The role of salicylic acid in plant resistance

Elsa Ballini – October 2018

Announcement

We are three students from Montpellier Supagro University and the aim of this work is to present briefly the role of salicylic acid in plant resistance and its impacts in Agronomy.

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How do plants achieve immunity?

The immune system discovered so far was studied and characterized only in higher organisms. However, plants are able to defend themselves with different mechanisms simultaneously at the local and systemic scale (Ali et al., 2018). The first layer of their active defence occurs at the cellular level and is called pathogen-associated molecular pattern PAMP-triggered immunity (PTI). Plants are capable of a pathogen molecular pattern recognition to prevent their further infection. Nevertheless, plant pathogens have developed a mechanism to overturn PTI. They produce effectors and insert them inside the plant cell. At this point, the hypersensitive response (HR) may occur and block the harmful pathogen mainly by cell apoptosis. Once the plant reacts to the pathogen, signals are released that trigger resistance in adjacent cell as well as distant tissue (Ryals et al., 1994). This system is called Systemic Acquired Resistance (SAR) and salicylic acid is the main signalling molecule involved. A later reaction named Induced Systemic Resistance also occurs and is triggered by beneficial microorganisms with jasmonic acid and ethylene as the main signalling hormones (Fig.1).

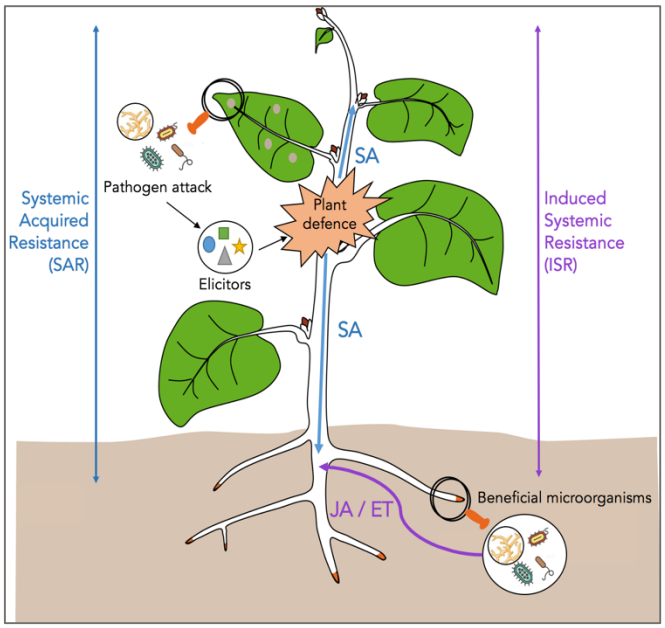


Fig. 1: Scheme of the SAR and ISR mechanisms with salicylic acid (SA), jasmonic acid (JA) and ethylene (ET)

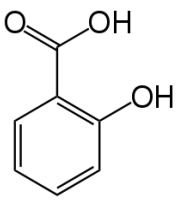
Definitions

Effector: protein produced by a pathogen to aid infection of specific plant specie.
Apoptosis: form of programmed death that occurs in multicellular organisms and involves biochemical events.
Hormone: signal molecule produced within the plant at low concentration and acting on target cells.

A little bit of history…

Salicylic acid (SA) has been characterized as a phytohormone when scientists discovered his role in flowering induction on voodoo lily. Later on during the 70s, it was known that applying SA to tobacco plants induces defense gene expression and enhances virus resistance. Still, SA's role on plant resistance was only demonstrated in 1990. How? Tobacco and Arabidopsis mutants unable to accumulate SA couldn't fight against the pathogen infection like the control plants, confirming that SA is required for PTI, ETI and SAR (Dempsey et al., 2017).

Salicylic acid, what is it?

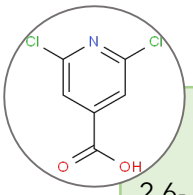


Salicylic acid (2 hydroxybenzoic acid, opposite chemical formula) is a phenolic compound synthetized by plants. SA is a critical hormone involves in many aspects of plant growth, development and disease resistance.

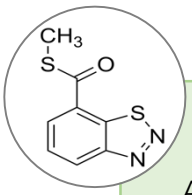
SA and its acetylated derivate (commonly known as aspirin) are used for human health treatment. SA is mainly used to cure skin problem like warts, psoriasis and acne whereas aspirin is the main medication used worldwide to treat pain, fever, inflammation.

Product description – how to use it?

Following the discovery of this new knowledge about SA role (especially at the plant immunity scale) scientists have developed a new approach in disease control based on **the use of compounds able to activate the SAR response in plants**. One major breakthrough in the plant activator field is related to the discovery of **functional analogues of salicylic acid.** Several classes of exogenous chemical inducers have been identified by directed screening process and two compounds have been deeply studied (Gullino et al, 2000):



INA
2,6- dichloroisonicotinic acid

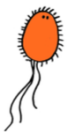


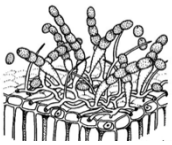
BTH
Acibenzolar-S-methyl

Those two molecules have been studied and deeply tested to identify if they can be used as a plant activator. Phytotoxicity has been revealed for INA molecule, even at very low dose, involving that those SA's analogue can not be used. However, acibenzolar-S-methyl (BTH) has been developed because it fulfils all the criteria of a plant activator: it has no direct effect on pathogens and its mode of action is distinctly different from any other conventional fungicide (Gullino et al., 2000).

Application

Targets



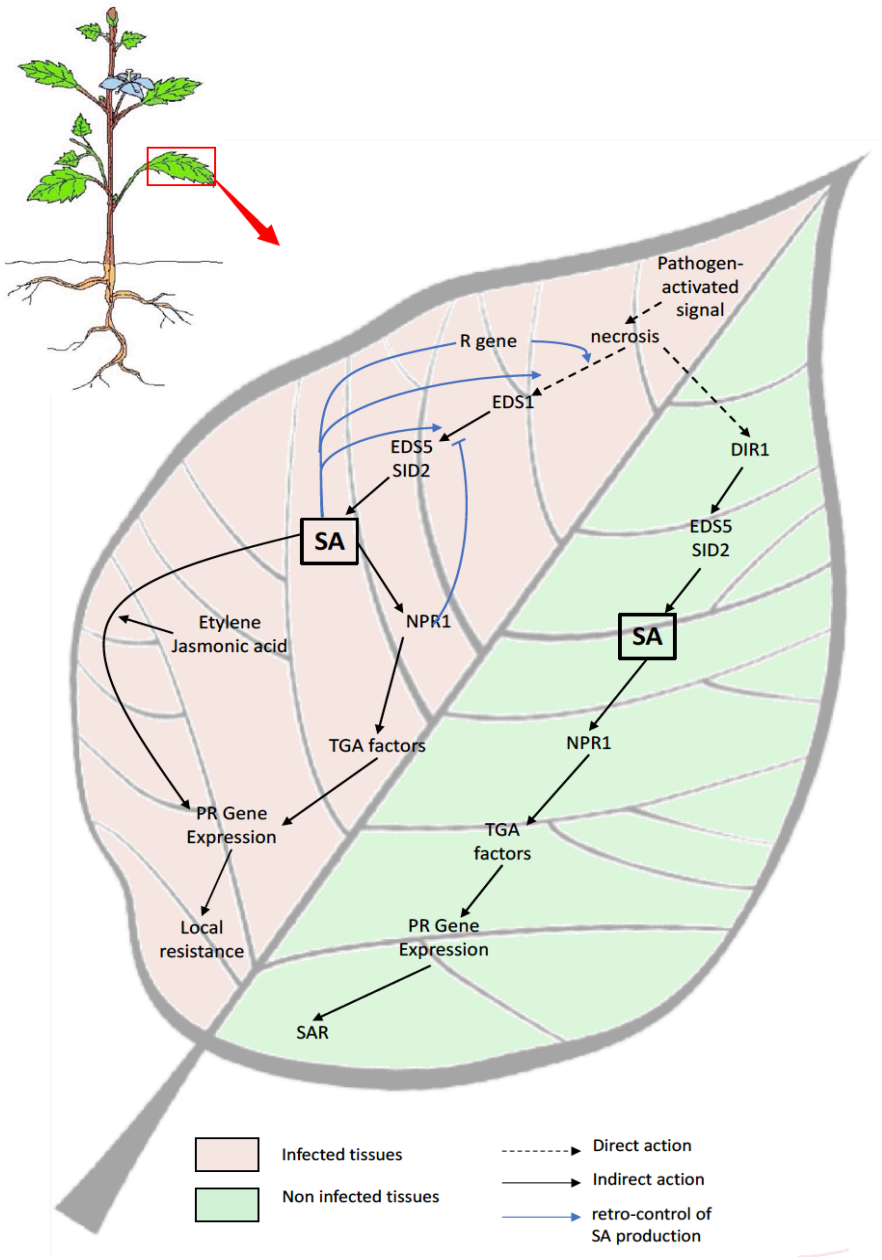


Acibenzolar-S-methyl is the main compound of a plant activator product that has been homologated. Due to his mode of action, it has to be applied preventively. Moreover, a lag-time is required between the application moment and the fully effective plant resistance. For most of the crops, this time ranges between 3 and 7 days. The product is diluted in water and sprayed directly on the plant leaves.

Which crops?

- Cereals against powdery mildew
- Rice against *Pyricularia oryzae*
- Tomato against bacteria speck disease
- Banana against *Mycosphaerella spp.*
- Wide range of other crops…

Mechanisms



Mechanisms of Salicylic Acid in plants and its self-regulating/down-regulating (adapted from Shah, 2003 and Ali et al., 2018).

Abbreviations

NPR1: Non-expressor of PR1 gene
PR: Pathogenesis-Related
EDS: Enhanced Disease Susceptibility gene
SID: Salicylic-Acid-Induction Deficient gene
TGA: TGA-element binding protein
DIR protein: translocator for discharge of the movable signal into the vascular structure and/or chaperone the signal through the plant.

Salicylic Acid (SA) affects both **resistance to biotic stress** (pathogens), **tolerance to abiotic stresses** and several aspects of **plant growth** and **development** (Dempsey et al., 2017). There are two main pathways to synthesize SA: isochorismate and phenylalanine ammonia-lyase pathways (Dempsey et al., 2017).

To summarize

When a pathogen infects a plant, infected and non-infected tissues both product SA. But its production and its mechanisms of action are lightly different.
First, in the infected plant part, pathogen-activated signal indirectly generates a necrosis which indirectly activates EDS1. Then, a cascade involving gene/protein interactions stimulates SA production. However, in non-infected tissues, the necrosis generates another cascade.
Then, in infected tissues, SA activates PR gene expression by two pathways. In the first one, SA activates NPR1 gene which triggers the production of TGA factors. The second pathway involves Ethylene and/or Jasmonic acid. In non-infected tissues, the second pathway is absent.

SA can also control its own production by regulating upstream genes. NPR1 also repress the gene/protein cascade.

ⓘ For your information :

The priming process is an enhanced capacity for a plant to mobilize infection-induced cellular defense response (Conrath et al., 2002). This phenomenon is induced by the SA. However, some plants react differently and need more time to trigger this response (Resistance gene activation) involving that they are not showing any resistance symptoms (necrosis).

Limits

- SA synthetic analogue products may be useless against HR and SAR suppressive plant pathogen as some microorganisms have mechanisms that block the HR, no matter the SA concentration in the plant.
- Interactions between SA and other plant hormones (JA mainly) in the HR/SAR establishment are unknown.
- Abiotic and biotic factors, as well as the physiological state of the plant, affect the efficiency of the SA synthetic analogues products.
- The lag-time before the SA-induced plant resistance effectiveness commands an indiscriminate use of the product. The length of the induced plant resistance varies a lot.
- The expensive cost of SA synthetic-analogue products may prevent their use at a large scale.
- Companies sell these products as fungicides, while they are efficient against every kind of pathogens because they are designed to enhance the global plant resistance.

Possible improvements

Problematic

We have shown that other plant hormones can have an impact on the plant response to salicylic acid. We want to test the SA efficiency to trigger plant resistance, in presence of jasmonic acid.

Plant material

5 plants

x

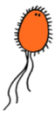
modality

Varieties: Beef tomato and Roma tomato

Easy to grow in growth chamber

Plant model but with a high agronomic value

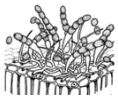
Pathogen used



Xanthomonas campestris pv. Vesicatoria
97-2 wild type strain

Tomato Yellow Leaf Curl Virus

(TYLCV Sardinia strain)



Botrytis cinerea

Strain BC1 (INRA Avignon)

Media formulation

- 100% SA
- 75% SA + 25% JA
- 50% SA + 50% JA
- 25% SA + 75% JA
- 100% JA
- Control

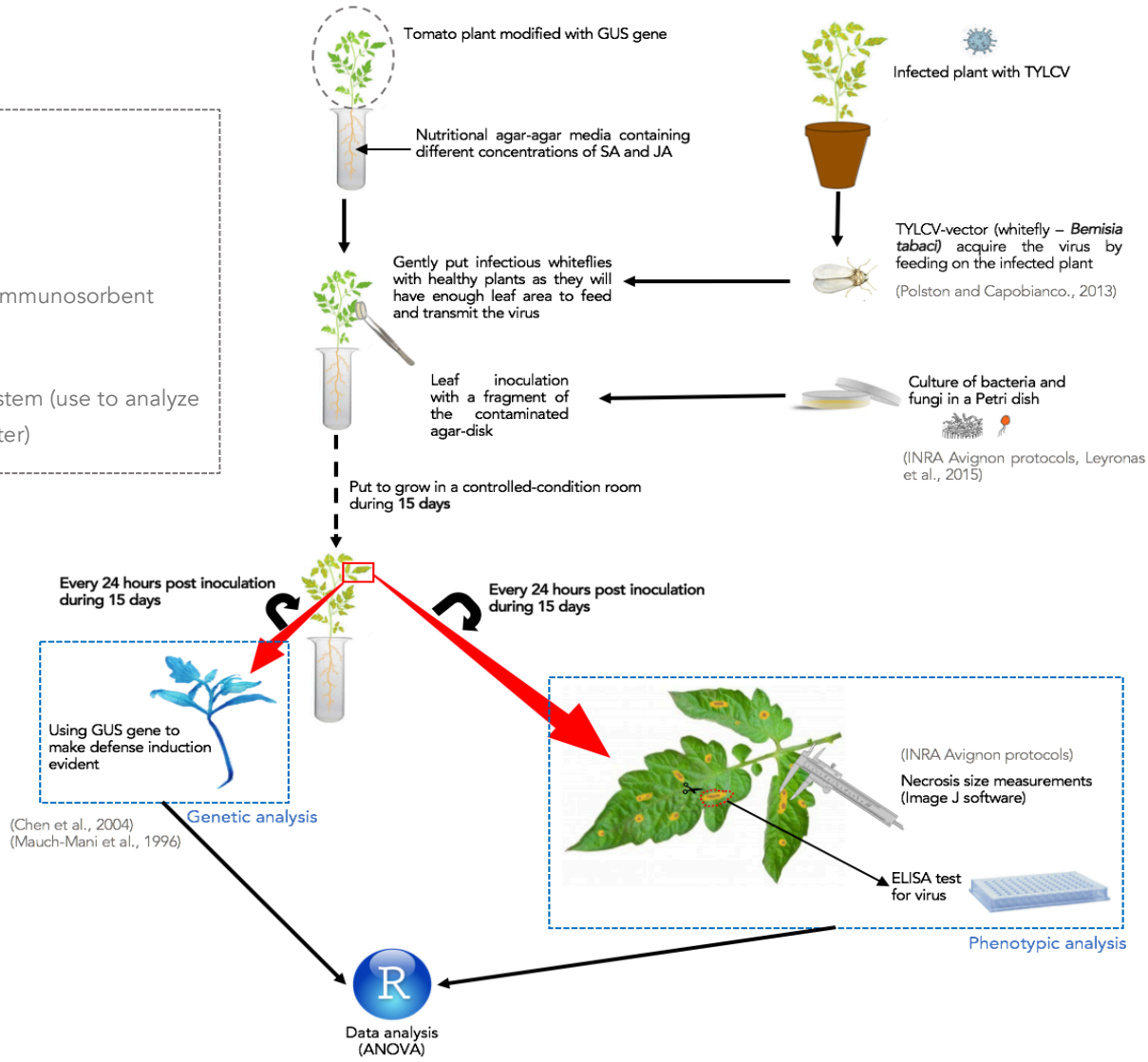
Protocol

SA: Salicylic Acid

JA: Jasmonic Acid

ELISA: Enzyme-linked immunosorbent assay

GUS: reporter gene system (use to analyze the activity of a promoter)



The aim of this experiment is to highlight the antagonist effect of two different plant hormones: salicylic and jasmonic acid (Doares et al., 1995). Modified-tomato plants with GUS reporter system are used to visualize the plant defense induction system. The main pathogen strains found in France or nearby have been chosen to reflect the tomato-greenhouse pathosystem and two very famous tomato varieties have been tested: Beef and Roma tomato.

Keep in mind!

Salicylic acid is a plant hormone which has a key role in plant resistance by activating the Systemic Acquired Resistance (SAR) process. Through a reaction cascade triggered by a plant-pathogen signal (bacteria, fungi or virus), close cells and then the whole plant acquire an enhanced plant resistance. With this knowledge, scientists have studied SA analogues and designed a natural plant protection product able to reproduce those mechanisms. Nevertheless, there are still some limits with this product especially it application and it interactions with other plant hormones.

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