International Journal of
Molecular Microbiology

A Peer-reviewed Journal

Mini-review 2018 | Volume 1 | Issue 1 | 17-22

Plant Defenses vs Pathogen Weapons: A Continuation of Battlefield: A Mini-review

Sehrish Tariq[1]*, Kamran Saleem[2]

[1]Nuclear institute for Agriculture and Biology (NIAB) P.O.Box-128, Jhang Road, Faisalabad.
[2]Plant Protection Division, Nuclear institute for Agriculture and Biology (NIAB) P.O.Box-128, Jhang Road, Faisalabad.

Article Info

Open Access
Citation: Tariq, S., Saleem, K., 2018. Plant Defenses vs Pathogen Weapons: A Continuation of Battlefield: A Mini-review. Int. J. Mol. Microbiol., 1(1): 17-22.

Received: June 23, 2018

Accepted: June 30, 2018

Online first: July 1, 2018

Published: July 16, 2018

***Corresponding author:**
Sehrish Tariq;
Email:
sehrishtariq892@gmail.com

Abstract
Plants and their pathogen co-evolved simultaneously and therefore survive either through symbiotic or parasitic interaction. With the human civilization and increasing population, food security and food safety are of major concern. For achieving that, plants are being modified to attain maximum yield and minimum loss. Therefore, in reaction pest and pathogens also mutate themselves to evolve new tools and weapons for feeding and infection. In this race, plants have to defend for attaining yield and reproduction. Plants are blessed with many structure which minimize entry of pathogens specially cell wall, spines and thorns. Furthermore, biochemical defense in plants is highly sophisticated with many antimicrobial compounds, which trigger whole plant system to defend. Many genes incorporated in crop plants also lead to enhance biochemical defense through elicitors- receptors interaction. On the other hand, pathogens utilized toxins, enzymes, growth regulators and polysaccharides to suppress the host defense system and breakdown the resistance barriers. So its continuous race between host and pathogen but through details study and understanding of such interaction, better management strategies can be deployed.
Keywords: Symbiotic or parasitic interaction, pathogens, biochemical defense.

INTRODUCTION

Plants form the nucleus of living system without them there would be no life on earth. No one can deny this reality (Odjakova and Hadjiivanova, 2001). Plants capture radiant energy and change this energy into chemical energy that is used by all living organisms for their survival. Plants are the reason of existence of life on this planet hence welfare of plant is of paramount importance for us. Like animals and humans, plants also get maladies that influence their growth and yield that decrease their usefulness for humans. It is not known whether diseased plants feel pain or not. The agents that cause maladies in plants are the same that infect animals and humans. These agents include pathogenic fungi, bacteria, viruses, protozoa, nematodes, and phytoplasmas, environmental conditions e.g.; excess or lack of nutrients, temperature etc. Plants also face competition with other plants (weeds) that compete for nutrients etc. Due to these disturbances, plants deviate from its normal functioning, which is harmful for plants. Disease in plant, consist of a series of harmful physiological process caused by a constant irritation of the plant by a primary agent (Campbell and Madden, 1990). Interaction between plants and pathogenic agents at cellular level appears in the form of abnormalities at morphological and histological conditions called symptoms (Agrios, 2005). Transcription factors play important roles to drive different pathways by regulating gene expression (Fatima *et al.,* 2018). Plants normal physiology is destroyed by pathogens that interact with plants by their toxins, infection structures. Pathogen interaction with plants not only reduces the quality of produce but also quantity and usefulness of yield for humans.

In natural environment plants are attacked by a number of micro-organisms for all of which plant might be host or non-host for them. Plants lack a circulating blood immune system like animals and humans. Therefore, plants defend themselves by a combination of structural and biochemical barriers. The combination of structural and biochemical characteristics varies with the kind of host plant and its pathogen. Rhizobacteria play an important role in plant defense and could be promising sources of biocontrol agents. The defense that is employed by plant is directly or indirectly controlled by its genetic material and same mechanism in pathogen. Plants overcome pathogen attack by using its structural and biochemical barriers named as incompatible interaction. Pathogen has also evolved a number of weapons to overcome plant defense named as compatible interaction (Lucas, 2009). It was found that rice chitinase gene expression in potato confers enhanced resistance against two major fungal diseases of potato (Zaynab *et al.,* 2017). Compatibility and incompatibility are not absolutes but originates in natural environment of attack and counter attack of plant and pathogen. Plant inducible defenses are thought to be appeared by individual cells in the form of hypersensitive response and named as innate immunity as occur in animals and human. Plant defenses to counter different pathogens are described here.

Plant defenses

Rhizobacteria play an important role in plant defense and could be promising sources of biocontrol agents (Iqbal and Ashraf, 2017). In a natural ecosystem, numerous microbes and natural enemies feed on trees, agricultural crops, shrubs, weeds and grasses. Many microbes become pathogen and insect become pest on specific host plant depending upon the feasibility of both counterparts. Nature equipped the plants with variety of structures, which can be used as a defense strategy against pathogens and insects in a battlefield (Peumans and Van Damme, 1995). Such plant defenses can be categorized into four types; Pre-existing Structure defense, Pre-existing Biochemical defense, Induced Structure defense and Induced Biochemical defense (Doornbos *et al.,* 2012).

Pre-existing structural defense

Preexisting defenses, also known as constitutive defenses, are present in healthy plants and contribute major detrimental effects on pathogens. Constitutive defenses include many preformed barriers such as cell walls, waxy epidermal cuticles, and bark. These substances not only protect the plant from invasion, they also give the plant strength and rigidity. Plant cell wall consists of cellulose, hemicelluloses and pectin. Some plants evolved epidermal cells into a specialized structures e.g; trichrome which restrict insect movement (Dixon *et al.,* 1994). Some plants develop spines as a structural defense to repel insects that are vectors of many viral diseases (Raffa and Smalley, 1995). Plant extracts showed antibacterial and antifungal activities (Kalim *et al.,* 2016; Hussain *et al.,* 2016; Amin and Edris, 2017; Ali *et al.,* 2017; Shahzad *et al.,* 2017; Al-Deen and Al-Jobory, 2018).

Pre-existing biochemical defense

Compared to preexisting structural defenses, biochemical defenses are more important because most of the pathogens are blocked or killed within plant system after crossing structural barriers. Biochemical defense consist of variety of substances, including fungitoxic compounds. Fungitoxic compounds are secreted on the surface of some plants e.g,; tomato, sugar beet to inhibit the germination of spores of fungi *Botrytis* and *Cercospora* respectively (Singh *et al.,* 2005). An imperative of plants is the collection of secondary metabolites that are not directly involved in plant growth and reproduction but they are often involved in plant defense. These secondary metabolites influence the plant pathogen interactions. Secondary metabolites are terpenes, phenolics and nitrogen-containing compounds. Terpense e.g. gossypol from cotton a liquid compound that discourages a large number of plant- feeding insects (Pichersky and Gang, 2000). In a previous study, one triterpene (Stigmasterol) was isolated and two were flavonoides (Pentahydroxy flavanone and Dracophaney), and fourth one identified as Orobol from *Dracaenaceae* resin (Al- Mahweety, 2016a). Four compounds were isolated and identified as, triterpenes (Lupeol), Dioxo-urs-12-en-28-oic acid and Longistylin A and Piceid (stilbenoid glucoside) from the leaves of *Cyphostemma digitatum* (Al- Mahweety, 2016b). Tannins are phenolic compounds that reduce the growth and survival of herbivores by inactivating the digestive enzymes (Robbins *et al.,* 1987). Alkaloids are nitrogen-containing compounds that vary in their mode of action but most probably, they interact with the nervous system (Roberts, 2013). Another type of compounds are the lectins, protein in nature that bind specifically to certain sugars and present in large concentrations in many types of seeds cause loss and growth inhibition of many fungi. Plant surface cells also contain hydrolytic enzymes such as gluconates and chattiness causing the breakdown of pathogen cell wall components contributing to resistance to infection (Wittstock and Gershenzon, 2002).

Induced structural defenses

Induced defenses are alternation of normal plant structures for blocking pathogens or insect after their attacked and damage the host plants. In other words, such structures appear after the infection/invasion (Mehdy, 1994). Most prominent are the toughness and hardness of epidermal wall, waxy cuticle, cell wall size, location and shape of stomata, lenticels modification and morphology of thorns and spines. At histological level, formation of cork layers, abscission layer and formation of tyloses are the structures, which are induced by pathogens. Furthermore, change in plasma membrane permeability and hypersensitive responses are the visible structures at cellular level. Although the phenomena of hypersensitive response is mediated by chemical compounds but result in cell death. Plant defense in different morphological form are dependent on resistant genes function (Darvill and Albersheim, 1984).

Induced Biochemical defenses

This defense is most important in all types because of its efficiency and mechanism. A rapid change in many compound concentrations occurs after attack of pathogen or insects. Many resistant genes incorporated in crop plant function through this type of defense. Every gene produce specific type of protein which in involved in such resistance cascade. Usually compound produced in plants after attack are known as Phytoalexins compared to Phytoanticipins, which are present as a constitutive part of plant. Phytoalexins are antimicrobial compounds, which kill the pathogens or restrict its movement (Yedidia *et al.,* 1999). Hypersensitive response is the result of action of such compounds, and some gene product induces this phenomenon. It is also well understood that some pathogen races does not trigged such gene product and able to produce disease so such races are called virulent races of pathogen (Sharma *et al.,* 2012). Once such defense is activated then the whole system of plant is induced through hormonal signals to defend and it is known as induced systemic resistance (ISR). Sometime pathogen after attacked release some compounds, which act as elicitors and act as, signal for activation of plant defense. Such resistance is acquired systemic resistance, which are based on pathogen signals. In case of virulent pathogen, such signals are not produced and no recognition occur between two counter parts (Langebartels *et al.,* 1991) .

Plant defense through non-host resistance

Each crop plants have specific pathogen and specificity is bases on the compatibility of both. Not every pathogen can infect each host and this query is well answered by specific essential factor, which are necessary for infection. For wind borne pathogens, spores of fungus land on host as well as on non-host and succession of life cycle is completed on true host. There are many features in non-host, which does not allow other pathogens to grow, and such features are both structural as well as biochemical (Nuernberger and Lipka, 2005). Many genes are identified which express in non-host when encounter non-specific pathogens and such genes can be incorporated in true host to confer resistance. Many successful examples were reported e.g. Blast resistance gene from maize was incorporated into rice (Heath, 2000). Limitation in such type of defense is the identification of true mechanism, which actually limits the pathogens and its comparison in true host.

Weapons owned by Plant pathogens

In nature, coevolution is the phenomena in which microorganism evolved together with all organisms in their food chain. All living entities have to live in the same universe as plants are living, therefore, equipped with many weapons, which can be useful for their nutrition and reproduction. A large number of pathogens attacks crop plants and these pathogens utilize specialized mode to infect plant or to get entrance into the plant tissues (Mitchell *et al.,* 2006). Mode of introduction of pathogens varies with their type also depending upon their host kind. Most of weapons are biochemical compounds. It includes toxins, enzymes, growth regulators and polysaccharides. Some are owned by different pathogens and some are common in all plant pathogens.

Weapons of Plant Pathogenic Fungi

Among plant pathogens, fungi constitute a huge variety for its mode of infection as compared to other microorganisms. Pathogenic fungi attack all of the ~ 300,000 species of flowering plants. Fungal phytopathogens are the reason of the major epidemics in the history of plant diseases including rust disease on the coffee plantations of Ceylon, now in Sri Lanka. Fungi revolutionized a number of mechanisms to overcome the host defense, secrete a number of host specific and non-host toxins to approach into the host cells. These include hydrolytic enzymes cutinases, pectinases, cellulases and proteases to dissolve host cell barriers and known as pathogenicity weapons (Maor and Shirasu, 2005). Some pathogens generate such compounds that act as suppressors of the defense responses of the host plant. Plant pathogen fungi may be biotrophic (feed on living tissues) or necrotrophic (feed on dead cells). Biotrophic pathogens have evolved sophisticated mechanisms to parasitize living cells, minimize damage and perpetuate host cell viability until they can complete their life cycle. Against such fungal pathogens like wheat rust disease, cell suicide or hypersensitive response is the most effective defense response of plants. At the other extreme, necrotrophic pathogens often required wound sites or dying tissues to invade. They rapidly macerate host cells and derive nutrients from dead tissues to spread. Many fungal pathogens fall between these two categories and they are hemi-biotrophic pathogens, such as the potato late blight fungus *Phytophtora infestans.* Such pathogens are difficult to control but ISR strategy of host may mitigate the effect of this pathogen (Judelson and Blanco, 2005) . Many fungi produce enzymes to disintegrate the plant structural barriers such as cutinases, pectinases that dissolve cell wall as well as malfunctioning of invaded tissues. Some physical structure uniquely connected with fungi is appresorium and haustoria which facilitate attachment and feeding of nutrients respectively.

Weapons of plant pathogenic bacteria

Bacteria are unicellular prokaryotic organisms that exploit almost every environmental niche on earth and have evolved sophisticated tools to overcome plant defense and cause disease. Bacteria produce toxins, which are unique feature of this pathogen, and toxins may be endotoxin or exotoxin. This weapon causes chlorosis and clogging of vascular tissues and sometime death of tissue due to necrotic toxins (Vivian and Gibbon, 1997). Some bacteria like *Erwinia* spp. cause maceration of tissue through lytic enzymes while *Agrobacterium tumefaciens* distort the cell division by abnormal plant hormone balance. Pathogenic bacteria are not able to cross-intact plant surfaces and entry is via natural openings or wounds. In a previous study, a total of 14 isolates belonging to 4 different species of bacteria (*Bacillus subtilis*, *B. amyloliquefaciens*, *Klebsila* spp. and *Micrococcus* spp.) with inhibitory activity against selected fungi were isolated from soil samples (Alsohiby *et al.,* 2016). Many phytopathogenic bacteria e.g. *Pseudomonas, Erwinina* are equipped with secretion systems, which inject effector proteins (Proteins expressed by plant pathogens to aid infection), into host cells and releases into cytosol. There are seven types of secretion systems identified in bacteria and most common in plant pathogenic bacteria is type III secretion system (TTSS) (Block *et al.,* 2008).

Weapons of plant viruses

Viruses are simple entities of nucleic acid surrounded by a protein coat or by lipoprotein membrane. Viruses are obligate parasites since they rely entirely on the replication machinery and metabolism of host cell to propagate. Viruses infect plants through mechanical or vector transmission since they have no means by themselves to move or breach plant surfaces. Once a virus reaches the cytosol it starts to replicate, exploiting the host's resources and cell-to-cell movement is through plasmodesmata using virus encoded movement proteins. Some viruses infect plant without smyptoms while other cause rapid cell death. For example, *Barley yellow dwarf virus* (BYDV) form chlorosis and *Tobacco mosaic virus* form mottled spots of necrotic cells. Plants have evolved multiple defense strategies i.e. immune receptors that specifically recognize viral components and trigger cell death (Hadidi *et al.,* 2004). Plants also employ an elaborate system of RNA silencing or RNA interference (RNAi) to target the viral genome. In an evolutionary counter defense, some viruses have developed weapons to suppress the RNAi machinery and thereby reassert their infectivity.

Weapons of plant nematodes

Nematodes (or roundworms) are multicellular animals, free living in soil and water, reproduce sexually a feed on plant roots. Plant parasitic nematodes are obligate biotroph that feed only on living cells. Two most damaging groups of nematodes that affect crops species worldwide are root knot nematodes (*Meloidogyne* spp.) and cyst nematodes (*Heterodera* and *Globodera* spp.). parasitic nematodes possess a hollow axial spear weapon called stylet in the oral aperture that also secretes into the cell and absorbs its cytoplasmic contents (Bakhetia *et al.,* 2005). Root knot nematode forms the multinucleated giant cells at feeding sites while cyst nematode give rise to cyst. Plants protect themselves through chemical and physical barriers as well as specific resistance mediated by immune receptors.

CONCLUSION AND FUTURE PERSPECTIVES

Interactions between plants and pathogens are of complex nature. Plants are host to many pathogens in their environment and are not host for many pathogens. In agriculture, battlefield a continuous Boom and Bust cycle occur in which sometine host win and sometime pathogen.

When a new gens for disease resistance is incorporated in host plant, it escalate the yield ad is called Boom period during battle. These genes kill many pathogens and reduce its population significantly. Meanwhile some individuals of pathogen somehow survive and multiplied which later on, after few years, breakdown the resistance gene and reduce yield. This stage is bust cycle and pathogen win. Now new source of resistance is required by host plant to continue the battle. Knowledge of complex host-pathogen interaction is of prime importance to identify new genes and their mechanisms. Mode of attack in different plant pathogens are important to study and there is a need of more research work to explore such phenomenon, which ultimately lead to win the continuous battle against pathogens and ensure food security.

ACKNOWLEDGEMENT

We are highly thankful to Nuclear institute for Agriculture and Biology (NIAB) P.O.Box-128, Jhang Road, Faisalabad, for supporting this research.

CONFLICT OF INTEREST

The authors declare that no competing interests exist.

REFERENCES

Agrios, G., 2005. Plant diseases caused by fungi. Plant pathology, 4.

Al-Deen, A.T., Al-Jobory, H.J., 2018. Native Yemeni *Plumbago auriculata* as a Promising Antioxidant and Antifungal Plant against Different *Fusarium* species. PSM Biol. Res., 3(3): 92-98.

Ali, K., Shuaib, M., Ilyas, M., Hussain, F., Hussain, F., 2017. Medicinal Uses of Chemical Extracts from *Withania somnifera* and Its Antimicrobial Activity: A Mini-Review. PSM Microbiol., 2(1): 20-23.

Al-Mahweety, J.A.N., 2016a. Phytochemical Studies on Medicinal Plants, *Dracaenaceae* resin, of Socotra Island, Yemen. PSM Biol. Res., 01(2): 62-65.

Al-Mahweety, J.A.N., 2016b. Chemical study on the leaves of *Cyphostemma digitatum*. PSM Biol. Res., 01(2): 66-69.

Alsohiby, F.A.A., Yahya, S., Humaid, A.A., 2016. Screening of Soil Isolates of Bacteria for Antagonistic Activity against Plant Pathogenic Fungi. PSM Microbiol., 01(1): 05-09.

Amin, R.A., Edris, S.N., 2017. Grape Seed Extract as Natural Antioxidant and Antibacterial in Minced Beef. PSM Biol. Res., 2(2): 89-96.

Bakhetia, M., Charlton, W., Atkinson, H.J., McPherson, M.J., 2005. RNA interference of dual oxidase in the plant nematode Meloidogyne incognita. Molec. Plant-Microbe Interactions, 18(10): 1099-1106.

Block, A., Li, G., Fu, Z.Q., Alfano, J.R., 2008. Phytopathogen type III effector weaponry and their plant targets. Curr. Opin. Plant Biol., 11(4): 396-403.

Campbell, C.L., Madden, L.V., 1990. Introduction to plant disease epidemiology. John Wiley & Sons.

Darvill, A.G., Albersheim, P., 1984. Phytoalexins and their elicitors-a defense against microbial infection in plants. Ann. Rev. Plant Physiol., 35(1): 243-275.

Dixon, R., Harrison, M., Lamb, C., 1994. Early events in the activation of plant defense responses. Annu. Rev. Phytopathol., 32(1): 479-501.

Doornbos, R.F., van Loon, L.C., Bakker, P.A., 2012. Impact of root exudates and plant defense signaling on bacterial communities in the rhizosphere. A review. Agron. Sustain. Dev., 32(1): 227-243.

Fatima, M., Abbas, S., Ahmad, Z., Sharif, Y., Umair, M., Bahadar, K., Zaynab, M., 2018. Plants Defense System Resist against the Pathogen Attack: Transcription Factors in Focus. Int. J. Nanotechnol. Allied Sci., 2(1): 7-11.

Hadidi, A., Czosnek, H., Barba, M., 2004. DNA microarrays and their potential applications for the detection of plant viruses, viroids, and phytoplasmas. J. Plant Pathol., 97-104.

Heath, M.C., 2000. Nonhost resistance and nonspecific plant defenses. Curr. Opin. Plant Biol., 3(4): 315-319.

Hussain, F., Kalim, M., Ali, H., Ali, T., Khan, M., Xiao, S., Iqbal, M.N., Ashraf, A., 2016. Antibacterial Activities of Methanolic Extracts of *Datura inoxia*. PSM Microbiol., 01(1): 33-35.

Iqbal, M.N., Ashraf, A., 2017. Antagonism in Rhizobacteria: Application for Biocontrol of Soil-borne Plant Pathogens. PSM Microbiol., 2(3): 78-79.

Judelson, H.S., Blanco, F.A., 2005. The spores of Phytophthora: weapons of the plant destroyer. Nature Rev. Microbiol., 3(1): 47.

Kalim, M., Hussain, F., Ali, H., Iqbal, M.N., 2016. Antifungal activities of Methanolic Extracts of *Datura inoxia*. PSM Biol. Res., 01(2): 70-73.

Langebartels, C., Kerner, K., Leonardi, S., Schraudner, M., Trost, M., Heller, W., Sandermann, H., 1991. Biochemical plant responses to ozone: I. Differential induction of polyamine and ethylene biosynthesis in tobacco. Plant Physiol., 95(3): 882-889.

Lucas, J.A., 2009. Plant pathology and plant pathogens. John Wiley & Sons.

Maor, R., Shirasu, K., 2005. The arms race continues: battle strategies between plants and fungal pathogens. Curr. Opin. Microbiol., 8(4): 399-404.

Mehdy, M.C., 1994. Active oxygen species in plant defense against pathogens. Plant Physiol., 105(2): 467.

Mitchell, C.E., Agrawal, A.A., Bever, J.D., Gilbert, G.S., Hufbauer, R.A., Klironomos, J.N., Maron, J.L., Morris, W.F., Parker, I.M., Power, A.G., 2006. Biotic interactions and plant invasions. Ecol. lett., 9(6): 726-740.

Nuernberger, T., Lipka, V., 2005. Non-host resistance in plants: new insights into an old phenomenon. Molec. Plant Pathol., 6(3): 335-345.

Odjakova, M., Hadjiivanova, C., 2001. The complexity of pathogen defense in plants. Bulg. J. Plant Physiol., 27(1-2): 101-109.

Peumans, W.J., Van Damme, E., 1995. Lectins as plant defense proteins. Plant Physiol., 109(2): 347.

Pichersky, E., Gang, D.R., 2000. Genetics and biochemistry of secondary metabolites in plants: an evolutionary perspective. Trends in Plant Sci., 5(10): 439-445.

Raffa, K.F., Smalley, E.B., 1995. Interaction of pre-attack and induced monoterpene concentrations in host conifer defense against bark beetle-fungal complexes. Oecologia, 102(3): 285-295.

Robbins, C., Mole, S., Hagerman, A., Hanley, T., 1987. Role of tannins in defending plants against ruminants: reduction in dry matter digestion? Ecol., 68(6): 1606-1615.

Roberts, M.F., 2013. Alkaloids: biochemistry, ecology, and medicinal applications. Springer Science & Business Media.

Shahzad, M.I., Ashraf, H., Iqbal, M.N., Khanum, A., 2017. Medicinal Evaluation of Common Plants against Mouth Microflora. PSM Microbiol., 2(2): 34-40.

Sharma, P., Jha, A.B., Dubey, R.S., Pessarakli, M., 2012. Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. J. Bot., 2012. ID 217037, 26 pages http://dx.doi.org/10.1155/2012/217037

Singh, U., Maurya, S., Singh, D., 2005. Phenolic Acids in Neem (Azadirachta indica) A Major Pre-Existing Secondary Metabolites. J. Herb. Pharmacother., 5(1): 35-43.

Vivian, A., Gibbon, M.J., 1997. Avirulence genes in plant-pathogenic bacteria: signals or weapons? Microbiol., 143(3): 693-704.

Wittstock, U., Gershenzon, J., 2002. Constitutive plant toxins and their role in defense against herbivores and pathogens. Curr. Opin. Plant Biol., 5(4): 300-307.

Yedidia, I., Benhamou, N., Chet, I., 1999. Induction of defense responses in cucumber plants (Cucumis sativus L.) by the biocontrol agentTrichoderma harzianum. App. Environ. Microbiol., 65(3): 1061-1070.

Zaynab, M., Kanwal, S., Hussain, I., Qasim, M., Noman, A., Iqbal, U., Ali, G.M., Bahadar, K., Jamil, A., Sughra, K., Rehman, N., Buriro, M., Abbas, S., Ali, M., Alvi, A.H., Anwar, M., Khan, M.I., Tayyab, M., 2017. Rice Chitinase Gene Expression in Genetically Engineered Potato Confers Resistance against *Fusarium solani* and *Rhizictonia solani*. PSM Microbiol., 2(3): 63-73.