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APPLICATION OF PLANT RESISTANCE INDUCERS (PRIs) IN MANAGEMENT OF PLANT DISEASES

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Introduction

Plants are found to be infected by various microbial organisms such as virus, bacteria and virus, which threaten their survival or reduce growth of the plants. In response to pathogen attack, plants have evolved several strategies to counteract pathogen infection. There are changes in plants physiology of plants after microbial attack results in active induced defense mechanisms. These active defense mechanisms refer as induced resistance, which occur after infection of plants by the pathogen and provide protection against subsequent attack of pathogen. Induced resistance is divided into two groups systemic acquired resistance (SAR), which is induced by inoculation of virulent or non virulent pathogen and Salicylic acid dependent. Other one is Induced Systemic Resistance (ISR), induced by colonization of root by plant growth promoting rhizobacteria and depend on Jasmonic Acid and Ethelene Pathways. Resistance to pathogen infection can be induced in plants by a wide range of biotic and abiotic agents (da Rocha and Hammerschmidt, 2005; Lyon, 2007). Agents that induce resistance in plants called as resistance inducers.

What are PRIs:

Plant resistance inducers (PRIs) are agents that lead to improved protection to pathogen attacks by inducing the plant’s own defense mechanisms, so called induced resistance (IR). They are also referred to as plant resistance activators, plant defense activators and elicitors. PRIs are known to be effective against various pathogens, including viruses, bacteria, oomycetes and fungi attacking crop plants. PRIs can be chemical compounds as well as microbial or plant extracts. However, they seldom lead to full pathogen control (Walters and Fountaine, 2009) and several factors influence the success such as plant genotype, developmental stage, environment, as well as timing and way of application of the PRI (Walters et al., 2013). Importantly, all PRI strategies need to be tested in an agricultural setting as many treatments have only been shown to be successful in more controlled conditions.

Pioneer work exploring SAR was done in the solanaceous species tobacco in the 1970s, when it was shown that injection of SA led to distal resistance to tobacco mosaic virus (TMV) (White, 1979).The plant’s response to PRIs can also be associated with alterations in cell wall composition, production of phytoalexins and anti-microbial protein as well as to hypersensitive response (HR). The HR is in turn linked to the production of reactive oxygen species (ROS) and nitric oxide (NO) (Walters *et al.*, 2008).

Many agents have been identified which can elicit defense responses in plants after application. Many studies have shown field application of resistance inducers. Some of them are listed in table no.1.

Table 1: **Examples of resistance elicitors and resistance-inducing agents reported to provide plant disease control (from 2010 to present).**

Type of elicitor/resistance inducer	Protected plant	Targeted pathogen	Reference
Chemical and non-biological inducers			
Acibenzolar-*S*-methyl (ASM)	Cucumber	*Tricothecium roseum* (post-harvest)	Ren *et al*. (2012)
	Rice	*Xanthomonas oryzae*	Du *et al*. (2011)
		Magnaporthe grisea	Du *et al*. (2011)
	Maize	*Bipolaris maydis*	Du *et al*. (2011)
	Pea	*Uromyces pisi*	Barilli *et al*. (2010)
β-Aminobutyric acid (BABA)	Apple	*Penicillium expansum* (post-harvest)	Quaglia *et al*. (2011)
Probenazole	Maize	*Bipolaris maydis*	Yang *et al*. (2011)
Saccharin	Soybean	*Phakopsora pachyrhizi*	Srivastava *et al*. (2011)
Potassium phosphite	Grapevine	*Plasmopara viticola*	Pinto *et al*. (2012)
Thiamine	Pearl millet	*Sclerospora graminicola*	Pushpalatha *et al*. (2011)
Silicon	Rose	*Podosphaera pannosa*	Shetty *et al*. (2012)
Biochar	Pepper	*Leveillula taurica*	Elad *et al*. (2010)
Biological inducers			
Plant growth-promoting rhizobacteria			
Ochrobactrum lupine/	Pepper	*Xanthomonas axonopodis*	Hahm *et al*. (2012)
Novosphingobium pentaromativorans			
Azospirillum brasilense REC3	Strawberry	*Colletotrichum acutatum*	Tortora *et al*. (2012)
Bacillus subtilis FZB24	Strawberry	*Sphaerotheca macularis*	Lowe *et al*. (2012)
Pseudomonas fluorescens WCS417r	Arabidopsis	*Pseudomonas syringae* pv. tomato	Weller *et al*. (2012)
Plant growth-promoting fungi			
Fusarium equiseti	Cucumber	*Colletotrichum orbiculare*	Saldajeno and
Biocontrol fungi			
Trichoderma asperellum SKT-1	*Arabidopsis*	Pseudomonas syringae pv. tomato	Yoshioka *et al*. (2012)
T. harzianum T39	Grapevine	*Plasmopara viticola*	Perazzolli *et al*. (2011)
T. harzianum/*T. atroviride*	Tomato	*Botrytis cinerea*	Tucci *et al*. (2011)
T. atroviride	Pine	*Diplodia pinea*	Reglinski *et al*. (2012)
Arbuscular mycorrhizal fungi			
Glomus intraradices	Rice	*Magnaporthe oryzae*	Campos-Soriano *et al*.
Glomus mosseae	Maize	*Rhizoctonia solani*	Song *et al*. (2011)
Endophytes			
Piriformospora indica	Barley	*Blumeria graminis f.*sp. *hordei*	Molitor *et al*.(2011)

Application of PRIs

In modern agriculture, two main strategies have so far been employed to combat crop pathogens: resistance breeding and application of chemical pesticides. In potato and tomato, traditional breeding has been used to introduce resistance genes from wild relatives for which there are available resistance sources. However, this is time-consuming and since many pathogens adapt rapidly, there are numerous examples were the resistance based on introduced resistance genes has been overcome rapidly if not combined (Fry, 2008). Likewise the use of pesticides targeting cellular processes to hinder the growth of the pathogen can cause resistance, such as highly problematic metalaxyl resistance in *Phytophthora infestans* (Davidse *et al.*, 1981). A third way would be to enhance the plant's own innate immunity by PRIs, which has some appealing aspects. Since PRIs are working indirectly on the pathogen through the plant's innate immunity, the PRI does not need to be directly toxic to living organisms, which is the basis of plant pesticides. Thus, PRIs have the potential to be more environmentally sustainable with less impact on human health. Most farmers in developing countries do not use appropriate safety equipment during the application of harmful chemicals (Kromann *et al*, 2012). Non-toxic alternatives in plant protection such as the use of PRIs activating the plants' own defense could therefore come to play an even more important role in developing countries. Furthermore, many PRIs give a broad spectrum resistance, which in turn lessens the likelihood of the development of pathogen pesticide resistance (Oostendorp *et al.*, 2001). For example, probenazole has been used against *Magnaporthe grisea*, the rice blast fungus, and *Xanthomonas*, causing bacterial leaf blight in rice, for more than 30 years and resistance in the pathogen has not been reported [Bektas and Eulgem, 2014]. Likewise, potassium phosphite has been used in potato for many years in some tropical countries (Kromann *et al*, 2012). There is also the possibility to combine PRIs with biocontrol agents, i.e., living organisms controlling disease or pests by acting as a predator, parasite or pathogen of the disease-causing species. In addition, PRIs can complement current pesticide treatments and thereby reduce the amount of pesticides necessary for efficient control.

Integration with Other Methods to Maintain Plant Health

Combinations of agents that induce resistance (e.g., ASM) with fungicides or biological control agents has been shown to provide effective disease control, especially in situations where achieving acceptable disease control is difficult. For example, a mixture of a strobilurin fungicide and ASM was shown to be effective in controlling *Albugo occidentalis* and increasing leaf quality in spinach (Leskovar and Kolenda, 2002), while a mixture of ASM and mancozeb was shown to have potential to provide protection against *Claviceps africana* on sorghum, especially where fungal isolates resistant to the usual fungicide treatment, triadimenol, were present (Ryley *et al.*, 2003). More recently, Gent and Schwartz (Gent *et al.*, 2005) found that integration of ASM and biological control agents with copper hydroxide could be used to replace less desirable fungicides without compromising effective control of Xanthomonas leaf blight on onion. Field experiments with grapevines showed that BABA can enhance the activity of fosetyl- Al against *Plasmopara viticola* (Reuveni *et al.*, 2001). Combinations of BABA with Mancozeb also demonstrated a synergistic effect against *Phytophthora infestans* and *Pseudoperonospora cubensis* in several crops (Baider and Cohen, 2003)

Current and possible uses of resistance inducers in the field

Despite all the investigations about induced resistance in plants, field applications are not a common practice, and only a few compounds have been tested or used in woody crops. It is well known that the protection obtained with inducers in the field against high pressure of disease is often incomplete. However, promising results were obtained when several resistance inducers were applied together or with chemical treatments. In citrus, application of BABA with ASM showed high and stable reduction of 'Candidatus *Liberibacter asiaticus*', reducing the population of bacteria near 1 Log unit per gram of tissue (Li *et al.*, 2015). The synergistic effect of resistance inducers (as a preventive compound or in combination with classical pesticides) can offer a valuable tool for reducing the residues of chemical pesticides in the fruits. However, these approaches need to be further studied in more detail in order to set up effective treatments. On the other hand, one of the most important problems of the abuse of chemical treatments is the appearance of resistant strains of pathogens. Copper-resistant strains of *Xanthomonas citri* have been identified in citrus groves in Argentina (Behlau *et al.,* 2013). In a previous evaluation, ASM was particularly useful for management of bacterial speck and bacterial spot where copper-resis- tant strains predominated (Louws *et al*., 2001). Therefore, soil-applied SAR inducers could be employed for copper-resistance management by reducing the rate and frequency of copper bactericide applications.

Conclusion

There are the continuing problems of pathogen adaptability leading to fungicide resistance and breakdown in the effectiveness of host genetic resistance. Then there are the newer problems of a slowing down in the rate of delivery of new fungicides to the market and the increasing public concern related to the environmental effects of widespread fungicide use. There is also the potential problem of climate change and its impact on pathogen spread. The aim of plant pathologists always has been to keep one step ahead of the pathogens, through understanding every aspect of the plant–pathogen interaction and the factors that influence it. Because of these issues and the fact that plant–pathogen interactions continue to evolve, the need for understanding will not diminish. There clearly is a great deal we understand about induced resistance, but there is equally a great deal still to understand. In our haste to realize the great potential offered by induced resistance for disease control, we have paid too little attention to the factors that are likely to influence its effectiveness in the field, largely using it inappropriately assimply a fungicide replacement. Induced resistance offers the prospect of durable, broad- spectrum disease control using the plant's own resistance. However, induced resistance is plagued by inconsistency and relatively poor disease control compared with pesticides, reflecting the fact that induced resistance is a host response and as such is greatly influenced by genotype and environment. Farmers and crop protectionists, who have grown accustomed to high levels, or even complete, disease and pest control, are unlikely to enthusiastic about adopting a disease control method which is viewed as inferior to fungicides. Ultimately, for induced resistance to gain more widespread acceptance in global crop protection, there will need to be a lowering of expectation in terms of levels of disease and pest control. There is much to be done, therefore, to convince farmers and growers that induced resistance can work and could provide a useful addition to their disease management programmes. As important as this is, it will take more than getting farmers and growers on board to get induced resistance into practice. A serious obstacle to real progress in this area is getting induced resistance products to the marketplace (Walters *et al*., 2012). In particular, the high cost of registration, coupled with limited market size for some products, has been identified as a major barrier by Richardson (2005) and Kleeberg (2007).

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