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# Pathogenesis related proteins act as a plant defence mechanism

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**Abstract**
Plant have several types of defence mechanism against the pathogen attack which include wax, cuticle, cell wall composition, phytoanticipin, cork layer formation, abscission layer, tylose formation, lignification of cell wall, production of Pathogenesis-Related proteins (PRPs), hypersensitive response, phytoalexins. Among which one of the most important plant defence mechanism is synthesized or induce of Pathogenesis-Related protien in plant after pathogen attack. PRPs are definition as the proteins that are induced specifically in response to infection by pathogen and which is encoded by a host plant's genome and are associated with the development to systemic acquired resistance (SAR). They are low-molecular weight proteins (643 kda), stable at low pH, thermo stable and selectively extractable. It's involved in the pathogen recognition and release defence trigger molecules by the infesting pathogen. Others are responsible for signals which are disclose message of the infection to adjacent cells. Seventeen families of PRPs have been recognized. These are chitinases, β-1, 3-glucanase, thaumatin, proteinase-inhibitors, endochitinases, peroxidase, ribonucleic, defensin, thionin, Lipid-Transferase Proteins (LTP), oxalate oxidase and oxalate oxidase like etc. PRPs aggregated in the vacuole and in the intercellular space. The intercellular PRPs present first line of defence to a infecting pathogen and if this break down, the release of second line defence which are vacuolar PRPs, bury pathogen with lytic enzyme, which have antifungal, antibacterial and antiviral activity. These PRPs directly induce the defence activity of plant by attacking particle in the fungus cell wall or bacterium cell wall. Some PRPs indirectly induce the defence activity of plant as lignification of cell wall. Hence, here this review paper provides an overview on the PRPs: classification, role in various biotic and abiotic conditions as well as in plant defence mechanism pathways. We also reviewed some successful case studies related to role of PRPs in plant defence mechanism.

**Keywords:** Plant defence mechanism, pathogenesis-related proteins (PRPs), systemic acquired resistance (SAR), hypersensitive response, phytoalexins, lignification

## Introduction
Various factors constantly threats to plants like as pathogenic microorganisms (e.g., fungi, bacteria and viruses), insect-pest, weeds and other biotic and abiotic. Among these plant pathogens, cause significant reduction in annual crop yield (Singh, 2002) [29]. Due to increasing negative environmental effects of fungicides and appearance of fungicide-resistant pathogen/pest strains, it is a motivate scientist to research for alternative protection methods. Among such novel technique, understanding basal defence mechanisms of plant has emerged as promising supplement in crop protection programme to plan effective disease control tactics. Plants protect themselves from various stresses such as insect's damage, wounding, pathogen attacks, harsh and coarse growing conditions, biotic stresses and abiotic stress by altering their physiological conditions. These protective mechanism induced in plant is called as "defence responses "of and the proteins actively synthesized in response to this reaction are called "defence-related proteins" (Bol *et al.*, 1990) [4]. Plant defence mechanism fall into two categories: Pre-infectional defence and Post-infectional defence, which include structural and biochemical defence mechanism. Pre-infectional defence mechanisms are present before contact with the pathogen which include wax, cuticle, cell wall composition, phytoanticipin and inhibitors released by plant. Post-infectional defence mechanisms are activated only after pathogen recognition which include cork layer formation, abscission layer, tylose formation, lignification of cell wall, generation of Pathogenesis-Related proteins (PR- proteins), hypersensitive response, phytoalexins (Singh, 2002) [29].
There is several definition given by different group of scientist. PRPs are definition as the proteins that are induced specifically in response to infection by pathogen and which is

encoded by a host plant's genome and are associated with the development to systemic acquired resistance (SAR) (Taheri and Tarighi, 2012) [32]. Pathogenesis Related proteins, in short it called PRPs which is a group of proteins coded by plant which are structurally distinct group toxic to infesting pathogens which results under stress, provide protection from biotic as well as abiotic stresses (Van Loon *et al*., 2006) [39]. The word "PR-Proteins" express a distinct group of proteins, which are induced by plant pathogens as well as defence-related signaling molecules. After pathogen attack, start activation of defence signaling pathways *viz*., Jasmonic acid (JA) and Salicylic acid (SA) take place which further accumulate PRPs that minimizes pathogen or disease load (Singh, 2002) [29].

**History of PR- protein**

PR Protein was first discovered and reported in tobacco plant reacting hypersensitively in plant infected by TMV (Bol *et al.*, 1990; Van Loon and Van Kammen 1970) [4, 36]. Antoniw *et al*. (1980) coined the term "Pathogenesis-Related Proteins" (PRs), which have been represent as "Proteins which is encoded by the host plant but produced only in pathological means pathogen attack or related situations". They are low-molecular weight proteins (643 kda), stable at low pH, thermostable and selectively extractable (Van Loon *et al.*, 2006) [39]. Primarily, there is only five main classes of PRPs *viz.*, PR1, PR2, PR3, PR4 and PR5 were identified in tobacco plants based on its molecular and biochemical properties (Bol *et al.*, 1990) [4]. In 1994, a proper nomenclature method was given to classify PRPs into different families based on different criteria like as biochemical, serological, molecular and other biological or enzymatic activity. After on, PRPs were further classification into eleven families (PR-1 to PR-11) were recognized and classified for tobacco and tomato plants which serve as a source for isolating the PRPs in other plant species including both monocots and dicots (Van Baarlen *et al.*, 2007) [1]. PR-8 and PR-10 reported in cucumber and parsley plants. Presented in table 1, Now, PRPs are classified into seventeen families that are classify based on their enzymatic activities, protein sequence similarities and other biological properties. PR-12, PR-13 and PR-14 were identified in radish, arabidopsis and barley, respectively. Germins and germin-like proteins (GLPs) have been classified as PR-15 and PR-16; PR-16 has been isolated from hot pepper (Ali *et al.*, 2017) [3].

**Genesis of PR proteins**

PRPs are found in all plant organs like as leaves, stems, roots and flowers, being particularly abundant in the leaves, where they can found up to 5-10% of total proteins. In the leaves, PRPs are found in mesophyll and epidermal tissues. In inflorescences PRs are detected in sepals, pedicels, anthers, pistils, stigma and ovaries. PRPs produced by biotic organisms like (pathogens, insects, nematodes, herbivores), chemicals such as salicylic, polyacrylic and fatty acids, inorganic salts, as well as physical stimuli, are involved in PRPs production. A special class of PRPs producers are hormones (Ethylene, Jasmonates, Abscisic acid, Kinetin, Auxins etc.) (Van Loon *et al*., 1994; Van Loon *et al*., 2006) [38, 39].

When a pathogen infect on plant, it either favorably infects the plant or plant protect themselves against attack. Plants do not have any phagocytic cells. Instead of, their cells have a thick, complex wall which acts as a obstacle to invasion. Plants exhibit an inherent pathogen specific resistance by producing responses like oxidative burst of cell, by altering of cell wall arrangment that prevent infection and anew synthesis of compounds like pathogenesis-related proteins and phytoalexin. All this responses can be induced by exposing the plant to avirulent, virulent, and nonpathogenic microbes and sometimes volatile molecules like such as salicylic acid, jasmonate (Wu and Bradford, 2003; Xu *et al*., 1994; Delaney *et al*., 1994) [44, 43], 2, 6-dichloro-isonicotinic acid or Benzo-(1,2,3)-thiadiazole-7-carbothioic acid S-methyl ester (BTH) (Vallad and Goodman, 2004). These types of resistance are called as Systemic Acquired Resistance (SAR) or Induced Systemic Resistance (IAR). Among all triggered responses, synthesis of "PRPs" is most important because they can lead to the increased resistance of the plant against a pathogen (Agrios, 2005) [1].

Commonly, there are two types of pathogens *viz.*, necrotrophic and biotrophic, the first one i.e., necrotrophic pathogen which stimulates JA pathway that trigger the activation JA genes (PR3, PR4 & PR12) and leads to accumulation of their product locally, and hence they provides only local acquired resistance (LAR). The second one activates the SA pathway that stimulates SA signature gene (PR1, PR2 & PR5) products locally as well as systematically leading to systemic acquired resistance (SAR). (Fig. 1) (Ali *et al.*, 2017) [3].

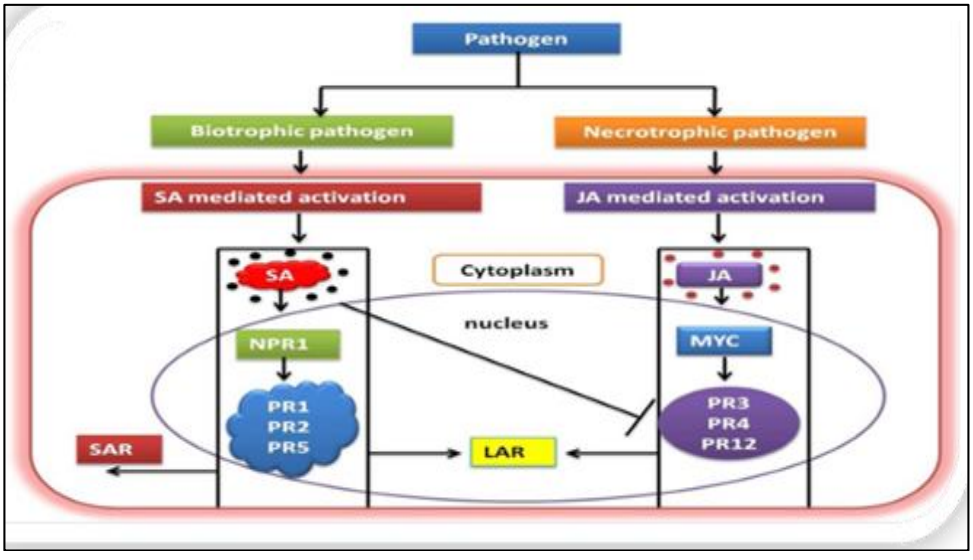


**Fig 1:** Signaling pathway in plants after bio trophic and necrotrophic pathogen infection (Ali *et al.*, 2017) [3].

**Characteristic of PRPs**

They are widely present in plants in small amounts before pathogen attack but are accumulate in high concentration after the pathogen attack or infection. PRPs concentrated locally in the infected and surrounding tissues. Most PRPs present in the plant are have low molecular weight, acid-soluble, and protease-resistant proteins, may be acidic or basic proteins. Acidic PRPs are present in the intercellular spaces and basic PRPs are present in the vacuole. The PRPs have been initially classify based on isoelectric point, molecular mass, and localization and biological activity (Geetha and Kavithamani, 2018) [12].

**Criteria for the classify new introduce families of PRPs (Sels *et al.*, 2008)** [30]

- It must have basal level expression in tissue before pathogen attack but increased expression after infected pathogen attack.
- Induced expression of PRPs in a single plant-pathogen combination must confirmed independently in two different labs or expression occur in at least two different plant-pathogen interaction.

**Table 1:** Identified families of PRPs (Van Loon *et al*., 2006; Sels *et al*., 2008) [39, 30].

| Family | Type member | Properties | Targeted pathogen sites | Reference |
|---|---|---|---|---|
| PR-1 | Tobacco PR-1a | Antifungal | Active against Oomycetes | Antoniw *et al*. (1980) [2] |
| PR-2 | Tobacco PR-2 | β-1,3-glucanase | Glucan cell wall of fungi | Antoniw *et al*. (1980) [2] |
| PR-3 | Tobacco P, Q | Chitinase class I, II, IV-VII | Chitin cell wall of fungi | Van Loon (1982) [37] |
| PR-4 | Tobacco R | Chitinase class I, II | Chitin cell wall of fungi | Van Loon (1982) [37] |
| PR-5 | Tobacco S | Thaumatin-like | Active against Oomycetes | Van Loon (1982) [37] |
| PR-6 | Tomato inhibitor I | Proteinase-inhibitor | Active on nematodes & insects | Green and Ryan (1972) [13] |
| PR-7 | Tomato inhibitor I | Proteinase-inhibitor | Microbial cell wall dissolution | Vera and Conejero (1988) [40] |
| PR-8 | Tomato $P_{69}$ | Chitinase class III | Chitin cell wall of fungi & mucopeptide wall of becteria | Metraux *et al.* (1988) [20] |
| PR-9 | Cucumber chitinase | Peroxidase | Cell wall biosynthesis | Lagrimini *et al.* (1987) [17] |
| PR-10 | Tobacco lignin-forming peroxidase | Ribonuclease-like | Viral – RNA | Somssich *et al.* (1986) [31] |
| PR-11 | Parsley "PR-1" | Chitinase, type I | Cell wall glucan of fungi | Melchers *et al.* (1994) [19] |
| PR-12 | Radish Rs-AFP3 | Defensin | Antifungal and antibacterial activity | Terras *et al.* (1995) [33] |
| PR-13 | Arabidopsis Thi2.1 and Thi2.2 | Thionin | Antifungal and antibacterial activity | Epple *et al.* (1995) [10] |
| PR-14 | Barley LTP4 | Lipid-transfer protein | Antifungal and antibacterial activity | Garcıa-Olmedo *et al.* (1995) [10] |
| PR-15 | Barley OxOa (germin) | Oxalate oxidase | Cell wall degradation by $H_2O_2$ | Zhang *et al.* (1995) [42] |
| PR-16 | Barley OxOLP | Oxalate-oxidase-like | Cell wall degradation by $H_2O_2$ | Wei *et al.* (1998) [41] |
| PR-17 | Tobacco PRp27 | Unknown | Antifungal and anti-viral | Okushima *et al.* (2000) [22] |

**Table 2:** Characteristic, subclass and mode of action (Van Loon *et al*., 2006; Sels *et al*., 2008) [39, 30].

| Family | Properties | Characteristic and subclass | Mode of action | Reference |
|---|---|---|---|---|
| PR-1 | Antifungal | ✓ M. W.- 14 to 16 kDa<br>✓ Identified in tobacco, *Arabidopsis*, barley, rice, pepper, wheat and maize.<br>✓ Soluble in acidic pH | ✓ Strengthening of host cell walls<br>✓ It act as inhibit the growth of pathogen | Antoniw *et al*. (1980) [2] |
| PR-2 | β-1,3-glucanase | ✓ M.W.- 33 to 44 kDa, in *Nicotiana* species:<br>Class I: Basic isoform, localized in vacuole<br>Class II: Acidic isoform, localized extracellularly<br>Class III: Include - acidic protein but distinct in their sequence of at least 43% as compare to class I and class II<br>✓ Identified in tobacco. | ✓ This is responsible for hydrolytic cleavage of the 1,3-β-D-glucosidic linkages in β-1,3-glucans, which is a major component of fungi cell wall.<br>✓ So it cause cell lysis and cell death due to hydrolysis of glucans. | Antoniw *et al*. (1980) [2] |
| PR-3 | Chitinase class I, II, IV-VII | ✓ M.W.- 15 to 43 kDa<br>✓ Isolated from tobacco, Chickpea, Cucumber, barley.<br>✓ Sub-classification based on localization of the enzyme, isoelectric pH, signal peptide, n-terminal sequence, and inducers.<br>✓ Class I chitinase have been reported in plants,<br>✓ Class II chitinase enzymes are contained in plants, fungi, and bacteria.<br>✓ There is no sequence resemblance with class III Chitinase to enzymes of class I or II.<br>✓ Class I chitinase have analogus characteristics to class IV-VII chitinases, but they are significantly smaller than class I chitinase. | ✓ Chitinases are endo β-1,4-glucosaminidases which hydrolyze the β-glycosidic bond at the reducing end found in chitin, chitosan or peptidoglycan (Neuhaus, 1999).<br>✓ Break the cell wall of chitin resulting in a weakened cell wall and make fungal cells osmotically sensitive.<br>✓ These chitinase have significant antifungal activities against plant pathogenic fungus like *fusarium* spp. | Van Loon (1982) [37] |
| PR-4 | Chitinase class I, II | ✓ M.W.- 9 to 30 kDa<br>✓ Basic pH | ✓ CBP has binds with insoluble chitin and encourage the hydrolysis of chitin by other | Van Loon (1982) [37] |

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|---|---|---|---|---|
| | | ✓ Isolate from sugar beet, tobacco, pepper, tomato and potato.<br>✓ High level of expression in phloem of pepper. | enzyme like Chitinase. | |
| PR-5 | Thaumatin-like protein / osmotin-like protein | ✓ M.W.- 18 to 25 kDa and pH 4.5 to 5.5<br>✓ Isolated from *Thaumatin*, barley, kiwifruit and maize. | ✓ It is associated with SAR and stress response in plant.<br>✓ Antifungal activity, anti-freezing activity and osmotic stress tolerance.<br>✓ Inhibition of hyphal growth and sporulation of various fungi. Antifungal activity by membrane permeabilization mechanism. (Kitajima and Sato, 1999).<br>✓ These PRPs is reported from cherry, apple and banana plant, which shows antifungal activity against the fungus *Verticillium alboatrum.* | Van Loon (1982) [37] |
| PR-6 | Proteinase-inhibitor | ✓ Highly stable defensive proteins. Induced in response to insect.<br>✓ Classified into 3 types Sub-classes depend on the active amino acid in its "reaction center" (Koiwa *et al*., 1997).<br>✓ Serine proteinase inhibitor<br>✓ Cysteine proteinase inhibitor<br>✓ Aspartate/metallo proteinase inhibitor | ✓ Protease inhibitor of insect.<br>✓ Broad spectrum of activity (suppression, antibiosis, elicitor). | Green and Ryan (1972) [13] |
| PR-8 | Chitinase class III | ✓ Occur in acidic and basic both forms.<br>✓ Broad range of pH, vast range of isoelectric points, and temp. Stability at 140-160º F.<br>✓ It has been reported from *Arabidopsis*, cucumber, chickpea and tobacco | ✓ Class III chitinase have antifungal and have lysozyme activity due to this it also have antibacterial activity. | Metraux *et al.* (1988) [20] |
| PR-9 | Peroxidase | ✓ The recent studies of peroxidase classified it into another three groups that including: (Das *et al*., 2011).<br>1. Class I (ascorbate type)<br>2. Class II (fungal secretary)<br>3. Class III (guaiacol type, plant secretary) | ✓ Catalyse the oxidation of hydrogen peroxide.<br>✓ It act in cell wall strengthen by catalyzing lignification which responsible for enhance resistance against different types of pathogens.<br>✓ Biosynthesis of lignin and other oxidative phenol which role in cell wall-building process. | Lagrimini *et al.* (1987) [17] |
| PR-10 | Ribonuclease-like Protein | ✓ Identified from various flowering plants.<br>✓ It found in numerous dicots, including parsley, pea, potato, white birch (*Betula verrucosa*), bean, apple, among the monocots, occur in rice, lily and sorghum.<br>**Four sub-classes**<br>✓ Sub-class-I : Proteins from dicots<br>✓ Sub-class -II and IV : Proteins from monocots<br>✓ Sub-class -III : Proteins from conifers | ✓ RLPs have ribonuclease activity act as depurinate sarcin loop of large rRNAs. Due to this inactivates the ribosome, because blocking its further participation in protein synthesis.<br>✓ It is the only PRPs family which have antiviral activity. | Somssich *et al.* (1986) [31] |
| PR-12, 13 | Defensin and Thionin | ✓ M.W.-5-6 kDa (small)<br>✓ Basic, cysteine-rich antifungal peptides peptides ranging from 45 to 54 amino acids, and are positively charged.<br>✓ "Plant defensin" was coined in 1995 by Terras, isolated from wheat and barley | ✓ It hinder the growth of fungi by disturbing cytosolic $Ca^{2+}$ gradients needed for hyphal tip growth and permeabi-lization of cell wall by aattacking the cell membrane trigger rapid $Ca^{2+}$ uptake and $K^{+}$ discharge from hyphae, thus | Terras *et al.* (1995); [33] Epple *et al.* (1995) |
| PR-14 | Lipid-transferase protein | ✓ LTPs are classified into two sub-families,<br>✓ LTP-1 with 9 kDA size<br>✓ LTP2 with 7 kDA size<br>✓ Located in the cell wall, small, cysteine-rich, cationic peptides.<br>✓ Participate in cutin formation, embryogenesis, and defence reactions against plant pathogens. | ✓ It shows antifungal and antibacterial properties, effect at site of plasma membrane. | Garcıa-Olmedo *et al*. (1995) |
| PR-15 and PR-16 | Oxalate oxidase and Oxalate-oxidase-like | ✓ Reported from germinating barley, rice, maize, oat, rye, other cereals and eudicot plants. | ✓ It produce $H_2O_2$ that can be harmful to different types of pathogen, which directly or indirectly arouse plant-defence reactions. | Zhang *et al.* (1995) [41]; Wei *et al.* (1998) [41] |
| PR-17 | Unknown | ✓ M. W. 27 kDa, isoelectric point of 8.54.<br>✓ Isolated from wheat, tobacco, *Arabidopsis*, tomato.<br>✓ It has attraction toward zinc and that's why it is same like as zinc metallo-proteinase. | ✓ Uncharacterized | Okushima *et al.* (2000) [22] |

**General functions of PR- protein**

Plays important role in defence against pathogen infection, eliciting acquired resistance and abiotic factor. Involved in the detection process and released defence stimulating molecules, which work as, signals that disclose "news" of the attack of any pathogen to nearest cells of plant. It also trigger the cross-linking of component in the cell wall and the deposition of lignin, this reaction set up a local barrier of pathogen that slows infection of the pathogen to other non-infected parts of the plant. Lignification by peroxidase, antiviral due to ribonuclease and degradation due to lysozyme activities. They has hydrolytic cleavage, proteinase-inhibitory and cause permeabiliziation of membrane. They inactivate the proteins released by the plant pathogenic organism in the infected plant parts (Geetha and Kavithamani, 2018) [12].

**Role of PRPs in plant defence**

Mauch *et al*. (1988) [18] revealed that combo of chitinase and β-1, 3-glucanase was more effective for control of most of fungal disease as compared to single treatment of chitinase and β-1, 3-glucanase in arhar when they studied. Crude protein preparations from infected arhar pods and by purified enzymes from it, check the growth of various eighteen fungi. Jebakumar *et al*. (2001) [15] observed β 1,3 glucanase activities in normal and *Phytophthora capsici* inoculated leaf and roots of black pepper, higher activity of β-1, 3-glucanase in leaf (70.9%) and roots (27.5%) in P24 variety (tolerant) of black pepper than Penniyur-1 and Subhakara (susceptible) after inoculation of *Phytophthora capsici* in both variety.

Saikia *et al*. (2005) [26] studied the activity of PRPs chitinase and β-1, 3-glucanase were extracted from infected Bengal gram plant and which is purified by gel filtration. Highest activities of these PRPs were observed after three days of inoculation in all (triggered by infection) plants. Then, the activity decreased with time. Two chitinases and three (β -1, 3-glucanases were observed in inoculated Bengal gram. The M. W. is 31 and 62 kDa of the purified chitinases and 23, 27 and 39 kDa of β-1, 3-glucanase. They also check the growth of *Fusarium oxysporum* f. sp. *ciceri* also other plant pathogenic fungi.

Rajendran *et al*. (2006) [23] observed peroxidase and chitinase activity was significant highest against bacterial blight in cotton due to bacteria *Xanthomonas axonopodis* pv. *Malvacearum* inoculated with EPCO102, EPCO16 and Pf1. They found that effect of inducing systemic resistance against *Xanthomonas axonopodis* pv. *malvacearum* in cotton by induction of defence enzymes with a talc-based bio formulation of the endophytic bacteria *Bacillus* strains EPCO 102 and EPCO 16 and *Pseudomonas fluorescens* strain Pf1, with or without the addition of chitin under protected conditions. The bio formulation, applied through seed, soil or foliar spray, significantly reduced disease incidence. The addition of chitin to the formulation reduced disease incidence. EPCO 102 with chitin led to the lowest bacterial blight incidence. The bacterial strains also induced chitinase, peroxidase, polyphenol oxidase and phenol in cotton.

Kumar *et al*. (2007) studied that effectiveness of different isolates of *Pseudomonas fluorescens* was tried for the induction of systemic resistance against dry root rot of Bengal gram caused by *Macrophomina phaseolina*. Pf4-99 was strong siderophore producing and plant growth promoter among five different isolates of *P. fluorescens*, It is also inhibited the mycelial growth of *M. phaseolina* in lab condition and decreased the root rot disease under greenouse. In Pf 4-99 treated plants, an increase in chitinase, β-1, 3-glucanase, peroxidase, activity phenolic content as well as PAL activity was observed after cultural inoculation with fungus of root rot. These all revealed that, *P. fluorescens* isolate Pf4-99 systemically enhance resistance against dry root rot of Bengal gram by the production of numbers of enzymes in respect to pathogen attack.

El-Komy *et al*. (2010) [9] were studied changes of potato PRPs upon attack with late blight pathogen. Their results revealed that in both resistant (Hanna and Cara) and susceptible (Diamant and Lady Rosetta) potato variety, leaves of potato plant inoculate with *Phytophthora infestans* pathogen culture induce a significantly higher total protein than the normal ones. In a bioassay experiment, the crude protein extracted from leaves of Hanna and Cara gives the lowest, while those from Diamant and Lady Rosetta revealed highest fungal growth. SDS-PAGE analysis of acid soluble proteins extracted from fungus inoculated plant at different periods with *P. infestans* showed that nine proteins were increased gradually with time of M. W. ranged from 12-45 kDa. The expression of OSM-1 gene in the resistant variety shows earlier and stronger, while express later in the susceptible.

Nisha *et al*. (2012) [21] experiment on plant extracts against bacterial leaf blight (BLB) disease of rice, inoculation of pathogen with phytoextract stimulate the PRPs. In SDS PAGE extra proteins bands were seen in *V. nedungo* extracts treated plants after pathogen. The BLB was more efficiently controlled by water and methanol extract due to peroxidase and β-1, 3-glucanase activity is more in this. Ramyabharathi *et al*. (2012) [21] observed in tomato that the application of *Bacillus subtilis* EPCO16 against fusarium wilt revealed that expression maximum activity of β-1, 3-glucanase and chitinase (28.09 and 99.45 µmol glucose released/h/g), after 7 days inoculation of pathogen, respectively.

Gupta *et al.* (2013) [14] studied the increase of PRPs in *Eruca sativa* in response to fungal pathogen *Alternaria brassicicola* was investigated in 10 days and one-month-old plants. Induction of pathogen resulted increase in the activities of β-1, 3-glucanase and chitinase in resistant cultivar (RTM-2002) as compared to susceptible (T-27) one.

Wu *et al*. (2013) [43] observed expression of different PRPs during plant defence against *Fusarium* head blight and *Yellow dwarf virus* in both resistant and susceptible genotypes after pathogen or insect attack. Quantitative real-time PCR (qRT-PCR) admit that PR1, PR2, PR3, PR5, PR6, PR8, PR9, and PR15 appeared to be stimulate or reduced in response to *Fusarium* head blight, *Yellow dwarf virus*. Alternative mechanisms may be involved in different interactions of wheat-*Fusarium*, wheat-YDV. However, strong up- or down-regulation of PR12 and PR14 had been detected after either pathogen infection or insect infestation, therefore showed broad responses a synergistic action of different PRPs genes in plants to defense against certain pathogens and insects.

Sayari *et al*. (2014) [27] studied expression of defence gene in two weeks old seedlings of rice inoculated with *Rhizoctonia solani* in resistant (Tarom) and susceptible (Khazar) cultivar. The expression of PR-3, 5, 10, 12 and 13 were higher in resistant than susceptible. Sharma *et al.* (2014) [28] found that the relative expression of chitinase gene in sorghum due to infection of *M. phaseolina* in sorghum PJ 1430 (resistant) and SU-1080 (susceptible) variety. Expression of PRPs was 4.79 and 1.66 fold change in resistant whereas, 2.97 and 1.07 fold change in susceptible variety sample of leaf and root, respectively. Expression of chitinase in resistant cultivar were significantly high between 24-72 hours post inoculation then susceptible.

Wu *et al.* (2016) [44] observed reduction in lesions of *Magnaporthe grisea* was reduced in Jasmonic inducible PR class 10 (*JIOsPR 10)* developed transgenic line Ox-1 and Ox-3 lines in compare with wild type plant (WT). Average infected part on the leaf of Ox-1 and Ox-3 lines was lower to 22.96% and 13.6%, respectively as compare 39.72% in the WT.

**Interesting facts**

PR-2, 3, and 5 proteins have antifreeze activity in rye. These proteins have both enzymatic and antifreeze activities, proteins induced much in response to cold, short day length, and dehydration. PR 5 gene show a high degree of homology with osmotin-like protein was first observed in sweet basil (*Ocinmum basilicum* L.) (Rather *et al.*, 2015) [25]. Osmotin cause death of yeast (*Saccharomyces cerevisiae*) by bind to phosphomannans of the cell wall. PR5 family are known as thaumatin like proteins (TLPs) due to its amino acid sequence and structural similarities with proteins from the fruits of West African forest shrub *Thaumatococcus daniellii* (Edens *et al.*, 1982) [8].

Defensin have structural similarities with thionin, such as the number of cysteine units and the same molecular size. However, their structure was not closely related to α- and β-thionin; therefore, they were separately grouped and termed as γ-thionins. Later, γ-thionin were redefined as "plant defensin" based on their antimicrobial action (Bruix *et al.*, 1993) [5].

These proteins promote the transfer of phospholipids like as galactolipids, phosphotidylcholine and phosphotidylinositol (Castro & Fontes, 2005) [6] among cell membranes, so it is known as Lipid-Transfer Proteins (LTPs). LTPs have less specificity for lipid substrate, and hence are termed "Nonspecific Lipid-Transfer Proteins" (Ns-LTPs). LTPs are present in relatively high concentrations in vascular tissue (Kader, 1975).

**Conclusion**

The role of PRPs represent their importance in defence mechanism in plants by activating systemic acquired resistance. PRPs in plants activated due to the pathogen infection as well as other biotic and abiotic factors. PRPs have different characteristics and mode of action. It has been occurred in cereals (rice, wheat, sorghum, barley), pulses (chickpea, pigeon pea), fruit crops, vegetables (tomato, potato) and others crops. Seventeen PRPs are identified till today, among which chitinase, β 1, 3-glucanase, peroxidase, protease and thaumatin are studied mostly.

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