Archives of Emergency Medicine*, 10(3), 239.
- Horsfall, J. G., & Cowling, E. W. (1980). Plant disease: An advanced treatise. Academic Press, New York, 15-21.
- Howe, G. A., & Jander, G. (2008). Plant immunity to insect herbivores. *Annual Review of Plant Biology*, 59, 41-66.
- Janzen, D. H. (1975). Ecology of plants in the tropics. Studies in biology. Edward Arnold London, 58.
- Jayaraj, S., & Uthamasamy, S. (1990). Aspects of insect resistance in crop plants. *Proceedings Indian Acadamic Science*, 99(3), 211-224.
- Jibril, S. M., Jakada, B. H., Kutama, A. S., & Umar, H. Y. (2016). Plant and pathogens: Pathogen recognition, invasion, and plant defense mechanism. *International Journal of Current Microbiology and Applied Sciences*, 5(6), 247-257.
- Johnson, H. B. (1975). Plant pubescence: An ecological perspective. *The Botanical Review*, 41, 233-258.
- Kennedy, G. G., & Barbour, J. D. (1992). Resistance variation in natural and managed systems. In R. S. Fritz & E. L. Simms (Eds.), Plant resistance to herbivores and pathogens: Ecology, evolution and genetics (pp. 13-41). The University of Chicago Press, Chicago and London.
- Khan, Z. R., Hassanali, A., Overholt, W., Khamis, T. M., Hooper, A. M., Pickett, J. A., Wadhams, L. J., & Woodcock, M. (2002). Control of witchweed *Striga hermonthica* by intercropping with *Desmodium* spp., and the mechanism defined as allelopathic. *Journal of Chemical Ecology*, 28, 1871-1885.
- Macias, F. A., Molinillo, J. M., Varela, R. M., & Galindo, J. C. (2007). Allelopathy- a natural alternative for weed control. *Pest Management Science*, 63(4), 327-348.
- Macias, F. A., Oliveros-Bastidas, A., Marin, D., Chinchilla, N., Castellano, D., & Molinillo, J. M. (2014). Evidence for an allelopathic interaction between rye and wild oats. *Journal of Agricultural and Food Chemistry*, 62(39), 9450-9457.
- McCloud, E. S., & Baldwin, I. T. (1997). Herbivory

and caterpillar regurgitants amplify the wound-induced increases in jasmonic acid but not nicotine in Nicotiana sylvestris. *Planta*, 203, 430-435.

- Mithofer, A., & Maffei, M. E. (2016). General mechanisms of plant defense and plant toxins. In P. Gopalakrishnakone (Eds.), Plant toxins, toxinology (pp. 1-22). Springer.
- Norris, D. M., & Kogan, M. (1980). Biochemical and morphological basis of resistance to insect pests. *Nature (London)*, 125, 411-412.
- Olofsdotter, M., Jensen, L. B., & Courtois, B. (2002). Improving crop competitive ability using allelopathy an example from rice. *Plant Breeding*, 121, 1-9.
- Patanakamjorn, S., & Pathak, M. D. (1967). Varietal resistance of rice to the Asiatic rice borer, *Chilo suppressalis* (Lepidoptera: Crambidae), and its association with various plant characters. *Annals of the Entomological Society of America*, *60*(2), 287-292.
- Radosevich, S. R., Holt, J. S., & Ghersa, C. (2007). Ecology of weeds and invasive plants: Relationship to agriculture and natural resource management. New York: Wiley, 454.
- Ram, P., Singh, R., & Dhaliwal, G. S. (2005). Biophysical basis of resistance in plants to insects. In G. S. Dhaliwal & R. Singh (Eds.), Host plant resistance to insects: Concepts and applications (pp. 42-83). Panima Publishing Corporation, New Delhi, India.
- Raupp, M. J. (1985). Effects of leaf toughness on mandibular wear of the leaf beetle, *Plagiodera versicolora*. *Ecological Entomology*, 10(1), 73-79.
- Sabelis, M. W., Janssen, A., & Kant, M. R. (2001). The enemy of my enemy is my ally. *Science*, 291, 2104-2105.
- Salim, M. (1988). Physiochemical stresses and varietal resistance in rice: Effects on white-backed planthopper, *Sogatella furcifera* (Horvath). Ph.D. Thesis, University of Philippines, Los Banos. International Rice Research Institute (IRRI), Philippines.
- Shepherd, R. W., Bass, W. T., Houtz, R. L., & Wagner, G. J. (2005). Phylloplanins of tobacco are defensive proteins deployed on aerial surfaces by short glandular trichomes. *Plant Cell*, 17, 1851-1861.
- Simmons, A. T., & Gurr, G. M. (2005). Trichomes of Lycopersicon species and their hybrids: Effects on pests and natural enemies. *Agricultural and Forest Entomology*, 7, 265-276.
- Singh, R., & Agarwal, R. A. (1983). Fertilizers and pest incidence in India. *Potash Review*, 23, 1-4.
- Singh, R., & Dhaliwal, G. S. (2005). Insect-plant interactions and host plant resistance. In G.S. Dhaliwal & R. Singh (Eds.), Host plant resistance to insects: Concepts and applications (pp. 3-41). Panima Publishing Corporation, New Delhi, India.
- Springer, T. L., Kindler, S. D., & Sorenson, E. L. (1990). Comparison of pod-wall characteristics with seed damage and resistance to the alfalfa seed chalcid (Hymenoptera: Eurytomidae) in Medicago species. *Environmental Entomology*, 19, 1614-1617.
- Tibebu, B. (2018). Defense mechanisms of plants to insect pests: From morphological to biochemical approach. *Trends in Technical & Scientific Research*, *2*(2), 555584.
- Trezzi, M. M., & Vidal, R. A. (2004). Potential of sorghum and pearl millet cover crops in weed suppression in the field: II- Mulching effect. *Weed Plant*, *22*(1), 1-10.
- Trezzi, M. M., Vidal, R. A., Junior, B. A. A., Bittencourt, V. H. H., & Filho, S. S. A. (2016). Allelopathy: Driving mechanisms governing its activity in agriculture. *Journal of Plant Interactions*, 11(1), 53-60.
- Verma, T. S., Bhagchandani, P. M., Singh, N. S. N, & Lal, O. P. (1981). Screening of cabbage germplasm collections for resistance to *Brevicoryne brassicae* and *Pieris brassicae*. *Indian Journal of Agricultural Science*, 51, 302-305.
- Wagner, G. J., Wang, E., & Shepherd, R. W. (2004). New approaches for studying and exploiting an old protuberance, the plant trichome. *Annals of Botany*, 93, 3-11.
- Walker, G. P. (1988). The role of leaf cuticle in leaf age preference by bayberry whitefly (Homoptera: Aleyrodidae) on lemon. *Annals of the Entomological Society of America*, *81*(2), 365-369.
- White, T. C. R. (1978). The importance of relative food shortage in animal ecology. *Oecologia*, 33, 71-86.
- Whittaker, R. H. (1969). Evolution of diversity in plant communities. *Brookhaven Symposium on Biology*, 22, 178-196.
- Whittaker, R. H. (1970). The biochemical ecology of higher plants. *Chemical Ecology*, 3, 43-70.
- Will, T., Furch, A. C., & Zimmermann, M. R. (2013). How phloem-feeding insects face the challenge of phloem-located defenses. *Frontiers in Plant Science*, 4, 1-12.
- Wold, E. N., & Marquis, R. J. (1997). Induced defense in white oak: Effects on herbivores and consequences for the plant. *Ecology*, 78, 1356-1369.
- Worthington, M., Reberg-Horton, S. C., Brown-Guedira, G., Jordan, D., Weisz, R., & Murphy, J. P. (2015). Relative contributions of allelopathy and competitive traits to the weed suppressive ability of winter wheat lines against Italian ryegrass. *Crop Science*, 55, 57-64.
- Wortman, S. E., Francis, C. A., Bernards, M. A., Blankenship, E. E., & Lindquist, J. L. (2013). Mechanical termination of diverse cover crop mixtures for improved weed suppression in organic cropping systems. *Weed Science*, 61, 162-170.
- Zanuncio, A., Teodoro, P. E., Ribeiro, L. P., Caio, C. G., Oliveira, M., & Torres, F. E. (2013). Allelopathy of green manures on *Cyperus rotundus*. *Journal of Agricultural Sciences*, *36*(4), 441-446.