Could you outline the overarching aims and objectives of this European Research Council funded project on the plant immune system (PlantImmuSys)?

The aim of our research programme is to investigate how certain microbes interact with root systems of plants upon which they live and stimulate the plant immune system to defend itself more effectively against pathogens and insect herbivores in foliar plant parts. This knowledge can be used to improve our future crops, increasing yield without adding fertilisers and pesticides.

How did you come to develop an interest in plant immunity? What is your academic background?

For many decades, Dutch plant breeding companies have played a leading role in the generation and production of new cultivars and varieties of many different horticultural and agricultural crops. I studied plant breeding at Wageningen University in The Netherlands, with a major focus on molecular plant biology. Disease resistance is a major topic for plant breeders worldwide because plant diseases and pests are prominent causes of crop loss.

As a PhD student in molecular phytopathology, I worked on one of the most devastating plant diseases: late blight caused by the Irish Famine pathogen Phytophthora infestans. This is when my interest in plant immunity began to develop more strongly. When I moved to Utrecht University in 1993, its phytopathology group had just discovered that beneficial microbes living on the root system of virtually every plant could boost the plant immune system, rendering the host better protected against pathogen attack. Building upon my background in molecular biology, we started to investigate the molecular mechanism of how these beneficial rhizosphere bacteria stimulate plant immunity. We subsequently made many important discoveries and established a leading role in this field.

Our research is not only of interest from a fundamental science point of view; knowing how plants interact with and benefit from mutualistic microbes on their root system also aids development of biological control agents that can be used in agricultural practices to protect crops using fewer pesticides.

Could you elucidate the significance of the hormones jasmonic acid and ethylene within induced systemic resistance?

Plant hormones are important regulatory signals that control many different types of processes, ranging from plant development to defence. Jasmonic acid, ethylene and salicylic acid are three plant hormones that play major roles in the regulation of defence responses. For instance, mutant plants that are incapable of producing or responding to one of these hormones show enhanced susceptibility to specific types of microbial pathogens or insect herbivores.

According to bibliometric analyses, your research group has a citation impact five times higher than the global average. What are the main reasons for your group’s success?

The ambition of the Plant-Microbe Interactions group is to work toward conceptually novel discoveries that move the research field forward. For instance, we have worked on the molecular mechanism of induced systemic resistance triggered in plants upon root colonisation by beneficial microbes. We were the first to discover the role of the plant hormones jasmonic acid and ethylene, and the role of major regulatory genes and proteins in this process. We later made important contributions to the field of hormone crosstalk between salicylic acid and jasmonic acid signalling.

By challenging the boundaries of current knowledge on topics with broad implications (in both our model plant species Arabidopsis, and also in other plants, including crops), we ensure that our work is relevant, and therefore interesting to other researchers.

Last year you were elected as a member of the Royal Netherlands Academy of Art and Sciences (KNAW). What does this mean to you on a personal level?

Each year KNAW elects a total of 15 new members from all scientific disciplines. New Academy members are nominated by peers from within and outside the Academy. Being elected as an Academy member was a great honour. It is an acknowledgement of the research conducted by my group as a whole and recognition of my performance as a scientist. It is also great motivation to keep up the good work!
The root of plant protection

A progressive laboratory at Utrecht University in The Netherlands is investigating plant immune systems, with particular emphasis on the beneficial microbes they recruit to help fight pathogens.

AT FIRST SIGHT, one might be forgiven for thinking that the humble plant root is among the simpler structures in nature. In fact, the root—and the habitat surrounding it, the rhizosphere—is a hive of activity, hosting a complex network of interrelated organisms. This micro-ecosystem is not incidental; mutualistic relationships between the plant and the microorganisms that inhabit the rhizosphere are actually a central factor in plant survival. Orchids, for instance, would be unable to exist without the mycorrhiza, or root fungi, which live quite harmoniously in and around their roots. Indeed many plant species owe their health, to a significant degree, to unseen yet indispensable microbial interactions.

Perhaps this dependence should not seem surprising; the human system is also reliant on symbiotic microorganisms in the digestive tract and on the skin, called the human microbiome. The rhizosphere microbiome might therefore seem comparable to that found in the human intestine; however, unlike the intestine, the rhizosphere is not a closed system. Maintaining a well-balanced ecosystem within the rhizosphere is extremely important to the plant, as evidenced by the fact that some species devote as much as 40 per cent of their photosynthetically fixed carbon to feeding microbes living on the root system—but how does the plant ensure that the right bacteria are being recruited to the roots, and how do these microbes aid the plant? These are perplexing questions for plant biologists.

DOING DAMAGE

Such questions are also of great importance to agriculture. Between 25 and 40 per cent of all major cash crops are lost to disease and pests, representing more than €450 billion in damage worldwide every year. Considering the input of fertiliser and pesticide, this is a high figure—but while planting crop plants in large, dense, homogenous populations is ideal for input efficiency, it is likely to be conducive to disease. Meanwhile, the global demand for food is set for a 70 per cent increase by 2050—a growth rate that far exceeds the current expansion of food production. Taking better advantage of the plant immune system could therefore be key to meeting targets and keeping the world fed in an unstable future.

Over the last few years, a laboratory in The Netherlands has been consistently responsible for advancing the scientific understanding of plant immune systems. Dr Corné Pieterse and his group at Utrecht University have made a series of discoveries illuminating the defence systems employed by plants, and in 2010 they embarked on PlantImmuSys, a five-year project funded by the European Research Council to answer three fundamental questions about plant immunity. The project focuses on resolving how plants communicate with and shape the microbial environment around them, how beneficial microbes aid the plant in defence against pathogens and how plants orchestrate their immune signalling network to respond appropriately to the beneficial and parasitic organisms surrounding them.

HORMONAL HELPERS

The PlantImmuSys project is now more than halfway through its duration, and Pieterse and his collaborators have already made a number of important discoveries. The first of these findings built on the prior work of other investigators into plant hormone signalling, which suggested that jasmonic acid and ethylene were responsible for protecting the plant against necrotrophic pathogens, while salicylic acid played a central role in the regulation of defence against biotrophic pathogens. Using mutants impaired in each of these three hormones, the Utrecht team has demonstrated that when plants use beneficial rhizosphere microbes to bolster their immune system, they also make use of jasmonic acid and ethylene. In addition, the group has unravelled for the first time the molecular workings of the antagonism between jasmonic acid and salicylic acid signalling, providing an important insight into how plants are able to sensitively regulate their immune response to multiple attackers.

Using a systems biology and bioinformatics approach, the researchers are now in the process of characterising the various hormone-regulated areas of the plant immune system. The team’s approach is to monitor the expression of all 25,000 genes in the plant in response to the defence hormones, reconstructing the complex molecular interactions occurring during immune response. Although the plant immune system is very complex, this work could provide new insights into the roles of crucial genes and proteins, which might subsequently be employed by breeders and growers to improve crop protection.

WORK IN PROGRESS

Using similar genome monitoring methods, the scientists are also investigating which genes change their expression patterns when the plant’s roots are colonised by beneficial bacteria. In this study, they have so far identified a number of genes in the root that play an essential part in the positive response of the plant to helpful bacteria. This opens the door to molecular markers of improved symbiosis, but it has also allowed the molecular biologists at Utrecht to construct a new line of test plants for experimental use. The roots of this line produce fluorescent proteins when they respond positively to a bacterial species, and therefore facilitate the search for beneficial microbes.

Other PlantImmuSys achievements have included the discovery that infection with the biotrophic downy mildew pathogen, which affects many crops, causes a plant to recruit specific microorganisms to its root system—perhaps to stimulate the immune system. They also observed that Pseudomonas syringae, the bacteria responsible for bacterial speck in tomatoes, produces a protease protein to degrade the flagellin molecules it releases during growth. The plant immune system is efficient at sensing and aggressively responding to these molecules, and so by masking them the bacteria can avoid being detected. While examining the genomes of mutualistic bacteria in the root system, however, Pieterse and his investigators found that many also possess this protein, and they are now examining the possibility that beneficial bacteria also make use of this ‘cloaking’ system. If successful, PlantImmuSys’s impact on the agricultural sector could be extensive. A key industrial priority in the EU is the reduction of fertilisers and pesticides and so, if naturally occurring symbiosis can be better harnessed to protect plants, the team may well have created an opportunity to aid agricultural ecosystems and lower production costs simultaneously.
ADOPTING ARABIDOPSIS AS A PLANT MODEL

The ubiquitous lab rat or ‘rodent model’ has been an excellent model species for countless studies into mammalian and human biology. But what about plants? Dr Corné Pieterse and his team rely on the model plant Arabidopsis thaliana (thale cress or mouse-ear cress) in their experiments, a plant the importance of which, he states, “can be compared to the importance of the mouse model for human systems”.

WHAT MAKES ARABIDOPSIS THE ‘LAB RAT’ OF THE PLANT WORLD?

In 2000, Arabidopsis became the second eukaryotic species to have its whole genome determined – the first being humans. Advantages include:

• It is a small weed, making it very easy to grow
• A short generation time of two months
• It is ideal for genetic and molecular studies
• For virtually every one of its 25,000 genes, a non-expressive mutant is available online

From the viewpoint of Pieterse and his collaborators, another important advantage is that Arabidopsis is also susceptible to a wide variety of pathogens and insect herbivores, and responds well to beneficial microbes in the root microbiome that promote plant health, making it an ideal candidate for those studying the plant immune system.

PlantImmuSys

A MULTIDISCIPLINARY APPROACH TO UNCOVER HOW PLANTS SIMULTANEOUSLY DEAL WITH BENEFICIAL AND PARASITIC ORGANISMS TO MAXIMIZE PROFITS AND PROTECTION

OBJECTIVES

• To investigate the molecular communication between plant roots and beneficial microbes in the root microbiome that promote plant growth and stimulate plant health
• To uncover novel key mechanisms of the plant immune system by which plants are able to simultaneously deal with beneficial and parasitic organisms
• To unravel the role of plant defence-related plant hormones in the plant immune signalling network that functions in accommodating beneficial microbes and protection against enemies
• To learn from nature to design novel tools for sustainable agriculture and resistance breeding of future crops

KEY COLLABORATORS

Core team: Dr Saskia van Wees • Dr Peter Bakker • Dr Guido van den Ackerveken

Members of the PlantImmuSys project: Dr Christos Zamioudis • Dr Roeland Berendsen • Dr Marcel van Verk • Dr Richard Hickman • Paul Wintemans • Giannis Stringlis • Lotte Caals • Anja van Dijken • Hans van Pelt

External collaborations: Professor Marcel Dicke, Wageningen University • Professor Johan Memelink, Leiden University • Professor Alain Goossens, VIB Ghent • Katherine Denby, Warwick Systems Biology Centre

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