Chapter 1

Plant Metabolism and Immunity

All organisms possess some type of defense mechanism that protects them from outside invaders. In plants, this primary defense mechanism is an immune response. The immune response in plants is a combination of physical barriers and chemical responses that work together to prevent pathogens from causing infection. Multiple metabolic systems in plants also play a vital role in the immune response. This chapter will focus on the threat that pathogens such as bacteria, viruses, and fungi pose to plants and the immune response employed by plants in order to combat these unwelcome outsiders.

1.1 The First Line of Defense

Understanding the role physical structures and organelles play in the plant immune response is crucial. Plants employ a variety of tactics when protecting themselves from pathogens; however, physical barriers are the first line of defense. A plants' **wax** and **cuticle** are on the front lines when it comes to defense. They make up the outside of the plant and act as physical barriers to infection. **Stomata** are also located on the outside of the plant but are specifically positioned on the underside of leaves. They also act as physical barriers via their ability to open and close which helps regulate what enters and exits the plant. Cell walls, on the other hand, are located on the inside of the plant. However, they still act as physical barriers on a microscopic level (Appalachian State University). The combined efforts of these physical structures and organelles make a great first line of defense for plants. However, what happens when a pathogen manages to make it through these physical barriers?

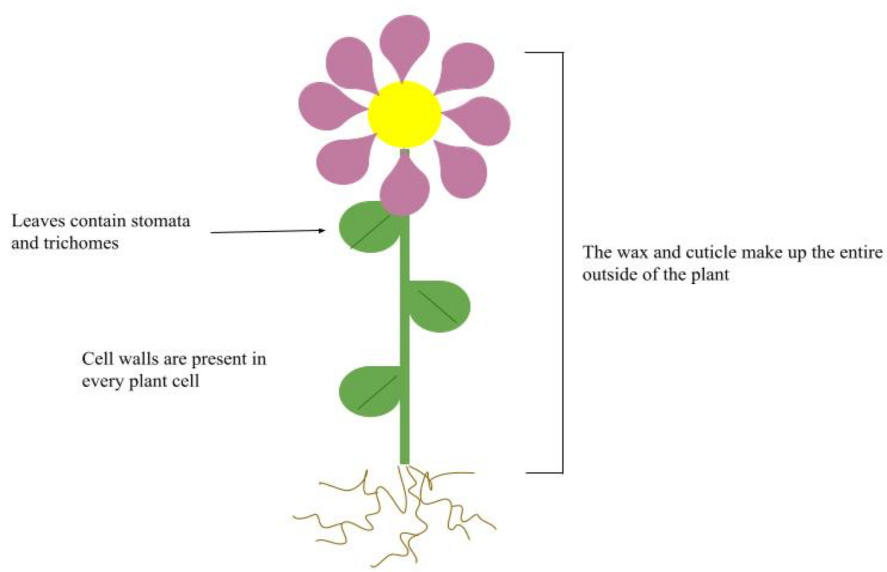

Figure I: Illustrated above are the locations of the main physical structures and organelles responsible for acting as physical barriers to infection in relation to the plant as a whole.

Learning Check
Q: What are the main structures and organelles that act as physical barriers to infection in the plant immune response?
A: Wax, cuticle, stomata, and cell walls

1.2 The Immune Response in Plants

Plants have two systems of innate immune response, primary and secondary (Jones and Dangl, 2006). **Innate immunity** refers to the non-specific defense from foreign microbes in the body via chemical and physical responses (The University of Arizona, 2000). **Adaptive immunity**, on the other hand, refers to antigen-specific defense via memory of **antigens** on foreign microbes in order to prevent future infection from said pathogen (The University of Arizona, 2000). The primary immune response activates the **basal defense system**, and the secondary immune response activates the **effector triggered defense system** (Grennan, 2006, De Wit, 2007). **Pathogen-associated molecular patterns (PAMPs)**, such as **lipopolysaccharides**, **peptidoglycan**, and **bacterial flagellin**, are in charge of activating the basal defense system via binding to **pattern recognition receptors (PRRs)** in the plasma membrane thus inducing **PAMP-triggered immunity (PTI)** (Grennan, 2006, Jones and Dangl, 2006). Remaining pathogens will then release effectors in order to interfere with PTI thus triggering a response from proteins that activate **effector-triggered immunity (ETI)** which ultimately results in **apoptosis**, or programmed cell death (Jones and Dangl, 2006). Different types of secretion systems are used by pathogens to deliver a variable number of effectors to cells. One study indicates that pathogenic bacteria will deliver anywhere from 15-30 effectors via a **type III secretion system (TTSS)** (Jones and Dangl, 2006). TTSS also appears to be the most common secretion system utilized by pathogenic bacteria in order to successfully infect the plant (De Wit, 2007). In addition, research suggests that TTSS is crucial for virulence, or the ability of a pathogen to infect. If the bacteria do not possess a TTSS then only a primary defense response will be activated in the plant and the bacteria will be non-pathogenic (De Wit, 2007).

While plants do not possess an adaptive immune system, they are capable of carrying out a form of adaptive immune response. Plants have the ability to obtain an acquired resistance if the initial infection results in resistance and spreads to another area of the plant (Nazarov et al., 2020). In other words, certain signaling molecules are able to transport themselves to other cells and increase resistance to a formerly exposed microbe (Nazarov et al., 2020). Plant hormones such as salicylic acid (SA), jasmonic acid (JA), ethylene (ET), and abscisic acid (ABA) are some of the signaling molecules in charge of plant defense. The type and amount of hormone used in defense is entirely dependent upon the type of pathogen (De Wit, 2007). Without these hormones, plants would be unable to utilize the adaptive immune response and prevent further exposure to the same pathogen.

Another interesting aspect of plants is that they are regulated by time (Grennan, 2006). Different types of immune responses occur at certain times after exposure to a pathogen. For example, fluctuations in **ion leakage** and **oxidative burst** occur within seconds to minutes of infection (Melotto et al., 2014). Whereas salicylic acid production and defense gene **transcription** occur within hours to days after infection (Melotto et al., 2014).

Learning Check
Q: What two types of innate immune response are most common in plants?
A: PAMP-triggered immunity (PTI) and effector-triggered immunity (ETI)

1.4 Metabolism in Relation to Plant Immunity

So where does metabolism come into play with regard to immunity in plants? While metabolism and immunity may seem like two distinct concepts, there is actually a large amount of overlap. Metabolism in plants is usually associated with common processes such as photosynthesis and cellular respiration (Rojas et al., 2014). However, recent research indicates that the upregulation of primary metabolic pathways may play a vital role in the immune response in plants (Rojas et al., 2014). Various metabolic systems, such as carbohydrate, amino acid, lipid, and photorespiration, utilize their pathways to not only produce energy to jumpstart the immune response but also to signal the onset of the immune response (Rojas et al., 2014). The use of these primary metabolic pathways really helps catalyze the response by the immune system for plant defense.

1.5 Symptoms of Plant Disease

When infected with a pathogen, plants will experience symptoms such as wilting, necrosis, rot, mold, discoloration, and deformation among many others (Nazarov et al., 2020). However, one of the crucial differences between the symptoms experienced by humans and symptoms experienced by plants is the negative effect these symptoms have on the health of plants. For example, necrosis is the result of the partial death of plant tissues, rot accelerates the decay of vital intracellular structures such as the cell membrane, and mold occurs due to fungal damage (Nazarov et al., 2020). All of these symptoms have a negative effect on the health of the plant.

Figure 2: A photo depicting the symptoms experienced by Brassica napus plants when exposed to a bacterial pathogen. The left half of the leaf was not infiltrated and is not experiencing cell death, whereas the right half of the leaf was infiltrated and is experiencing cell death.

Learning Check
Q: What plant symptom results in the partial death of plant tissues?
A: Necrosis

1.6 Negative Effects of Plant Disease

Why is understanding how plants defend themselves from pathogens and obtain immunity relevant? For starters, the agricultural industry is highly dependent upon understanding the mechanism behind plant immunity in order to develop methods that allow for the distribution of healthy crops. Disease has the potential to affect around 70-80% of the total plant population and decrease the crop yield by roughly 80-98% (Nazarov et al., 2020). Supplying healthy crops also decreases the number of plant-based food product recalls, which can be detrimental to the economy (Nazarov et al., 2020). For example, an 8-day recall of spinach occurred back in 2006 and resulted in a loss of $350 million to the U.S. economy which negatively affected farmers, distributors, and the agricultural industry as a whole (Melotto et al., 2014). Based on these statistics, it is apparent that understanding the mechanism behind plant immunity is pivotal as it allows researchers to develop better methods for controlling plant disease in nature.

1.7 Prevention of Bacterial Infection

Since food recalls pose such a major threat to the agricultural industry, how do farmers prevent infections in plants? Antibiotics are strictly utilized for infection prevention instead of treatment in plants. Research indicates that antibiotics are applied via routine sprays in order to decrease the amount of pathogenic growth on flowers and leaves of plants (Stockwell and Duffy, 2012). In addition, antibiotics are incapable of eliminating infection in plants if the pathogen successfully infiltrates and replicates (Stockwell and Duffy, 2012). Some of the main antibiotics used in disease resistance in plants are streptomycin, oxytetracycline, gentamicin, and oxolinic acid (McManus et al., 2002).

In conclusion, plant metabolism and immunity may appear to be two separate concepts in theory, but in actuality they are rather interrelated. Various types of metabolisms play vital roles in the immune response in plants. Many metabolic pathways contribute to energy production and are used for signaling, both of which are required for a successful immune response that will eliminate and prevent further infection. The use of the adaptive immune response via primary metabolic pathways is ultimately a plant's strongest weapon against foreign invaders. While the outer protection provided by the waxy cuticle and antibiotic sprays are excellent preventative measures, the two immune systems combined with the energy and signaling provided by the primary metabolic pathways that plants possess are the heavy artillery for immune defense.

Glossary

Adaptive Immunity: The antigen-specific defense via memory of antigens on foreign microbes in order to prevent future infection from said pathogen.

Antigen: Anything that elicits an immune response. In reference to pathogens, any physical structure or chemical signal that indicates a foreign microbe is present within a plant.

Bacterial Flagellin: A tail-like appendage found on some species of bacteria that act as a means of transportation via a "swimming-like" motion.

Basal Defense System: See innate immunity

Cuticle: The outermost layer of the plant; it's responsible for protecting the plant from drought, extreme temperatures, UV radiation, chemicals, and pathogens along with pests.

Effector: Proteins utilized by pathogens to assist in infection.

Effector-Triggered Defense System: See effector triggered immunity

Effector-Triggered Immunity (ETI): Immunity that results due to the activation of the innate immune response via the recognition of effectors on pathogens.

Innate Immunity: The non-specific defense from foreign microbes in the body via chemical and physical responses due to antigen and effector recognition.

Ion Leakage: The event of the leaking of ions from plant cells as a result of pathogenic infiltration and infection.

Lipopolysaccharides: A complex molecule composed of lipids and sugars.

Oxidative Burst: A respiratory event that occurs when a large amount of reactive oxygen species, such as O_2, H_2O_2, and OH^-, are release due to pathogenic infiltration and infection.

PAMP-Triggered Immunity (PTI): Similar to ETI, immunity that results due to the activation of the innate immune response via the recognition of PAMPs by PRRs**.**

Pathogen Associated Molecular Patterns (PAMPs): Molecules, such as lipopolysaccharides or peptidoglycan, that exhibit a specific "pattern" and alert the immune response to incoming pathogens.

Pattern Recognition Receptors (PRRs): Sensors that are in charge of detecting PAMPs and other infection indicating molecules located in the plasma membrane of plant cells.

Peptidoglycan: A main component in the cell wall of bacteria that also acts as a PAMP in the plant immune response.

Stomata: Pores located on the underside of the leaf that play a vital role in respiration and the gaseous exchange of H_2O, O_2, and CO_2 with the environment via opening and closing.

Transcription: The acting of copying a strand of DNA into a strand of RNA.

Type Three Secretion System (TTSS): A needle-like appendage delivery system utilized by certain gram-negative bacteria to aide in the infection of cells.

Wax: A protective, hydrophobic coating located on the outside of the plant that regulates hydration and evaporation.

References

De Wit, P. J. G. M. 2007. How plants recognize pathogens and defend themselves. *Cellular and Molecular Life Sciences*, 64: 2726-2732.

Dr. Neufeld. A short intro to botany. *Appalachian State University*. http://www.appstate.edu/~neufeldhs/bio1102/lectures/lecture8.htm

Grennan, A. K. 2006. Plant response to bacterial pathogens. Overlap between innate and gene-for-gene defense response. *Plant Physiology*, 142(3): 809-811.

Jones, J. D. G. and Dangl, J. L. 2006. The plant immune system. *Nature*, 444: 323-329.

McManus, P. S., Stockwell, V. O., Sundin, G. W., and Jones, A. L. 2002. Antibiotic use in plant agriculture. *Annual Review of Phytopathology*, 40: 443-465.

Melotto, M., Panchal, S., and Roy, D. 2014. Plant innate immunity against bacterial pathogens. *Frontiers in Microbiology*, 411(5): 1-12.

Nazarov, P. A., Baleev, D. N., Ivanova, M. I., Sokolova, L. M., and Karakozova, M. V. 2020. Infectious plant diseases: etiology, current status, problems, and prospects in plant protection. *Acta Naturae*, 12(3): 46-59.

Rojas, C. M., Senthil-Kumar, M., Tzin, V., and Mysore, K. S. 2014. Regulation of primary plant metabolism during plant-pathogen interactions and its contribution to plant defense. *Frontiers in Plant Science*, 5(17): 1-12.

Stockwell, V. O. and Duffy, B. 2012. Use of antibiotics in plant agriculture. *Revue Scientifique et Technique*, 31(1): 199-210.

The University of Arizona. 2000, May 24. Innate vs. Adaptive Immunity. *The Biology Project*. http://www.biology.arizona.edu/immunology/tutorials/immunology/page3.html