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## EFFECTS OF PHYTOPATHOGENIC FUNGI ON PLANTS (REVIEW)

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## ВЛИЯНИЕ ФИТОПАТОГЕННЫХ ГРИБОВ НА РАСТЕНИЯ (ОБЗОР)

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*Abstract.* This article outlines explanatory data on the interactions between phytopathogenic fungi and plants, as well as infestation ways of pathogenic fungi on plants. A thorough analysis of the literature revealed that phytopathogenic fungi use a number of biochemical and mechanical methods to penetrate into the plant tissues, including the production of cell wall-degrading enzymes, also use toxins, effector proteins, and growth regulators. Cell wall degrading enzymes (CWDEs) in pathogenesis are the main weapon of phytopathogenic fungi.

*Аннотация.* В статье приведены данные о взаимодействии фитопатогенных грибов с растениями, а также о путях заражения растений патогенными грибами. Тщательный анализ литературы показал, что для проникновения в ткани растений фитопатогенные грибы используют ряд биохимических и механических способов, в том числе продукцию ферментов, разрушающих клеточную стенку, а также используют токсины, эффекторные белки и регуляторы роста. Ферменты, разрушающие клеточную стенку (CWDE), в патогенезе являются основным оружием фитопатогенных грибов.

*Keywords:* phytopathogens, fungi, *Fusarium*, plant, disease, pathogen, phytotoxin, mycotoxin, enzyme, effector.

*Ключевые слова:* фитопатогены, грибы, *Fusarium*, растение, болезнь, возбудитель, фитотоксин, микотоксин, фермент, эффектор.

In recent years, the quantity and quality of agricultural crops have been declining under the influence of pests. This is due to the fact that pathogenic microorganisms are adapting to climatic conditions and effective control measures are not carried out in a timely manner. Development and

implementation of modern measures to combat pathogenic microorganisms will allow to obtain high and qualitative yields from agricultural crops [1–5].

Fungi are one of the main pathogens of plant diseases. Pathogenic fungi use a variety of methods to reproduce, spread, and cause disease in plants. Some fungi kill the host plant and feed on dead substances (necrotrophs), while others develop in living tissues (biotrophs). Fungi use a variety of virulent factors to reproduce and spread in the host plant. Depending on the method of damage, virulence factors perform different functions. While almost all pathogens disrupt the primary protection of plants, necrotrophs produce toxins to destroy plant tissue [6].

Phytopathogenic fungi can cause serious diseases that can adversely affect plant productivity. Some of these fungi have also been documented as human pathogens that can cause infectious diseases in immunocompromised individuals. In this context, the interaction of fungi with other organisms is of great interest because fungi use a number of biochemical and mechanical methods to penetrate and spread in nutrients. Produces enzymes or secondary metabolites that break down polymers as virulence factors during damage. In addition, fungi produce mycotoxins in plants, which pose a significant risk to human and animal health [7].

*Effectors.* Phytopathogenic fungi have evolved at different stages of life development to obtain and reproduce nutrients from the host plant during their coexistence with plants for millions of years. They use a variety of protein as well as protein-free molecules commonly called effectors to damage plant tissues. Effectors are important determinants of the virulence of pathogenic fungi and play an important role in successful pathogenesis. However, in addition to being important in pathogenesis, fungal effectors are eventually recognized by resistant plant varieties that produce a strong immune response to prevent pathogens. Various recent studies involving different pathosystems have identified the role of fungal effectors in controlling virulence / avirulence functions and the results of their plant-pathogen interactions. However, effectors and the plant resistance gene associated with them remain difficult for some economically important fungal diseases [8].

*Cell wall degrading enzymes (CWDEs).* One of the first barriers that phytopathogenic fungi must break down to enter plant tissue is the cell walls, which are composed primarily of carbohydrates. Many plant pathogenic fungi use special structures called appressoria to disrupt the cell wall [9–13].

Fungi typically produce enzymes belonging to five classes, namely glycosyl-hydrolases, glycosyltransferases, polysaccharide lyases, carbohydrate esterases, and carbohydrate-active enzymes that accelerate the oxidation-reduction process with auxiliary activity [14]. Polysaccharide lyases, glycosyl-hydrolases, and carbohydrate esterases are used to break down the cell wall. Typically, pathogenic species of plants contain more of these genes than saprophytic pathogenic strains [10, 15].

*Toxins.* Fungal toxins are metabolic products of various chemical natures that have specific pathological effects on the human body, animals, plants and microorganisms. Phytotoxins stop or slow down plant growth, damage or destroy tissues, and are an important factor in the development of diseases [16–21].

To date, the effects of more than 350 species of toxinogenic fungi have been studied, including dozens of species of toxins produced by fungi of the *Fusarium* genus. Representatives of this genus produce the most dangerous mycotoxins for plants, animals and humans [17, 20–23].

The mycotoxins of the micromycetes of the *Fusarium* genus are usually not specific to one species. Strains of many species synthesize fusaric acid (a nitrogenous heterocyclic compound

belonging to the group of nicotinic acids). Fusarium acid is highly toxic to various plant species and stops the growth of *Bacillus subtilis*, *B. megaterium*, *Pseudomonas aeruginosa*, *Staphylococcus* and other bacteria. This acid is formed in fungal mycelium and culture fluid and has different effects depending on the type of plant [20, 24–26].

Fusarium acid produces number of strains of *Fusarium oxysporum*, *F. moniliforme*, *F. heterosporum*, *F. subglutinans*, *F. sambucinum*, *F. napiforme*, *F. crookwellense*, *F. solani* fungi [20, 25].

Depending on the conditions and the level of toxicity of the producers, as well as the concentration in plant tissues, fusarium acid affects the conductive tubes of the plant in different ways. With a high dose of the toxin (100–200 mg/kg wet weight per hour), the conducting tubes are completely paralyzed and only half recover after 3–5 hours. At low doses (20 mg/kg) in the first stage of intoxication, the water supply to the tissues is increased and the plant does not suffer from water deficiency. After the appearance of necrosis in the tissues, as a result of the violation of water exchange in the second stage, the plant loses its turgor, i. e. the plant withers [17, 18, 20, 27, 26].

*Plant growth regulators.* When most pathogenic fungi penetrate into plant tissue, they begin to disrupt plant growth regulators such as auxin, cytokines, gibberel acid (GA), ethylene (ET), abscisic acid (ABA), brassinosteroids (BR), jasmonate acid (JA), as well as endogenous hormone levels in plants and produce salicylic acid (SA) to weaken plant protection [28]. Auxin-indolacetic acid, synthesized by the mycelium and conidia of *Magnaporthe oryzae*, may accelerate plant growth and weaken plant protection [29–31].

Cytokinin accelerates the growth of mycelium and spores of *Harpophora maydis* fungus and slows the growth of hyphae and spores of *Fusarium oxysporum* fungus. New drugs against phytopathogenic fungi can be developed by studying the methods of hormone synthesis and signaling methods of phytopathogenic fungi.

Over time, plants have developed a system of protection against a number of biotic and abiotic stresses, as natural systems produce many opposing forces on plants [32–34]. Different stress forces affect plants together, so any changes in a plant's metabolic physiology cannot be attributed to a specific stress factor. In the context of a particular stress, multiple response signals are used by the plant against the pathogen, and the response signal for both pathogens and insects are interrelated [35, 36]. Some of this response signal is caused by a pathogenic fungus and some is carried out regardless of its antagonistic nature. The formation of enzymes by pathogen to break down the cell wall and the synthesis of polymer barriers that prevent the entry of the pathogen is one of the main means of plant protection [37].

One of the barriers that phytopathogenic fungi must enter to break down plant tissue and damage the plant is the cell walls, which are mostly made up of carbohydrates. They usually use different methods to disrupt cell walls. Some pathogenic fungi produce carbohydrate-active enzymes that accelerate the redox process [38–40].

Through an in-depth study of the properties of phytopathogenic fungi, it serves as a basis for a better understanding of plant diseases and their effective control. However, the mechanisms of interaction between fungi and plants have been little studied. Today, the study of the interaction of plant and pathogenic fungi is one of the major issues facing phytopathologists.

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