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Terminology Related to Induced Systemic Resistance: Incorrect Use of Synonyms may Lead to a Scientific Dilemma by Misleading Interpretation of Results

SADIK TUZUN

1.1 Introduction

During the review process of the book, several reviewers suggested that the same terminology should be used throughout the book to describe the same phenomenon. Since I am a firm believer of academic freedom and freedom of expression, no changes to the chapter will be made. Instead, to comply with the second suggestion of the reviewers and to eliminate misunderstanding due to multiple ways of using the terms induced systemic resistance (ISR) and systemic acquired resistance (SAR) which has been accepted as synonyms, a comprehensive chapter dealing with the terminology is included. As described by Kuć in Chapter 2, inducible defense responses in plants have been observed since early 1900s (Beauverie, 1901; Ray, 1901) and reviewed by Chester as early as 1930s (Chester, 1933). Chester called the phenomenon “acquired physiological immunity”, since his review was based on “observations” rather than “scientific experiments”, and indeed this term was correct since he was describing disease resistance clearly “acquired” by plants. Later on, studies conducted by Kuć and his colleagues (Kuć et al., 1959; Maclennan et al., 1963) on apple and by Ross (1961, 1966) on tobacco, which lead to the induction of local and systemic resistance gave first evidences that indeed otherwise susceptible plants have inducible defense responses if they are previously treated with some chemicals or pathogens which are unspecific in nature, although both phenomenon involves salicylic acid as mediator (Ryals et al., 1996).

During the past 40 or more years nearly a thousand journal articles have been published calling the phenomenon “induced” or “acquired” systemic resistance. The mechanisms of resistance against viruses are still not understood well. Nevertheless, the elegant work of Kuć and his coworkers and several other research groups using cucurbits and many other plant species explained the broad nature

of resistance, and the term induced systemic resistance (ISR) was used in these pioneering publications using pathogens or chemicals as inducers which clearly involve salicylic acid as mediator, whereas systemic acquired resistance (SAR) was mainly used in recent publications by scientists using the *Arabidopsis* model system. ISR was proposed to be the correct term to describe the active nature of “inducible defense mechanisms in plants” regardless of the inducing agent or the pathway which they use to achieve the resistant state by Kloepper et al. (1992), and in the introduction to the book “Biology and Mechanisms of Induced Resistance to Pathogens and Insects” by Agrawal et al. (1999), considering the pioneering work of Kuć and many scientists trained in his lab who led the area for many years mainly used ISR as the term to describe the phenomenon. Induced resistance is still the most widely accepted terminology in meetings and workshops related to “inducible” defense mechanisms against pathogens and insects in plants.

1.2 Differentiation of ISR and SAR

As mentioned above, the terms “induced” and in some cases “acquired” systemic resistance were used interchangeably by the different research groups until Ryals et al. (1996) defined the type of resistance induced by pathogenic organisms and/or chemicals involving salicylic acid as mediator as systemic acquired resistance (SAR) as a tribute to Ross, disregarding many earlier publications describing entirely the same phenomenon using ISR as a synonym. Furthermore, a series of about 25 journal articles mainly published by Van Loon’s research group used ISR as the term solely to describe resistance mediated by plant growth-promoting rhizobacteria (PGPR) (Pieterse et al., 1996, 1998, 2000, 2002; Van Loon et al., 1998) while at least as much published by others indicating PGPR-mediated ISR used it as a synonym to SAR. This use of terminology by disregarding at least 10 times more publications using ISR to describe the phenomenon that is induced by many pathogenic organisms and chemicals actually created a dilemma leading to a misunderstanding of earlier literature and confusion among scientists.

1.2.1 *ISR and SAR are Decided to be Used as Synonyms*

PGPR is a generic term which includes many plant associated organisms some of which may be partially pathogenic to plants to be recognized by them (Tuzun and Bent, 1999) using the salicylate pathway for induction of resistance (see Chapter 10). Therefore, the results obtained on *Arabidopsis* plants using a few PGPR strains to use ISR as the term to describe only “jasmonate-mediated resistance” creates a major problem in scientific literature as mentioned above. This subject was extensively discussed amongst the attendees in detail during the “1st International Symposium of Induced Resistance” which was held in Greece in 1999. During this symposium, it was unanimously agreed by the participants that these terms that are describing essentially the same phenomenon should be used as

“synonyms”. Indeed, the paper came as a result of these meetings and authored by Ray Hammerschmid, Jean-Pierre Metraux, and Kees Van Loon (Hammerschmid et al., 2001) clearly stated that induced systemic resistance and systemic acquired resistance are “synonyms” and should be used in the scientific literature as synonyms and treated as the same.

Scientists hold a big responsibility when they introduce “new uses” for the “old terms” and, although we are not linguists, it is essential that we *must* understand and adhere to the meaning of the words before using it. In this chapter, the meaning of various words used in the literature are described using the 2003 Electronic Edition of Merriam Webster’s Collegiate Dictionary containing over 250,000 words. The meaning of “synonym” is “one of two words or expressions of the same language that have the same or nearly the same meaning in some or all senses”. The scientific problem becomes apparent if one or more groups of scientists decide to use synonyms to describe essentially two different phenomenon which involves different pathways that may even crosstalk amongst themselves (Kunkel and Brook, 2002). Even though this is used just for “convenience” (see Chapter 9), the use of existing terms (ISR and SAR) to differentiate two independent phenomenon activated by different pathways (see Figure 9.1 and 9.2 in Chapter 9) will cause even more confusion in the future since recent research also indicates that there are more than two biochemical pathways by which induced resistance can be activated (e.g., Bostock et al., 2001; Dong and Beer, 2000; Mayda et al., 2000a,b; Zimmerli et al., 2000).

1.2.2 Contradicting Results in the Literature with the Use of “Synonym”

In scientific literature, synonyms should be describing exactly the same phenomenon resulting from activation of the same pathways. So, there was no reason to call PGPR-mediated induction of systemic resistance as ISR and all others as SAR (Van Loon et al., 1998). Since ISR and SAR are accepted as synonyms, by no means should they interfere with each other, neither should they work synergistically nor should they inhibit each other’s expression. However, there is ample evidence that pathways leading to ISR and SAR actually work synergistically (Van Wees et al., 2002) by enhancing disease resistance or in a contradicting fashion by inhibiting each other (Doares et al., 1995; Ryan, 2000). Therefore, the use of synonyms “ISR and SAR” in the same publication to describe entirely different phenomenon is not scientifically correct and contradicts the meaning of synonym (see Chapters 8 and 9). The use of ISR and SAR to describe separate biochemical pathways relating to induced resistance is misleading for a variety of reasons. First, it contradicts the decision of the scientific community to use these terms as synonyms. Furthermore, it is the fact that researchers will tend to make the (erroneous) assumption that ISR must be distinct from every phenomenon referred to as SAR, regardless of whether any work has ever been done to actually characterize the biochemical pathway(s) involved in each system. Therefore, it is hoped that

ISR will no longer be used solely as the term to describe induced resistant state mediated by plant growth-promoting rhizobacteria (PGPR).

1.3 Definitions Used in the Literature to Describe Inducible Defense Responses in Plants

1.3.1 Acquired Immunity

This term was first used by Chester to describe achievement of resistant state in otherwise susceptible plants during 1930s (Chester, 1933). Although Chester did not perform experiments, he clearly described the phenomenon with various examples. Immunization of plants was used in several articles that experimentally described Chester's original observations. The term "immunity" was not widely accepted by the scientific community since it creates confusion with the immunization of animals. Nevertheless the term immunity that is being used since 14th century means: "a condition of being able to resist a particular disease especially through preventing development of a pathogenic organism or by counteracting the effect of its products" and immunization simply means "to make immune". Chester called the phenomenon "acquired immunity" since he thought that these plants acquired a state of being immune where acquired means: "to come into possession or control of often by unspecific means" or "to come to have as a new or added characteristic, trait or ability (as sustained effort or natural selection as in bacteria acquire resistance to antibiotics)". To Chester this definition was correct since he thought that plants were acquiring a state of resistance by an unspecified means of natural phenomenon.

1.3.2 Systemic Acquired Resistance

This term was first used by Ross (1961) to describe a phenomenon where he observed protection against TMV both local and systemically upon treatment of either the same leaf or leaves below the protected leaf upon treatment with live TMV. He described systemic nature of the phenomenon; however, plants did not passively acquire the resistant state as indicated in the definition above. Neither plants obtained resistance in a genetically inherited fashion as in bacterial resistance to antibiotics nor the phenomenon occurred naturally as in the observations of Chester and others. Ross actually induced a state of resistance in tobacco against TMV by using TMV which was not inherited by the offsprings of the tobacco plant. Although the term is widely used by scientists working in the area as attribute to Ross, it is not correct by any means to describe an active phenomenon which involves activation of many genes leading to the development of resistant state in otherwise susceptible plants. Indeed, experiments conducted by Kuć and his colleagues described the phenomenon of chemically induced resistance against scab disease in apple much earlier than Ross (Kuć et al. 1959, see Chapter 2), which clearly involves salicylic acid as mediator.

1.3.3 *Induced Systemic Resistance*

The term first used by Kuć and his coworkers in numerous publications (see Chapter 2) is actually the correct way of describing the phenomenon. The meaning of Induced is: “to call forth or bring about by influence or stimulation” or “to cause the formation of”, in this particular case ISR indicates an active phenomenon which causes the formation of systemic resistance in otherwise susceptible plants. According to Van Loon and his colleagues, only a few PGPR strains which induce the systemic state of resistance via salicylate-independent pathway (see Chapters 8 and 9) are justified to be called initiators of ISR whereas others as inducers of SAR as suggested by Ryals et al. (1996). This use of terminology is neither correct nor the common use of term SAR is fair to the overall contributions of Joseph Kuć who actually “for the first time” experimentally demonstrated the induction of systemic resistance using various derivatives of amino acids. If anyone “fathered this area” it must be him, not only through his contributions but also through numerous scientists, students, post-docs, collaborators etc. who published hundreds of papers, using the term ISR to describe “induced state of resistance in plants by biological or chemical inducers” which definitely uses salicylic acid as mediator. These are the pioneering scientists who led the field of ISR to become a “common phenomenon” found to be a part of the overall protection achieved by many biological and chemical agents including the organisms known for a long time as biological control organisms as described throughout this book. If we must be honest, no student or co-worker has actually followed the initial experiments of Ross against viruses until mid to late 1980s when the scientists working in then Ciba-Geigy started to work on ISR. Needless to say, most of these scientists also performed their initial experiments on induced systemic resistance in Kuć’s lab while he was collaborating with Ciba on this project. It is interesting that we still do not know the mechanism of resistance against viruses in plants.

1.4 Proposed Use of Terminology

Considering that ISR and SAR are well accepted by the scientific community as terms to describe inducible defense responses in plants, the use of all other terms such as systemic induced resistance (SIR) or acquired systemic resistance (ASR) should be avoided. ISR indicates actively-inducible defense mechanisms which may involve one or more metabolic pathways, as indicated above. Therefore, ISR is the correct term to describe “activated defense mechanisms” whether the inducers are pathogenic or nonpathogenic organisms or chemicals. SAR, however, should be indicated as synonym in each case when ISR is used for the first time in any article. If an author prefers to use SAR as the term, it is expected that ISR is indicated as synonym in the same fashion.

Certainly, the phenomenon can be differentiated by stating the inducer, i.e., PGPR-induced systemic resistance or PGPR-mediated systemic acquired resistance; or chemically induced systemic resistance or chemically mediated systemic acquired resistance (actually, using the term “induced” in “induced systemic

resistance” will eliminate the use of “mediated” while describing different inducers), however, one type of inducer may induce different pathways. It is the most correct way, therefore, we should follow the terminology where the phenomenon was described according to which pathway the induction of resistance is activated through, either jasmonate or salicylate, as ISR appears to involve these two major pathways (Spoel et al., 2003).

It is proposed that the different variants of induced systemic resistance should be distinguished according to the pathway they activate, i.e., “salicylate-dependent” ISR (or SA-ISR) and “jasmonate-dependent” ISR (or JA-ISR), as our knowledge increases new terms could be added in the same fashion.

1.5 Conclusion

As scientists we have to stick to the scientific guidelines when creating definitions, whether they are scientifically correct or not and the definitions must adhere to linguistic meanings, otherwise once mistakes are made it becomes very difficult to rectify them. It is unfortunate that the terminology used in publications may become part of textbooks misleading young minds and future scientists, whom we have the responsibility to educate with an open mind, without leading to any assumption. This requires respect of the previous use of terms to describe the same phenomenon yet the terms, which are introduced must be flexible enough to accommodate definitions as our knowledge base broadens by the development of new technologies that may not be currently available.

It is certainly hoped that this attempt to correct the terminology will be recognized by colleagues as a friendly suggestion and will be used in coming publications to further avoid any confusion that may arise by using synonyms to describe different phenomenon and every attempt to correct this error should be made.

References

- Agrawal, A., Tuzun, S., and Bent, E., eds. 1999. *Induced Plant Defenses Against Pathogens and Herbivores*. St. Paul, MN: American Phytopathological Society.
- Beauverie, J. 1901. Essais d’immunization des végétaux contre de maladies cryptogamiques. *CR Acad. Sci. III* 133:107–110.
- Bostock, R.M., Karban, R., Thaler, J.S., Weyman, P.D., and Gilchrist, D. 2001. Signal interactions in induced resistance to pathogens and insect herbivores. *Eur. J. Plant Pathol.* 107:103–111.
- Chester, K. 1933. The problem of acquired physiological immunity in plants. *Quar. Rev. Biol* 8:129–154, 275–324.
- Doares, S.H., Narvaez-Vasquez, J., Conconi, A., and Ryan C.A. 1995. Salicylic acid inhibits synthesis of proteinase inhibitors in tomato leaves induced by systemin and jasmonic acid. *Plant Physiol.* 108:1741–1746.
- Dong, H., and Beer, S.V. 2000. Riboflavin induces disease resistance in plants by activating a novel signal transduction pathway. *Phytopathology* 90:801–811.

- Hammerschmidt, R., Métraux, J.P., and Van Loon, L.C. 2001. Inducing resistance: a summary of papers presented at the First International Symposium on Induced Resistance to Plant Diseases, Corfu, May 2000. *Eur. J. Plant Pathol.* 107:1–6.
- Kloepper, J.W., Tuzun S., and Kuć J. 1992. Proposed definitions related to induced disease resistance. *Biocontrol Sc. Technol.* 2:347–349.
- Kuč, J., Barnes, E., Daftsios, A., and Williams, E. 1959. The effect of amino acids on susceptibility of apple varieties to scab. *Phytopathology.* 49:313–315.
- Kunkel, B., and Brook, D.M. 2002. Cross talk between signaling pathways in pathogen defense. *Curr. Opin. Plant Biol.* 5:325–331.
- MacIennan, D., Kuć, J., and Williams, E. 1963. Chemotherapy of the apple scab disease with butyric acid derivatives. *Phytopathology.* 53:1261–1266.
- Mayda, E., Marqués, C., Conejero, V., and Vera, P. 2000a. Expression of a pathogen-induced gene can be mimicked by auxin insensitivity. *Mol. Plant Microb. Interact.* 13:23–31.
- Mayda, E., Mauch-Mani, B., and Vera, P. 2000b. Arabidopsis *dth9* mutation identifies a gene involved in regulating disease susceptibility without affecting salicylic acid-dependent responses. *Plant Cell* 12:2119–2128.
- Pieterse, C.M.J., Van Wees, S.C.M., Hoffland, E., Van Pelt, J.A., and Van Loon, L.C. 1996. Systemic resistance in *Arabidopsis* induced by biocontrol bacteria is independent of salicylic acid accumulation and pathogenesis-related gene expression. *Plant Cell* 8:1225–1237.
- Pieterse, C.M.J., Van Wees, S.C.M., Van Pelt, J.A., Knoester, M., Laan, R., Gerrits, H., Weisbeek, P.J., and Van Loon, L.C. 1998. A novel signaling pathway controlling induced systemic resistance in *Arabidopsis*. *Plant Cell* 10:1571–1580.
- Pieterse, C.M.J., Van Pelt, J.A., Ton, J., Parchmann, S., Mueller, M.J., Buchala, A.J., Métraux, J.-P., and Van Loon, L.C. 2000. Rhizobacteria-mediated induced systemic resistance (ISR) in *Arabidopsis* requires sensitivity to jasmonate and ethylene but is not accompanied by an increase in their production. *Physiol. Mol. Plant Pathol.* 57:123–134.
- Pieterse, C.M.J., Van Wees, S.C.M., Ton, J., Van Pelt, J.A., and Van Loon, L.C. 2002. Signalling in rhizobacteria-induced systemic resistance in *Arabidopsis thaliana*. *Plant Biol.* 4: 535–544.
- Ray, J. 1901. Les maladies cryptogamiques des végétaux. *Rev. Gen. Bot.* 13:145–151.
- Ross, A.F. 1961. Systemic acquired resistance induced by localized virus infections in plants. *Virology* 14:340–358.
- Ross, A. 1966. Systemic effects of local lesion formation. In *Viruses of Plants*, eds. A. Belmster, and S. Dykstra, pp. 127–150. Amsterdam: North Holland.
- Ryals, J.A., Neuenschwander, U.H., Willits, M.G., Molina, A., Steiner, H.-Y., and Hunt, M.D. 1996. Systemic acquired resistance. *Plant Cell* 8:1808–1819.
- Ryan, C.A. 2000. The systeminsignaling pathway: differential activation of plant defensive genes. *Biochim. Biophys. Acta* 1477:112–121.
- Spoel, S.H., Kornneef, A., Claessens, S.M.C., Kozellius, J.P., Aan Pelt, J.A., Mueller, M.J., Buchala, A.J., Métraux, J.-P., Brown, R., Kazzan, K., Van Loon, L.C., Dong, X., and Pieterse, C.M.J. 2003. NPR1 modulates crosstalk between salicylate- and jasmonate-dependent defense pathways through a novel function in the cytosol. *Plant Cell* 15:760–770.
- Tuzun, S., and Bent, E. 1999. The role of hydrolytic enzymes in multigenic and microbially-induced resistance in plants. In *Induced Plant Defenses Against Pathogens and Herbivores: Biochemistry, Ecology and Agriculture*, eds. A.A. Agrawal, S. Tuzun, S., and E. Bent, pp. 95–115. St. Paul, MN: American Phytopathological Society.

- Van Loon, L.C., Bakker, P.A.H.M., and Pieterse, C.M.J. 1998. Systemic resistance induced by rhizosphere bacteria. *Annu. Rev. Phytopathol.* 36:453–483.
- Van Wees, S.C.M., De Swart, E.A.M., Van Pelt, J.A., Van Loon, L.C., and Pieterse, C.M.J. 2000. Enhancement of induced disease resistance by simultaneous activation of salicylate- and jasmonate-dependent defense pathways in *Arabidopsis thaliana*. *Proc. Natl. Acad. Sci. USA* 97:8711–8716.
- Zhang, S., Reddy, M.S., Kokalis-Burelle, N., Wells, L.W., Nightengale, S.P., and Kloepper, J.W. 2001. Lack of induced resistance in peanut to late blight spot disease by plant growth-promoting rhizobacteria and chemical elicitors. *Plant Dis.* 85: 879–884.
- Zimmerli, L., Jakab, G., Métraux, J.-P., and Mauch-Mani, B. 2000. Potentiation of pathogen-specific defense mechanisms in *Arabidopsis* by β -aminobutyric acid. *Proc. Natl. Acad. Sci. USA* 97:12920–12925.