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Virus Induced Biochemical Changes in Host Plant

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Plant viruses are among the most destructive pathogens worldwide, especially in tropical and subtropical regions, where they cause severe economic and agricultural losses. Among these, single-stranded DNA Gemini viruses are highly virulent, infecting major agronomic and horticultural crops. To defend against viral attacks, plants rely on naturally occurring phyto-chemicals and antioxidant enzymes that participate in immune responses. Viral infection triggers significant biochemical and physiological changes, including altered levels of photosynthetic pigments, increased phenolic content, elevated starch accumulation in leaves, and modulation of key antioxidant enzymes. These responses help activate multiple defense pathways, leading to hypersensitive reactions characterized by leaf lamina thickening, lignifications beneath the epidermis, stomatal closure, localized cell death, and stimulation of salicylic acid and jasmonic acid signaling systems. Collectively, these changes limit viral movement, confine infection sites, strengthen structural barriers, and enhance metabolic defenses. Starch buildup and enhanced production of stress-related compounds further support resistance mechanisms. Overall, the plant's coordinated defense strategies aim to restrict virus spread, protect unaffected tissues, and reduce potential yield losses, demonstrating a complex interplay between biochemical pathways and structural defense responses during viral invasion.

Introduction

Viral infections account for nearly half of newly emerging plant diseases, and new plant viruses continue to be identified. According to Baltimore's classification, plant viruses are grouped into DNA and RNA viruses, with RNA viruses being more widespread and responsible for major losses. Since viruses are obligate parasites, they rely entirely on host cellular machinery for replication and remain inactive outside their host, raising debate about whether they are truly "alive." Although viruses can infect plants, animals, fungi, and bacteria, most are host-specific. In plants, viral pathogens significantly limit vegetable crop yield across tropical, subtropical, and temperate regions. Infected plants typically display symptoms such as leaf yellowing, mosaic patterns, vein clearing, distortion, streaks, stunting, and overall growth reduction. Under favorable conditions, plant viral diseases can destroy entire crops and cause severe yield loss.

Plant Virus Interaction

Plants produce phyto-chemicals, including primary and secondary metabolites, which play essential roles in growth and defense. Leaf phytochemical analysis shows the presence of key secondary compounds like flavonoids, phenols, and polyphenols, along with biomolecules such as chlorophyll and carbohydrates. Under biotic or abiotic stress, especially viral infection, plants undergo biochemical and physiological changes. Viruses alter metabolite production, often increasing secondary metabolites and antioxidant activity to enhance plant defense. Viral infection typically raises levels of phenols, proline, and antioxidant enzymes such as CAT, PPO, SOD, and POX, helping improve plant tolerance.

PR pathway

The PR (Pathogenesis-Related) pathway in plant virus interactions refers to a series of molecular and cellular processes that plants use to defend themselves against pathogens, including viruses. This pathway involves the activation of specific proteins known as PR proteins, which play crucial roles in the plant's immune response**.**

Virus Recognition: The first step in the PR pathway is the recognition of the virus by the plant cells. Plants have innate immune receptors that can detect specific virus-associated molecular patterns (VAMPs) or can sense the effects of virus infection indirectly through damage-associated molecular patterns (DAMPs).

Signal Transduction: Once a virus is detected, this information triggers a signal transduction pathway within the plant cells. These pathways often involve the accumulation of signalling molecules like salicylic acid (SA), which is crucial for the systemic acquired resistance (SAR) response in plants.

Activation of PR Genes: The accumulation of signalling molecules like SA leads to the activation of various PR genes. These genes encode for PR proteins, which have diverse functions in plant defence. For example, some PR proteins have antimicrobial properties, others may work by reinforcing the plant cell walls to prevent virus spread, and some may be involved in signalling pathways to amplify the defense response.

Production of PR Proteins: Once the PR genes are activated, the plant cells produce PR proteins. These proteins can be classified into different families (PR-1 to PR-17) based on their sequence similarity and enzymatic or binding functions. For instance, PR-1 proteins are often used as markers for SAR, and others like PR-2 (β-1,3-glucanase) and PR-3 (chitinase) help degrade the walls of fungal pathogens or inhibit growth of the pathogens in other ways.

Systemic Response and Recovery: The effect of PR proteins can be localized (near the infection site) or systemic (throughout the plant), leading to an overall heightened state of defense readiness in the plant. This systemic acquired resistance helps the plant to resist future infections more effectively, not only by the same virus but also by other types of pathogens.

The PR pathway is a crucial aspect of the plant immune system, providing both immediate and long-lasting resistance against virus infections. This pathway exemplifies how plants can utilize both pre-existing defense mechanisms and adaptive responses to survive in environments filled with diverse pathogens.

PAL pathway

The PAL (Phenylalanine Ammonia-Lyase) pathway plays a key role in plant defense during viral infection. PAL initiates the phenylpropanoid pathway, leading to the production of important secondary metabolites that help protect plants against viruses and other pathogens.

Activation by Pathogen Detection: Upon virus infection, plants recognize viral components or the damage caused by the virus through various receptor proteins. This recognition triggers a series of signaling events aimed at activating defense responses.

PAL Enzyme Activation: PAL converts the amino acid phenylalanine into cinnamic acid. This reaction is the gateway to the phenylpropanoid pathway, which leads to the production of various important compounds including flavonoids, lignins, and tannins, as well as salicylic acid, which plays a key role in signaling for systemic acquired resistance (SAR).

Production of Phenylpropanoids: The phenylpropanoid pathway generates compounds with key defensive roles in plants. Lignin fortifies cell walls to restrict viral movement, while flavonoids act as antioxidants, provide UV protection, and can directly inhibit viruses. Additionally, salicylic acid activates systemic acquired resistance (SAR), boosting plant immunity against diverse pathogens.

ROS pathway

The ROS (Reactive Oxygen Species) pathway in plant virus interactions is a crucial defense mechanism employed by plants. Reactive oxygen species, such as hydrogen peroxide (H_2O_2), superoxide radicals (O_2^-), and hydroxyl radicals (OH^-), are chemically reactive molecules that play significant roles in plant stress responses, including responses to viral infections. Here's how the ROS pathway functions in plant defense against viruses:

Virus Recognition: When a plant cell recognizes the presence of a virus, typically through pattern recognition receptors (PRRs) that detect viral components or through disruption caused by the virus, it triggers an immune response.

ROS Production: One of the earliest responses to viral infection is the rapid production of ROS. This occurs mainly in cell organelles like chloroplasts, mitochondria, and peroxisomes, as well as in the plasma membrane through enzyme complexes such as NADPH oxidases.

Oxidative Burst: The initial and rapid production of ROS following pathogen recognition is often referred to as the "oxidative burst." This burst serves several functions:

Direct Antiviral Effects: ROS can damage viral proteins and genetic material directly, thus inhibiting the virus's ability to replicate.

Signal Transduction: ROS act as signaling molecules that can activate further defense responses, including the expression of genes involved in pathogen resistance.

Activation of Defense Genes: ROS can modulate the activity of various signaling pathways, including those involving salicylic acid (SA), jasmonic acid (JA), and ethylene (ET), leading to the activation of pathogenesis-related (PR) genes and other defense mechanisms.

Cell Wall Fortification: One of the defense strategies induced by ROS involves reinforcing the plant cell wall. ROS can promote the cross-linking of proteins and the strengthening of the cell wall, making it harder for viruses to spread from cell to cell**.**

Systemic Acquired Resistance (SAR): The localized production of ROS can also lead to the development of systemic acquired resistance, a plant-wide state of enhanced defensive readiness, which protects against a broad range of pathogens, not just the initially encountered virus.

Regulation and Modulation: Here is the **paraphrased and condensed** version:

Although reactive oxygen species (ROS) play a key role in plant defense, excess ROS can harm cells by causing oxidative stress. To balance ROS levels, plants use antioxidant enzymes such as superoxide dismutase, catalase, and ascorbate peroxidase, which prevent cellular damage. The ROS pathway not only provides direct protection against pathogens but also acts as a signaling system that activates wider immune responses, helping plants maintain health and resist viral infections.

Impact of Viral Infection on Phyto-Chemicals

1. Chlorophyll

- A series of typical changes followed by chlorotic symptoms imply the occurrence of chloroplast-virus interactions.
- It involve overall decrease of chloroplast numbers and chloroplast clustering, a typical appearance of chloroplast, such as swollen or globule chloroplast, chloroplast with membrane-bound extrusions or amoeboid shaped chloroplast, generation of stromule (a type of dynamic tubular extensions from chloroplast), irregular structures such as out-membrane peripheral cytoplasmic invagination, vesicle, membrane proliferations and broken envelope, changes of content inside the chloroplast such as small vesicle.
- Banana bunchy top virus (BBTV) upon infection reduced the concentration of chlorophyll a and b, maximum reduction was observed in chlorophyll b than chlorophyll a. Reported reason behind this reduction was the deposition of carbohydrates in the leaf of plant.
- YLCV was responsible for the reduction of Mg^{++} which is a main component of chlorophyll. This reduction also led to the decrease of chlorophyll in tomato plant while,

high temperature supported the reduction. On TYLCV infection, tomato plant showed chlorosis at high temperature, causing reduction in chlorophyll concentration in the plant.
- Significant impact of pathogenic viruses on the carbohydrate metabolism of infected plant has been reported. Different viruses caused varied infections in plants such as some completely altered carbohydrate synthesis, and translocation process while others have mild effect.

2. Carbohydrate
- Carbohydrates play a significant role in the plant body but accumulation of excessive starch in the leaf produced viral symptoms.
- Sucrose contents increased in infected plant on the incidence of viral infection.
- Carbohydrates have major role in the production of antioxidant enzymes.
- In tomato plant decrease in insoluble and soluble sugars in stem and leaf was observed due to infection caused by TLCV in infected plant.
- Changes in carbohydrates concentration due to viral infection also affect the leaf color, no change was observed in color of healthy leaf while infected leaf showed dark gray colour.

3. Effect on Polyphenols

Polyphenols are important secondary metabolites that play a key role in plant–pathogen interactions and defense. During viral infection, plants increase phenolic compounds, which promote lignin formation beneath the leaf surface. This lignin strengthens plant defenses by acting as a physical barrier against pathogen spread. Elevated phenol levels indicate an activated phenolic synthesis pathway in response to infection. For example, Yellow Vein Mosaic Virus (YVMV)–infected pumpkin plants showed up to a 73% rise in phenolic content, enhancing their defense mechanism.

Effect of Viral Infection of Oxidative Enzymes

- Biotic and abiotic stresses in plants induce the production of reactive oxygen species (ROS) such as superoxide, hydrogen peroxide, and hydroxyl radicals. To counteract oxidative damage, plants have evolved defense systems involving antioxidants like ascorbate and glutathione, along with antioxidant enzymes including superoxide dismutase, catalase, and glutathione-related peroxidases.

Effect on Polyphenol Oxidase (PPO)
- Plant defense was boosted in the presence of polyphenol oxides, when plant membrane gets damaged on pathogenic invasion, phenols in the plant produced chlorogenic acid, which create an unfavorable environment for the pathogen to spread, polyphenol increased the phenol production that leads to restrict the spread of pathogen.
- Banana bunchy top infection caused the elevation in PPO activity in banana cultivars. PPO after combining with phenols shows activation of defense in the plant towards pathogen.

Effect on Ascorbate Peroxidase (APX)

Ascorbate peroxidase (APX) helps control reactive oxygen species (ROS) in plants. When APX levels increase, peroxidase activity also rises, allowing cells to better manage ROS. Studies show that during compatible host-pathogen interactions, APX accumulates in epidermal and mesophyll cells, helping cells stay alive even though they cannot stop pathogen spread.

Future Direction and Application

Exploring future directions and potential applications of virus-induced biochemical changes in plants opens up a range of possibilities for both fundamental research and practical applications in agriculture and biotechnology. Here are several key areas to consider:

Advanced Understanding of Viral Mechanisms

Genomic Studies: With advancements in genomic technologies, researchers can study the complete virus and host genomes to understand specific interactions that lead to biochemical changes. This can help in identifying viral genes responsible for detrimental or beneficial traits in host plants.

Crop Improvement and Breeding

- **Virus-Resistant Varieties**: Insights into the biochemical pathways altered by viruses can guide the development of genetically engineered or traditionally bred plants that are resistant to viral infections. This could involve modifying the host plant's genes that interact with viral components.
- **Use of Viral Vectors**: Viruses can be engineered to carry beneficial genes into plants. This technique can be used for crop improvement, including enhancing resistance to abiotic stresses (drought, salinity), which may be indirectly affected by viral control of biochemical pathways.

Biotechnological Applications

- **Pharming**: Plants can be engineered to produce pharmaceuticals through viral vectors, a process known as pharming and understanding how viruses alter plant biochemistry helps optimize the production of vaccines, antibodies, and other therapeutic proteins in plants.
- **Eco-Friendly Pest Management**
- **Virus-Induced Gene Silencing (VIGS):** This technology uses viruses to transiently silence genes in plants, enabling functional genomics studies and the development of novel plant protection strategies by suppressing genes critical for pest and pathogen survival.
- **Cross-Protection**: This strategy involves infecting plants with a mild strain of a virus to protect against a more harmful strain. Understanding the biochemical changes induced by the mild strain can optimize cross-protection methods.

Conclusion

Plants respond to viral infections by activating secondary metabolic pathways influenced by ecological factors and their genetic code. Primary metabolites are converted into secondary metabolites or phytochemicals such as flavonoids, phenols, polyphenols, and antioxidant enzymes (POX, PPO, APX, CAT), along with key biomolecules like chlorophyll and carbohydrates. These compounds play a crucial role in triggering plant defense mechanisms. Upon infection, plants exhibit both structural and biochemical defense responses to resist viral invasion.

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