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Research Article

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Role of Enzymes in Plant Defense Against Phytopathogenic Fungi

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Abstract Abiotic (cold, drought, heavy metals, salinity, wounding) and biotic (plant parasite organisms) stressors frequently inhibit plant growth and development. One of the most harmful plant parasite organisms, phytopathogenic fungi, can cause severe diseases and major yield losses in crops. By physically strengthening their cell walls through lignification, suberization, and the production of various defense-related enzymes, plants protect themselves against fungi. The defense-related enzymes β-1, 3-glucanase, chitinases, polyphenol oxidases (PPO), phenylalanine ammonia-lyase (PAL), and peroxidases (POX) are the main focus of the study.

Keywords plant pathogenic fungi, defense-related enzymes, plant defence

1. Introduction

The eukaryotic group of living organisms known as fungi is very large and varied. Fungi have a variety of effects on plant growth and development. Plants and fungi that have mutualistic relationships produce more biomass, have higher survival rates, are healthier, and are more resistant to pathogen attacks. However, fungal pathogen infections can result in decreased agricultural crop plant yields and growth rates, making them significant economically [1]. Beginning when a spore or hyphae makes contact with the plant surface, a variety of factors affect that the fungal pathogen and host plant interact. The abilities of the organisms involved and the environment in which they interact determine how things proceed after contact. Rusts and powdery mildews are examples of biotrophic fungi that exploit the nutrients supplied by their live host and inflict little harm when they invade. However, in order to spread, necrotrophic fungi frequently destroy plant cells by secreting toxins and enzymes that break down cell walls. Numerous pathogenic fungi cause characteristic symptoms on their host plants, including but not limited to leaf spots, leaf curl, necrosis, blights, cankers, galls, rust, mildews, and epinasty [2].

Plants have evolved efficient resistance mechanisms to deal with pathogen attack. Breaking through the host cell wall, the main physical barrier defending plants from microbial invasion, is one of a pathogen's main challenges. Plant cell walls serve as barriers against both abiotic and biotic stresses in addition to giving the body of the plant structure. In response to fungal pathogen attack, plants activate a variety of defense mechanisms. Preexisting chemical and physical barriers as well as inducible defense responses, such as the induction of defense-related enzymes that become active following pathogen infection, are examples of these mechanisms.

2. Defense-related enzymes

All defense-related enzymes are pathogenesis-related (PR) proteins that are responsible for the development of disease resistance responses in plants. The enzymes phenylalanine ammonia-lyase (PAL), polyphenol oxidases (PPO), peroxidases (POX), chitinases, and β-1, 3-glucanase are associated with plant defense.

2.1 Phenylalanine Ammonia-Lyase (PAL)

PAL (E.C.4.1.3.5) is primarily essential for plant disease resistance responses and is involved in the manufacture of phenolic secondary metabolites of antimicrobial nature compounds [3]. PAL is the primary enzyme in the manufacture of several secondary compounds associated to defense, such as phenols and lignins, and its presence in the metabolic activities of numerous higher plants has been proven [4]. Plant resistance to disease is associated to the synthesis of phenolic compounds in response to infection and their presence in the plant. Due to its crucial function in the production of phenylpropanoid, PAL is one of the enzymes in plant secondary metabolism that has been investigated the most [5]. PAL is an inducible enzyme that reacts to biotic (pathogens) and abiotic (UV radiation and low temperature) stresses [6]. There is research showing that changes in PAL activity occur during pathological events (Table 1).

2.2 Polyphenol Oxidase (PPO)

Plant polyphenol oxidases (PPOs, EC 1.14.18.1 or EC 1.10.3.2) are widely distributed and extensively researched oxidative enzymes, and for a long time, it has been known that these enzymes affect the changing the color of in diseased and damaged plant tissues. PPOs are nuclear-encoded enzymes of almost ubiquitous distribution in plants [7]. The oxygen-dependent oxidation of phenols to quinones is catalyzed by PPO [8]. It has often been proposed that PPOs play a role in plant defense against pests and pathogens due to their noticeable response products and induction by wounding and pathogen attack [9,10]. Plants react quickly to diseases, therefore there is immediate rise in PPO, indicating that antimicrobials are being synthesized to ward off the pathogens. Pathogen-induced PPO activity has been reported for several plant species (Table 1).

Table 1: Studies of defense-related enzymes against phytopathogenic fungi in some plants.

Defense-related proteins/enzymes	**Fungi species**	**Plants**	**References**
Phenylalanine ammonia-lyase	*Bipolaris sorokiniana*	Barley	[36]
	Cercospora nicotianae	Tobacco	[37]
	Magnaporthe oryzae	Rice	[38]
	Rhizoctonia solani	Rice	[39,40]
Polyphenol oxidase	*Acremonium zonatum*	Water hyacinth	[41]
	Alternaria alternata, *Colletotrichum capsici*	Pepper	[42]
	Alternaria solani	Tomato	[9]
	Alternaria triticina	Wheat	[43]
	Ascochyta rabei	Chickpea	[44]
	Colletotrichum lagenarium	Cucumber	[45]
	Erysiphe necator	Grapevine	[46]
	Fusarium graminearum	Wheat	[47]
	Fusarium oxysporum f. sp. *albedinis*	Date palm	[48]
	Fusarium oxysporum f. sp. *ciceri*	Chickpea	[49]
	Fusarium oxysporum f. sp. *cubense*	Banana	[50]
	Fusarium oxysporum f. sp. *lycopersici*	Tomato	[51-53]
	Fusarium solani	Eggplant	[54]
	Hemileia vastatrix	Coffee	[55]
	Ramulispora sorghicola	Sorghum	[56]

	Rhizoctonia spp.	Alfalfa	[57]
	Rhizoctonia solani	Cowpea	[58]
	Rhizoctonia solani	Rice	[39,40]
	Sclerospora graminicola	Pearl millet	[59]
	Sphaerotheca fuliginea	Cucumber	[60]
	Stemphylium vesicarium	Onion	[61]
	Ustilago tritici	Wheat	[62]
	Verticillium dahliae	Olive	[63]
	Verticillium dahliae, V. albo-atrum	Pepper	[64]
Peroxidase	*Bipolaris sorokiniana*	Wheat	[65]
	Colletotrichum gloeosporioides	Townsville stylo	[29,30]
	Colletotrichum lagenarium	Cucumber	[66]
	Erysiphe graminis f.sp. *hordei*	Barley	[28,67]
	Erysiphe necator	Grapevine	[46]
	Fusarium oxysporum f. sp. *cubense*	Banana	[68]
	Fusarium oxysporum f. sp. *lycopersici*	Tomato	[53]
	Hemileia vastatrix	Coffee	[69]
	Magnaporthe grisea	Rice	[70]
	Neovossia indica	Wheat	[71]
	Puccinia graminis f. sp. *tritici*	Wheat	[72]
	Rhizoctonia solani	Rice	[39,40]
	Uromyces fabae	Broad bean	[73]
	Uromyces vignae	Cowpea bean	[74]
Chitinase	*Alternaria alternata*	Tomato	[75]
	Alternaria brassicicola	Arugula	[76]
	Botrytis cinerea	Cucumber	[77]
	Colletotrichum falcatum	Sugarcane	[78]
	Colletotrichum sp.	Mango	[79]
	Erysiphe necator	Grapevine	[46]
	Fusarium graminearum	Wheat	[80]
	Fusarium oxysporum f. sp. *ciceri*	Chickpea	[81]
	Giberella fujikuroi	Sugarcane	[82]
	Puccinia striiformis f. sp. *tritici*	Wheat	[83]
	Puccinia triticina	Wheat	[84]
	Rhizoctonia solani	Rice	[40,85]
	Sclerotium rolfsii	Peanut	[79]
	Sclerotinia sclerotiorum	Rapeseed	[86]
β-1,3-Glucanase	*Alternaria alternata*	Tomato	[75]
	Alternaria brassicicola	Arugula	[76]
	Colletotrichum falcatum	Sugarcane	[87]
	Erysiphe necator	Grapevine	[46]
	Magnaporthe oryzae	Rice	[88]
	Sclerotinia sclerotiorum	Beans	[89]
	Sporisorium scitamineum	Sugarcane	[90]

2.3 Peroxidase (POX)

Peroxidases (POX, EC 1.11.1.7) play a key role in plant physiology by catalyzing the oxidoreduction of different substrates utilizing hydrogen peroxide. Numerous studies have indicated that POXs play roles in several plant defense responses, including lignification and suberization [11,12], crosslinking of cell wall proteins [13,14], xylem wall thickening [15)], generation of reactive oxygen species [16-18], hydrogen peroxide scavenging [19], phytoalexin synthesis [20], wound healing [21-23], antifungal activity of POX itself [24], and auxin metabolism [25-27]. POXs help plants defend themselves against pathogens such as fungus [28-30]. Expression of peroxidase contributes to plant defense in two ways: passively (by strengthening barriers) or actively (by producing ROS to fend off attacking pathogens). Plant peroxidases, β-1,3-glucanases, and chitinases work together in the early phases of plant infection [31].

2.4 Chitinase

A broad and diverse group of enzymes known as chitinases (E.C. 3.2.1.14) are also one of the key proteins connected to plant pathogenesis (PR) that breaks degrade chitin and strengthens plant defenses against disease-causing agents that contain chitin [32]. Chitinases are enzymes that degrade chitin, the second-most prevalent structural polysaccharide in nature found in insect exoskeletons; they are also important components of fungal cell walls [33]. Chitinases have been proven to have significant antifungal efficacy against plant pathogenic fungi (Table 1).

2.5 β-1,3 Glucanase

Multifunctional enzymes known as β-1,3 glucanases (E.C.3.2.1.39) are found in many living organisms, such as bacteria, fungus, and some invertebrate animals and plants [33]. Through its ability to degrade the cell walls of fungal pathogens, β-1,3-glucanase may play a role in plant defense against pathogens [34]. When overexpressed in many crops, the defense protein glucanase catalyzes glucan hydrolysis, which is an essential part of the pathogenic fungal cell wall and crucial to increased resistance to infections of fungal diseases [35]. In conclusion, studies have shown that chitinase and β-1,3-glucanase are important components of plant defense against phytopathogenic fungi. (Table 1).

3. Conclusion

In order to protect themselves from many threats including phytopathogenic fungi, plants have evolved a variety of defense mechanisms. Preexisting chemical and physical barriers as well as inducible defense responses, such as the induction of defense-related enzymes that become active following pathogen infection, are examples of these mechanisms. Changes in enzyme activity such as phenylalanine ammonia lyase, polyphenol oxidases, peroxidases, chitinases, and β-1, 3-glucanase are mostly induced by contact between the pathogen and the host plant. Based on the findings of numerous completed and ongoing studies, more research is needed to stimulate resistance in the host plant and to bring the usage of defense-related enzymes against plant pathogens into practice.

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