Stanford Microbiology and Immunology 104/204: Innate Immunology, Lecture 4
The immune system in plants

Why study plant immunity?

1. One's life depends on plant immunity in a far more immediate manner than it depends on a cure for almost any disease. All of our food comes from plants.
2. Mechanisms are conserved in biology and different systems have different strengths. New biology discovered in plants can take a long time to find its way into the animal literature.

Plants suffer from infections

Every class of organism that infects us also infects plants – not the same ones but bacteria, fungi, viruses, nematodes and insects all cause plant disease.
In addition plants have developed immune methods of dealing with herbivores

Differences between plants and animals

Plants have no antibody/T cell response.
There are not circulating cells in a plant.
Systemic signals can be sent through a plant.
Plant parts are disposable and replaceable.

I will divide the lecture into a molecular description of plant immunity and an organism level description of the immune responses

Classes of plant immune responses

Basal response: transcription of genes in response to PAMP recognition.
Hypersensitive response (HR); apoptosis of cells at the site of infection
Systemic acquired immunity: The entire plant becomes resistant to infection
Jasmonic acid/ethylene pathway: The entire plant and neighboring plants develop resistance to herbivores.
Non-host immunity

The basal response

This is the response induced by PAMP elicited signaling.
The effectors of this response are currently being characterized.

Hypersensitive response

This is a rapid apoptosis response that kills cells in the area of infection.
It can be induced by the interaction of an R gene carrying plant with an Avr carrying microbe.
In the lab one can infiltrate bacteria into the whole leaf, causing a massive cell death response but in the field the HR response is likely tiny and limits the growth of microbes to a small area on the leaf. This should stop the growth of biotrophic pathogens that require living tissue in order to survive.
Nitric oxide (NO) and hydrogen peroxide (H_2O_2) regulate the response.
The HR can trigger systemic acquired resistance described below.

Stanford Microbiology and Immunology 104/204: Innate Immunology, Lecture 4
The immune system in plants

Systemic Acquired resistance (SAR)

Challenge a leaf with an infectious agent and distal tissues become resistant.
The distal tissues have broad resistance – not just to the original pathogen.
Can be induced by cell death; either HR or otherwise.
The effects are broad range, acting on bacteria, fungi and viruses.
A number of genes are induces by SAR but the mechanism behind the resistance in unknown.
Salicylic acid must accumulate to induce the SAR but salicylic acid is not the systemic signal; an unidentified lipid likely serves as the signal.
An SAR signal (but not salicylate) travels through the plant and increases the resistance of the plant to further infection.
This response has found a use in agriculture in the form of inducers of SAR like Actigard, Messenger and Vacciplant.

Jasmonic acid response (JA)

This chemical is a volatile plant hormone involved in regulating immunity.
JA synthesis is induced upon herbivory (crushing wounds).
JA induces the transcription of a number of genes that are anticipated to reduce the digestion of the herbivore.
For example, the induction of arginase in tomato plants.
This reduces the availability of arginine to the insect gut and reduces growth of the caterpillar.

Plant cells can recognize PAMPs

The Arabidopsis receptor Fls2 is a flagellin receptor
The structure is reminiscent of Toll in that the extracellular domain of the protein contains Leucine Rich Repeats.
The intracellular domain contains a serine threonine kinase
Signaling is transduced through a MAP kinase cascade and activates transcription factors in the WRKY family.
As in animals, there are many PRRs in plants that presumably can recognize microbes by more than one PAMP.

Fls2 can be shown to have an immune function because loss of function mutations sensitized the plants to infection. Forced expression of the MAP kinases or WRKY29 will force the activation of the pathway and protect the plant from fungal and bacterial infections
This suggests that this PAMP activated pathway is required for fighting fungal as well as bacterial infections. The pathway may have originally been identified as responding to bacteria but its output can affect fungal growth as well.

Stanford Microbiology and Immunology 104/204: Innate Immunology, Lecture 4
The immune system in plants

Bacteria have evolved methods of blocking the plant innate immune response

One common mechanism often studied in plants involves the secretion of virulence factors across the plasma membrane and into the cytoplasm of the host cell.

This occurs through a type III secretion system.

Such systems are also used by pathogens infecting vertebrate cells

YopJ, which we talked about last week, is injected into cells using this type of system.

One example of a bacterial effector is AvrRpm1

RIN4 is a negative regulator of PAMP elicited signaling

The presence of this protein results in increased phosphorylation of the plant protein RIN4.

AvrRpm1 interacts physically with RIN4

Increased phosphorylation of RIN4 presumably results in decreased PAMP triggered immune defense.

The bacteria grow better because they are no longer inhibited by the PAMP triggered immune response.

A second effector, AvrRpt2 is a protease that cleaves RIN4

Multiple effectors can gang up on important plant proteins.

The plant has countermeasures to defend against bacterial effectors.

This is where the guard hypothesis or the elicitor triggered immunity (ETI come in.

The plant can detect manipulation of its immune system and this can induce a strong immune response.

This work developed from the study of R genes in plants.

R genes are dominant plant genes that provide resistance to pathogens carrying dominant Avr genes.

A plant carrying an R gene that is infected by a bacterium carrying an Avr gene will be immune to disease.

All other combinations will lead to disease.

Molecular analysis of R genes revealed that they form two basic classes

1. LRR containing extracellular proteins.
2. LRR containing intracellular proteins.

Host resistance

"gene-for-gene" resistance- a plant strain is resistant to a bacterial strain and this depends upon a single gene in each organism. This type of resistance does not last long in the field – the microbes eventually find a way around it.

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The immune system in plants

R gene in the plant – required to provide resistance, dominant trait
Mutant plant is sensitive to infection
Avr gene in the bacterium – required for avirulence
Mutant plant is virulent on a resistant host.

Model had been that microbe made a product (avr) which was recognized directly by the R gene and this raised an immune response.

This provides an important lesson about how your system defines the way design experiments. Note that virulence and avirulence are defined for the resistant plant. If you define things from the non-resistant host, you are thinking more like a scientist working on microbial pathogenesis in animals.

The role of avr genes play when infecting susceptible plants is to serve as virulence factors.

For example, the plant protein RPM1 detects the AvrRpm1 induced change in RIN4 phosphorylation, which presumably interferes with the binding of RPM1 to RIN4. When binding is altered, the plant raises an immune response.
RPM1 is not directly recognizing the bacterial protein; instead it recognizes the physiological effects of the bacterial protein on the host cell.

This is only one example of the way bacteria might try to manipulate the host and the manner in which the host responds. There are many variations on this theme.

The bacterial effector AvrRpt2 is a protease that cleaves Rin4
This can prevent the detection of AvrRpm1 by Rpm1
Cleavage activates the R protein RPS2, which normally binds to RIN4
Disruption of binding leads to signaling
AvrRpt2 is secreted in an inactive form and is only folded correctly by a chaperone in eukaryotic cells.
The AvrRpt2 then cleaves itself to become fully activated and then leads to cleavage, directly or indirectly of RIN4

Non-host resistance

Genetic trait is stable in the field
Entire plant species is resistant to entire pathogen species

This is an important and difficult problem to study. It is simpler to study a microbe that can cause an infection. You can look for factors that make the infection more or less intense. With non-host resistance you do not know before you start doing experiments whether you will ever be able to make a plant susceptible to infection by a microbe that does not normally infect that plant.
In human terms you might ask: "why does my dog get heartworm but I don't?" or "why doesn't feline leukemia virus infect me?"

Model system

Stanford Microbiology and Immunology 104/204: Innate Immunology, Lecture 4
The immune system in plants

Arabidopsis thaliana and Blumeria g. hordei
- Barley powdery mildew
- In a susceptible plant get sporulation,
  - Formation of an appresorium
  - Penetration Peg
  - Haustorium
  - Mycelia
- Plant reacts by depositing callose at the sites of contact with the fungus
  - Is this a defense reaction or can this be abused by the pathogen?
- Search for plant mutants that permit haustorium formation or have altered callose deposition
- Plant with deficiency in callose deposition is resistant to fungal infections.
  - This was a surprise as it was assumed the callose played a purely defensive role in the process.
- Also found mutants that permitted penetration by the fungus and also had less callose deposition.