Unveiling Plant defence Strategies: Exploring Induced Systemic Resistance in the Battle Against Pathogens

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Plants are continuously exposed to pathogen attack, but successful infection is rare because plants protect themselves against pathogens using a wide range of response mechanisms. Although all plants have physical and chemical barriers which provide first line of resistance in the form of protection, but when the protection fails and pathogen get succeed in getting entry into the plant a dynamic or active defence mechanism is pressed.

There are two main mechanism which induce resistance in the plant SAR (Systemic Acquired Resistance) and ISR (Induced Systemic Resistance). Brief about the Induced Systemic Resistance are discussed below.

The term induced resistance is a generic term for the induced state of resistance in plants triggered by biological inducers, which protects nonexposed plant parts against future attack by pathogenic microbes and herbivorous insects.

The term induced systemic resistance was given by Van loon in 1997 and suggested as a novel type of induced resistance. Induced systemic resistance is an activated resistance process which is activated by biological or biotic factors. Induced systemic resistance is mediated by jasmonic acid and ethylene signalling pathway which is triggered by non-pathogenic micros example pgpr, *Trichoderma, Bacillus, Pseudomonas* etc.

The induced state of resistance is characterized by the activation of latent defence mechanisms that are expressed upon a subsequent challenge from a pathogen or insect herbivore. Induced resistance is expressed not only locally at the site of induction but also systemically in plant parts that are spatially separated from the inducer, hence the term ISR. Generally, induced resistance confers an enhanced level of protection against a broad spectrum of attackers, induced resistance is regulated by a network of interconnected signalling pathways in which plant hormones play a major regulatory role. The signalling pathways that regulate induced resistance elicited by beneficial microbes.

Beneficial microbes in the microbiome of plant roots improve plant health. Induced systemic resistance (ISR) emerged as an important mechanism by which selected plant growth–promoting bacteria and fungi in the rhizosphere prime the whole plant body for enhanced defence against a broad range of pathogens and insect herbivores. A wide variety of root-associated mutualists, including *Pseudomonas*, *Bacillus*, *Trichoderma*, and mycorrhiza species sensitize the plant immune system for enhanced defence without directly activating costly defences.

Besides microbial pathogens and insect herbivores, plants also nurture a vast community of commensal and mutualistic microbes that provide the plant with essential services, such as enhanced mineral uptake, nitrogen fixation, growth promotion, and protection from pathogens these plant microbiota are predominantly hosted by the root system, which deposits up to 40% of the plant's photosynthetically fixed carbon into the rhizosphere, rendering this small zone around the roots one of the most energy-rich habitats on earth several genera of the rhizosphere microbiota, which are referred to as plant growth–promoting *rhizobacteria* (PGPR) and fungi (PGPF), can enhance plant growth and improve health.

Wei *et al*., (1991) demonstrated that colonization of roots by different beneficial *Pseudomonas* and *Serratia* PGPR strains resulted in a significant reduction in disease symptoms after challenge inoculation of leaves with the anthracnose pathogen *Colletotrichum orbiculare*. In both seminal studies, PGPR and pathogen were demonstrated to have remained spatially separated during the experiments, which allowed the authors to conclude that the enhanced level of disease resistance was caused by a plant-mediated immune response called rhizobacteria-induced systemic resistance (ISR).

Role of induced systemic resistance

- ✓ Plants treated with PGPR or biological agent supposed to be more rapidly to the pathogen attack due to activation of new system resistance in plant.
- ✓ Reduce the negative effect of the pathogen and promotes positive response in plant.
- ✓ Improve photosynthetic efficacy.
- ✓ Increase nutrient absorption and nitrogen use efficiency.
- ✓ Enhance growth and yield by eliminating harmful microorganisms.

Root Colonization and stimulation of ISR

Initiation of ISR requires beneficial microbes to efficiently colonize the root system of host plants. For the establishment of a successful mutualistic association, host plants and microbes need to respond to reciprocal signals and accordingly prioritize their responses to develop a lifestyle that provides mutual benefits. In the well-studied mycorrhizal and rhizobial symbioses, host-secreted strigolactones and flavonoids stimulate the production of symbiotic Sym and Nod factors by the microbes, which in turn activate a common symbiosis (Sym) signalling pathway in plant roots that is necessary for the establishment of a successful symbiotic relationship. How nonsymbiotic PGPR and PGPF establish a prolonged mutualistic interaction with plant roots is less well characterized, but a picture is emerging that a molecular dialog is also essential for these mutualistic interactions.

Jasmonic acid and ethylene are the signalling molecules for ISR, which act in a sequence in activating the induced systemic resistance response. These bacteria are referred as PGPR because they improve plant growth and yield by suppressing deleterious rhizobacteria (DRP) seed bacterization with PGPR results in colonization of emerging roots and shoot by the introduced rhizobacteria. Once the induction of ISR has occurred, the number of introduced bacteria may decline without loss of their protective effect against DRB. Beside seed bacterization, direct application of PGPR to roots during transplantation, or transplanting seedling in bacterized soils, are also used for inducing ISR.

The signalling pathway are dependent on the positive regulatory protein NPR1, which moves to the nucleus and interact with TGA transcription factors to induce defense gene expression. The NPR1 differentially regulates ISR related gene expression, depending on the signalling pathway. ISR must depend on a different induced state, whose effector defense compounds are yet not known.

Jasmonic Acid and Ethylene in Control of Induced Systemic Resistance

Along with SA, the plant hormones JA and ethylene (ET) are also important regulators of the plant immune system. By using Arabidopsis mutants impaired in JA or ET signalling, it was demonstrated that JA and ET are central players in the regulation of rhizobacteria-mediated ISR. JA signalling mutants jar1, jin1, and coi1 and diverse ET signalling mutants, including etr1, ein2, ein3, and eir1, were shown to be defective in *P. fluorescens*. For many other PGPR, such as Serratia marcescens, *Pseudomonas protegens*, and *P. fluorescens*, and PGPF, such as *Penicillium* sp, *Trichoderma harzianum*, and *P. indica*, genetic evidence in Arabidopsis pointed to a role for JA and/or ET in the regulation of ISR. The same holds true for other plant species, such as tomato and rice, supporting the notion that JA and ET are dominant players in the regulation of the SA-independent systemic immunity conferred by beneficial soilborne microbes. In accordance with its dependency on JA and ET signalling, rhizobacteria-mediated ISR was shown to be effective against attackers that are sensitive to JA/ET-dependent defenses, including necrotrophic pathogens and insect herbivores.

Plant signaling pathways induced by Beneficial Microbes

when plant interact non-pathogenic or pathogenic micro-organism it triggers wide range of defense mechanism. Two main mechanisms are recognized: systemic acquired resistance (SAR) and induced systemic resistance (ISR).

SAR is usually triggered by local infection, provides long-term systemic resistance to subsequent pathogen attack, is correlated with the activation of PR genes, and requires the involvement of the signal molecule salicylic acid (SA).

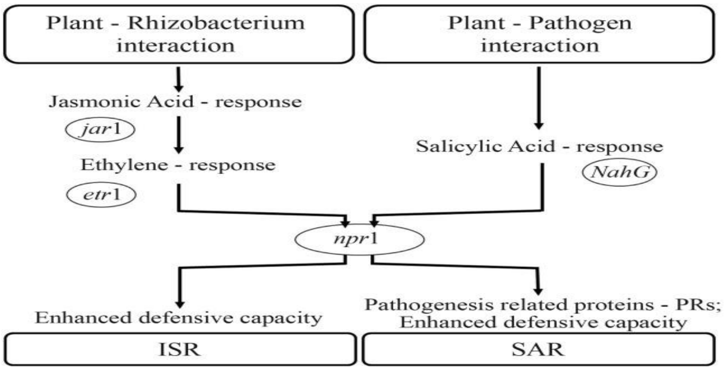

Fig 1. Signal Transduction leading to rhizobacteria-induced and ISR pathogen-induced SAR

(Source: Van Loon, 1998)

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ISR is not SA-dependent, but rather requires components of the jasmonic acid (JA) signaling pathway followed by the ethylene signaling pathway. when we apply *Trichoderma spp.* It regulates Pal-1 which in-codes for phenylalanine ammonia lysate, further Pal-1 activates the JA and ethylene signaling pathway which Catalyze phenyl propanoid Pathway leading to the production of Phenolic compound like phytoalexins in the form of defense against the pathogens (Shores and Harman, 2010).

Is Induced Systemic Resistance Constitutively Active in the Field?

The microbial community in the rhizosphere is extremely diverse, and members of many genera have the potential to elicit ISR. On top of that, many different microbial determinants have been implicated in eliciting ISR. Thus, the question of whether all plants in the field are already in the state of ISR seems reasonable, and it may explain some observations of inconsistent performance of induced resistance in the field. However, there are many examples of PGPR or PGPF that induce ISR under field conditions when introduced to soil or planting material. This suggests that untreated plants do not constitutively express ISR or at least that they are not induced up to their full potential.

This apparent contradiction may be explained by the relatively high population densities of introduced bacteria that are required for effective elicitation of ISR. For example, the threshold population density of *P. fluorescens* required to elicit ISR in radish is 105 colony-forming units per gram of root. The occurrence of such a high density of a single bacterial genotype in the rhizospheres of field-grown plants seems unlikely, apart from the situation in some disease-suppressive soils. For example, in take-all decline soil, population densities of DAPG-producing *Pseudomonas spp.* are consistently above the 105 thresholds. Given the observation that DAPG production by *P. fluorescens* is a major determinant of ISR may be operative in take-all decline soils in which DAPG-producing *Pseudomonas spp.* A demonstration that suppressive soils not only control a single target soilborne pathogen or disease but also stimulate the plant immune system would greatly enhance their standing as an important approach to managing diseases and insects in conventional and organic crop production system.

PGPF and PGPR

PGPF

The definition of plant growth-promoting fungi, or PGPF, is like that of PGPR except that the organisms in question are fungi (here including true fungi as well as oomycetes) rather than bacteria. While mycorrhizal fungi are known to improve the growth of plants and affect the expression of plant defense responses (Lambais and Mehdy, 1995), a comprehensive discussion of the interactions between mycorrhizal fungi and plant. Fungi reported in the literature as PGPF primarily include ascomycetes (*Penicillium, Trichoderma, Fusarium, Phoma, Gliocladium*) and oomycetes (*Pythium, Phythophthora*). Interestingly, some reported PGPF are non-pathogenic or hypo virulent strains of phytopathogenic fungi.

PGPR

PGPR have include Firmicutes or Gram-positive bacteria (e.g., members of the *Actinomycetales*, including Frankia and Streptomyces, and Bacilli, including Bacillus and Paenibacillus), as well as Gram-negative organisms in various subdivisions of the Proteobacteria: Rhizobiaceae *(Rhizobium, Bradyrhizobium*), Rhodospirillaceae (*Azospirillum*), and Acetobacteraceae (Acetobacter) in the α-Proteobacteria; members of the Burkholderia group (Burkholderia) in the β-Proteobacteria, and members of the Enterobacteriaceae (Enterobacter, Pantoea, Serratia) and Pseudomonaceae (*Pseudomonas, Flavimonas*) in the γ-Proteobacteria.

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Table: 1 *Trichoderma* MAMPs identified in different species

Sl	MAMP/Effector	*Trichoderma* species	Activity	References
1.	Protein Xylanase Xyn2/Eix	*T. viride*	A xylanase that elicits ET biosynthesis and hypersensitive response in tobacco leaf tissues	Rotblat *et al.* (2002)
2.	Cellulases	*T. Longibrachatum*	Activated and heat denatured cellulase elicit melon defences through the activation of the SA and ET Signalling pathway respectively	Martinez *et al.* (2001)
3.	Cerato platanin	*T. virens/ T. atroviride*	Hydrophobin like SSCP orthologous that can induce expression of defence responses in cotton and maize	Djovonic *et al.* (2006)
4.	Swollelin	*T. asperelloide*	Expansion like protein with cellulose binding domain capable of stimulating local defence responses in cucumber roots and leaves and affording local protection against *B. cineria* and *P. Syringae*	Brotman *et al.* (2008)
5.	Endo polyglacturonase (ThPG-1)	*T. harazianum*	Involved in colonization of tomato roots and ISR like defence in Arabidopsis.	Moran-Diez *et al.* (2009)

(Source: Hermosa *et. al.*, 2012)

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