

Direct and indirect defense mechanisms of plants

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Direct defenses are based on the presence of morphological (physical) characteristics – trichomes, etc. or on the production of toxic chemicals that directly suppress insect feeding.

In **indirect defense**, plants attract natural enemies of phytophagous insects by various means – through the release of specific volatile substances, the presence of different structures such as extrafloral nectaries, hollow spines, etc., or the production of protein bodies.

The presence of natural enemies reduces the risk of attack on the plant by phytophagous insects.

A common way to attract natural enemies is to provide them with food.

Extrafloral nectaries are glands located outside the flowers that produce sweet secretions. Wasps, ants, flies, moths, etc. are attracted to these liquids. Moths are usually considered pests, but the presence of predators and parasitoids may lead to a reduction in the density of their caterpillars.

In the absence, however, of predators and parasitoids, the presence of extrafloral nectaries may have the opposite effect. Cotton varieties without extrafloral nectaries are less severely attacked by the pink bollworm.

Plants may provide habitat and food for the natural enemies of phytophagous insects, a phenomenon known as a “biotic” defense mechanism. For example, trees of the genus *Macaranga* have adapted their thin stem walls to create ideal habitats for a species of ant (genus *Crematogaster*), which in return protects the plant from phytophagous insects. In addition to providing habitat, the plant offers the ants an additional food source – special protein bodies.

Similarly, some species of acacia (*Acacia*) have developed thorns that are greatly swollen at the base, forming a hollow structure suitable as an ant habitat. In practice, nectar-like liquids, molasses and other products can be applied to stimulate the natural enemies of phytophagous insects. Such trials have been conducted in potatoes and the result has been a reduction in the density of phytophagous insects.

An interesting strategy for using other organisms for plant protection is the coexistence with endophytic microorganisms. Endophytes are organisms (bacteria or fungi) that live in a given plant (for at least part of their life cycle) in the intercellular spaces, tissue cavities or conducting vessels, without causing visible disease. They are ubiquitous and have been found in all plant species. Endophytes can help host plants by preventing colonization by pathogenic or parasitic organisms.

Colonization of plant tissue by endophytes creates a “barrier effect”. Endophytes can also produce chemicals that affect the growth of pathogenic organisms (competitors). Some endophytes may release substances that are toxic to phytophagous insects (or phytopathogens). Scientists are working intensively on possibilities for protecting crops from pests through endophytically developing fungi or bacteria.

The described mechanisms for attracting natural enemies or coexisting with endophytes relate to the so-called constitutive defenses (inherently present in plants).

Induced defense mechanisms of plants, which are expressed upon pest attack, are particularly interesting.

In order to perceive the threat, the plant has developed a signaling system that responds to external stimuli and regulates the synthesis of defensive compounds. Plants distinguish between mechanical injury and insect feeding by the presence of certain substances found in insect saliva. In response to attack, plants may release volatile organic compounds (VOCs), including monoterpenoids, sesquiterpenoids and homoterpenoids, with which they can repel harmful insects or attract beneficial ones that feed on the pests.

The examples in scientific research are already countless: wheat seedlings can produce VOCs that repel aphids; faba bean and apple release chemicals that attract predatory mites when attacked by spider mites; cotton produces substances that attract parasitic wasps when attacked by caterpillars, etc.

Almost all plants are capable of emitting VOCs, and the content and composition of these organic compounds show both genotypic variation and phenotypic plasticity. VOCs are released from leaves, flowers, fruits and other plant organs into the atmosphere and from roots into the soil.

The release of VOCs occurs after “signal perception” – an elicitor, which is a macromolecule originating either from the host plant (endogenous elicitor) or from the plant stressor (exogenous elicitor), and which can trigger structural and/or biochemical reactions related to plant resistance.

Specifically in the case of insect attack, the substance volicitin in the saliva and in the attacked plant tissues plays the role of elicitor. Feeding in one part of the plant may induce systemic production of volatile organic compounds in undamaged tissues and organs, and once released, these compounds may act as signals for neighboring plants to start producing similar compounds.

In addition to the release of VOCs, after perception of a specific signal, most plants begin rapid formation of oxylipins, which activates a cascade of reactions leading to changes in plant cells. The accumulation of plant stress hormones (jasmonic acid, salicylic acid, abscisic acid, ethylene, etc.) and their role in the regulation of defense genes are being studied very actively.