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Plant Defence Mechanisms: How Plants Battle Pathogens Naturally

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Abstract

As explained earlier, there are multiple layers of defence, which plants have developed to fend off pathogens and resist diseases. This article precisely discusses these natural defense mechanisms, which consist of morphological barriers such as waxy cuticles and thick cell walls, in addition to biochemical and molecular procedures. When pathogens are trying to penetrate the plant tissues they encounter anti-microbial chemicals – alkaloids and phenolics as well as endogenous proteins that can even kill pathogen cells. Guard also use systemic defense mechanisms such as the hypersensitive response (HR), and systemic acquired resistance (SAR) which defends the whole living plant against infection. Despite the significance of plant defense mechanisms, little is known about the hormonal signaling pathways governing defense reactions with respect to the type of pathogen invasion, namely salicylic acid, jasmonic acid, and ethylene. Further, plants produce defense related genes which are resistance genes where a plant signal recognizes the pathogen and triggers a defense mechanism, known as PTI and ETI. Some of the latest papers stress the importance of the plant microbiome, which helps the plant to activate the defensive mechanisms against pathogens, enhances its immunity. Knowing these natural mechanisms that exist, scientists are looking for means of making them usable for agriculture. Selecting for disease resistance and promoting biocontrol measures, and using beneficial plant microbes are environmentally friendly approaches to chemical pesticides. In light of these challenges that affect agriculture such as climate change and evolving pathogen resistance the use of natural defense system in plants could support future food security and sustainable

agriculture.

Introduction

Plants are always under attack by a wonderful number of pathogens such as fungi, bacteria, viruses and nematodes which can greatly affect plant health and production levels. Plants cannot move and possess no adaptive immune system so they have to evolve sophisticated ways of how to defend themselves. These are approximately several million years' adaptive mechanisms of physical, chemical and molecular nature to help plants identify and fight hostile pathogens. Knowledge of how plants defend themselves on their own using biochemistry is not only an interest in plant biology; it also offers solutions for the control of diseases in farming. The major part of the defense strategy in plants includes the mechanical barriers in the shape of waxy cuticles, thick cell walls, and specific morphological structures like trichomes that protect the plants from pathogens. When these barriers are compromised, plants have secondary physical chemical defense where biochemical change occurs, and plants release antimicrobial compounds and pathogenesis-related proteins that slows down or kills the pathogen. Transgenic plants also have outstanding immune memory' through induced defense responses like hypersensitive response (HR) and systemic acquired resistance (SAR) that allow the plant to respond quickly to frequent attacks. These defenses are controlled by hormonal pathways, including those comprising SA, JA, and ET, which direct defense reactions depending on the received danger signal. Later, the molecular genetics contributing to pathogen recognition and host defense have also been identified that plants bear particular resistance genes responsible to detect pathogen presence and occurring both local and systemic immunity. Additionally, interest has been drawn to the way that beneficial microbes can fortify plants from harm caused by pathogens because these microbes are capable of helping to suppress pathogens and induce the plants' defence mechanisms. Studying these tactics might reveal ways of invulnerable plants against diseases, lower the usage of pesticides and promote environmentally friendly farming. Given the new emerging constraints in the agriculture production such as climate change, pathogen resistance; improving plant defense mechanisms mitigate the effects is very vital towards feeding the increasing population while at the same time sustaining the environment.

Physical Barriers a Fundamental of Protection

Plants must have one form of physical barriers as the first line of defense against these pathogens given that they are structural form from which they create barriers to the pathogens. Among them, the plant cuticle which appears as a waxy, hydrophobic layer on the outer surface of epidermal cells of aerial organs, including, leaves and stems only can be mentioned as one of the major obstacles. This cuticle not only reduces the rate of water loss but also acts a barrier to physical infection since it creates an impenetrable layer which excludes many pathogens. Borne at both the global and cellular level, pathogens trying to penetrate the plant must also overcome this strengthened layer. Under the cuticle exist the cell wall which is another layer of protection that is made up of cellulose, hemicellulose, and pectin. The cell wall also has a homeostatic role in plant cells and generally acts a barrier shielding the plant cells from pathogens that would wish to invade the cell. Moreover, under attack, plants increase a protein cross-linkage to strengthen the cell wall as well as callose – a polysaccharide – accumulation to increase the cell wall firmness. These reinforcements make it frustrating for pathogens to enter into the cell and spread within tissues of the plant. Plants also have other defense mechanisms including trichomes, guardian hairs which include thorns and spines that prevent herbivores and mechanical damage that can develop an entry point for the pathogens. Such as trichomes, which are just like hair, are on the out layer of the plant and can chamfer the spores and insects from accessing crucial parts of the plant. Others even excrete those sticky or toxic substances which will repel anything or anyone that wants to approach them. Aside from these, inherent barriers, plants have an ability to shut their stomata, the tiny flexible pores on the surface of the leaves to exclude the invaders. They make use of the stomata to minimize opportunities of attack by diseases by closing the stomata. All these physical barriers are in fact part of the defense strategy that plants use to prevent a variety of pathogens from advancing, exploiting deeper tissues of the plants. This multiple-layered physical defense is basic to plant survival and well-being.

Function of Chemical Defense Compounds

Plants use a wide variety of secondary metabolites as protection against pathogens and herbivores and increase the effectiveness against a wide spectrum of dangers. The former types of these compounds include the constitutive compounds or those that can be synthesized only when there exists an attack while the latter includes the compounds synthesized in response to attack by the herbivores or pathogens and reduces pathogen growth or deters the herbivores. Among these, phenolics, alkaloids and terpenoids inhibits microbial growth through toxic actions affecting the pathogen cells, or preventing their metabolism or growth.

Michailin et al (2005) says that one of the well-known groups of defensive compounds are the phytoalexins , which are antimicrobial compounds produced by plants in response to pathogen invasion. Phytoalexins are synthesized very fast at the infected tissues, thereby maintaining high toxic levels that reduce the ability of the pathogen to Renders. For instance, when plant tissues are invaded by fungi, they produce phytoalexin, chemicals that target only fungi and thereby prevent spread of the fungi. Again, phytoalexins are essentially a better system with which to combat biotic stress since they are targeted to the identified pathogen. Another class of proteins is the pathogenesis related (PR) proteins, The PR proteins also have a defensive function of being proteinases that hydrolyse pathogen cell walls or directly affect pathogen cells. For instance, chitinases and glucanases attack chitin and glucan molecules in the fungal cell walls making the fungus lose its structural integrity and impacting its capacity to penetrate into the plant tissues. These proteins apart from helping in stopping the proliferation of pathogens also serve to signal and consequently activate other defensive responses in neighbouring cells. To countersink herbivores and prevent pathogens from setting up infections, plants also bear toxic secondary metabolisms like tannins, saponines and cyanogenic glycosines. Also yet other compounds serve to inform the surrounding tissues and even neighbouring plants of potential threats. Such a complex chemical defense mechanism allows plants not only to protect themselves from pathogens but also to react differently to various pathogens, demonstrating the greatest developed defense in strengthening plant survival and yield.

Induced Defense Mechanisms

Phytopathogen-triggered defense responses are rapid and directed in nature and provide the first-line of defense to physical and chemical barriers in plants. Induced defenses work differently from constitutive defenses that are always active: instead they may be triggered by the perception of a threat and ensure energy conservation. Amongst these responses the hypersensitive response (HR) and systemic acquired resistance (SAR) are particularly important in controlling and containing infections. The hypersensitive response is a localized, rapid cell death that occurs around an infection site and which acts to limit the spread of the pathogen to other parts of the plant. By self-immolation the plant deprives the pathogen of the nutrients and confines it to the infected cells, keeping healthy tissue out of harm's way. The HR is especially useful against biotrophic pathogens which require live host cells, as they are starved to death of the digested nutrients necessary to their way of life. Systemic acquired resistance is a second type of response, which is initiated throughout the plant after a localized hypersensitive response and prepares distal tissues for the increased resistance against subsequent invasions of pathogens. SAR is normally initiated by the production of signaling molecules such as salicylic acid (SA) which moves throughout the plant to mobilize cells at a distance to respond to pathogen attack. Thereby, the "immune memory" allows plants to quickly andample enhance their immunity across the entire plant after the subsequent invasion. Another category of induced defense is induced systemic resistance, ISR which is initiated by microbes in the ecosystem notably the rhizobacteria. These microbes also activate the plant's immune system, increasing its ability to fight all possibilities of pathogens without having to get a direct attack. Consistent with SAR, the primary ISR is controlled through jasmonic acid (JA) and ethylene (ET) signaling pathways exist as a second-tier defense mechanism. Collectively, HR, SAR, and ISR develop an elaborate and tiered defense system that let plants generate specific responses, adequate to the conditions, and strengthen resistance against diseases at local and systemic level.

Hormonal signaling pathways in defense of plants

Plants use hormonal signal transduction systems in defense, where individual signals are allocated to unique responses to pathogens and herbivores. The present study shows how plants can sense biotic threats using a set of hormones such as SA, JA, and ET to elicit the corresponding defense response. These signaling molecules coordinate within the plant and induce reactions that inhibit pathogen expansion, activate chemical allergy, and prepare the plant's immune system in case of subsequent invasions. Salicylic acid carries out a very central function in safeguarding itself from biotrophic pathogens, which gain their nutrition from living plant tissues. If a plant recognizes such a pathogen, SA accumulates near the site of infection triggering localized response such as the hypersensitive response (HR). SA also triggers SAR, a whole-plant defence response that primes other tissues to defend against future attack. By pysar, that's what salicylic acid does all circulate and create immunity memory in a plant and become even more sensitive to attacks to the plants next time. On the other hand, jasmonic acid is more widely linked to resistance against necrotrophic pathogens that kill plant cells and feed on the tissues, as well as insects feeding on plants. When touched or eaten, JA triggers production of defense genes that produce nasty tasting or toxic chemicals and proteins for the plant to become unappetizing for herbivores. The jasmonic acid pathway also interacts with ethylene which reinforces the plant's ability to protect against certain pathogens that cause cell death. Ethylene is a general hormone involved in plant defense, and acts in concert with both the SA and JA signaling cascades. It regulates according to the type of pathogen, participating in stress signaling and increasing antibiosis where pathogen-biotic and abiotic stress occur simultaneously. Singh and co-authors pointed out that there can be cross-talk between SA, JA, and ET pathways, and thereby provide plants the ability to calibrate its defense mechanisms and avoid wastage of resources. This hormonal signaling forms a flexible multiple tiered defense system where the plants are capable of discerning between a threat and launching precise, efficient and cost effective defense mechanisms to protect them from the pathogens.

Genetic Basis of Plant Defense Mechanisms

The identification of the genes within plants that are involved in defense mechanisms against pathogens provides evidence of pathogen recognition and reaction in plants. Pattern-triggered immunity (PTI) and Effector-triggered Immunity (ETI) are two fundamental parts of this genetic defense system, are intervened by the plant genes and proteins which identifies pathogen and responds. This immunity is initiated by PAMPs which are identified on the plant cell surface by special receptors called PRRs; for instance while bacterial flagellin or fungal chitin are PAMPs. PRRs detect these conserved microbial PAMPs and initiate PTI; this includes reactive, prompt and local mechanisms such as thickening of the cell walls and release of compounds toxic to microbes. PTI offers a basal resistance that duly counters most of the invasive pathogens from consolidating an infection. Effector-triggered immunity is a second line of defense more specific than PTI, it is initiated when the resistance (R) genes within the plant recognize the pathogen effectors, molecules the pathogen uses to preferably inhibit plant defense mechanisms. When pathogen effector is recognized by an R protein, ETI triggers a strong localized defense including the hypersensitive response (HR), a form of sacrificial cell death at the site of pathogen attack to prevent the pathogen's spread. ETI is more stringent than PTI and is normally effective, affording resistance against certain pathogens capable of overcoming PTI effector-based immunity. Plants and pathogens have co-evolved over time, and this has emerged in a classical enabling of an ever-changing genetic arms race in which plants constitute fresh R genes that militate against the increasingly elaborate pathogen effectors. Genetics and genes for defense systems have been advanced to a level where these technologies such as CRISPR and gene editing enable the crops' protection. Scientists are in the process of developing disease-resistant seeds that rely on PTI and ETI thus acting as a natural disease identifier and a tool for biologists to control spread of diseases among plants, and they serve as a natural sustainable control for pests as compared to the use of chemicals that would harm the plants.

Microbiomes in planta defense mechanisms.

The plant microbiome encompasses a complex assemble of microorganisms that inhabit plant tissues including bacteria, fungi, archaea and viruses and is vital for plant health. These microorganisms being present in the site of plant surface, roots and interior tissues are involved in many ways in the natural defense of the plant against pathogen attack. An important function of host plant microbiome is that it excludes the growth of pathogens by occupying their niches and using their resources. The beneficial microbes consequently establish a biofilm on the body of the plant that hinders pathogen biodestablishment and colonization in the rhizosphere. This works in the Principle of Competitive Exclusion which minimizes the avenues for pathogen attach and penetration. Plant-beneficial microbes that inhabit the rhizosphere area can inhibit the proliferation of pathogenic microbes through secretion of chemistries that are toxic to the pathogens, or through causing conditions that are unfavorable for pathogen establishment. Next to physical and chemical competition, the plant microbiome influences the activation of the plant's immune system as well. Some beneficial microbes can activate systemic acquired resistance (SAR) and induced systemic resistance (ISR), the mechanisms that improve the plant's defense against a wide range of pathogens. Some of these microbes for instance Pseudomonas and Bacillus by stimulating immunity response in the plant which is same as when the plant is attacked by pathogens prepare it for subsequent attack. What is more, certain microbiomes produce enzymes and metabolites capable of directly breaking down or inactivating the toxins that are specific toxins of pathogens, in this case. This plant microbial symbiosis is crucial to plant health and is adopted organically as a means to replace chemical pesticides and to develop disease-free food crops. The expanding knowledge about plant microbiomes has created opportunities for the new agro development, for instance, the possibility to create microbial inoculants or grow plant varieties that will attract specific good bacteria that improve plant natural ability to defend against diseases and pests and therefore, reduce the appliance of chemical products.

Conclusion

Plants have one of the best and a complex defense systems that help them grow in environments full of diseases and foragers. In this sense, we come to realize that the snapshots of plant defenses ranging from physical barriers to deter pathogen entry to very complex chemical and molecular reactions are a litmus sign of adaptability. In add margin of, the cuticle and cell walls proved to be structural barriers, the secondary metabolisms products are also used as barriers established against potential threats. When these barriers have been overcome what is termed as induced defenses such as the hypersensitive response (HR) and the systemic acquired resistance (SAR) this offers a rapid and systemic response to the attack. Other hormones signaling involving pathways such as SA, JA, and ET even more refine these defense responses to enable the plant to trigger the most effective defense according to the kind of pathogen that is atick. This cross talk of hormones within the plants ensures that not only are the plants protective in the shortest time possible but also the plants are energy wise in that they do not activate protections where they are not necessary. Genetics is also critical for manage of plant disease, with resistance (R) genes allowing the plant to recognize a pathogen and respond specifically. In PTI and ETI, plants own complicated genetic tools to distinguish beneficial organisms from pathogens, and such defensive system is not static but dynamic. Furthermore, the concept of plant microbiome has been proved as a key driver that modulates plant defenses since positive microorganisms not only inhibit pathogens and induce immunity but also ameliorate plant defense capabilities. Thus creating healthy microbiomes becomes an added advantage and shield to the plants. Given the inherent issues with traditional agriculture such as climate change and emergence of new varieties of pathogens, it is imperative to use these natural defense mechanisms to come up with sustainable disease resistant crops. The combination of first-line physical, second-line chemical generic and microbial barriers can provide the way to continually improve the agricultural immunity and the productivity with decreased utilization of chemical pesticides and contribute to the food security for the whole world.

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