

Physical (morphological) and chemical defense mechanisms of plants

Author(s): проф. д-р Вили Харизанова, от Аграрен университет в Пловдив

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Morphological (physical) resistance to insects depends on plant structures that physically influence the insect's choice, movement, feeding, copulation or oviposition. These may include colour, trichomes (hairs), surface waxes, stone cells (sclereids) containing silicon, etc.

The colour of leaves, flowers, fruits and other plant organs is not random and has arisen at least in part in order to reduce attack by certain insect species.

Trichomes (hairs) influence the movement of insects, feeding and egg laying through their shape, density, length, etc.

The wax layer on the cuticle of leaves and other organs, in addition to protecting against excessive evaporation, serves as a physical barrier to a number of pathogens and repels pests.

Stone cells in fruits and other organs also play a role in plant resistance to insect attack.

Chemical defence mechanisms of plants

Since the late 17th century it has been known that plants contain toxic substances that are avoided by insects. As early as 1690 nicotine was extracted from tobacco and used as a contact insecticide, and later pyrethrin – from the flowers of pyrethrum (a species of chrysanthemum). Other remarkable examples include azadirachtin (from the tree *Azadirachta indica*), d-limonene from citrus, rotenone from the tree *Derris elliptica*, capsaicin from hot peppers, etc.

Today the diversity of known chemical defence substances in plants is enormous and exceeds tens of thousands, but in general they can be divided into 5 main groups: nitrogen compounds (mainly alkaloids), terpenoids, phenolics, protease inhibitors and substances that affect the endocrine system of insects.

Nitrogen compounds

Some nitrogen compounds, such as **non-protein amino acids**, act as *antimetabolites*. When ingested by insects they lead to disruption of metabolism. More often non-protein amino acids act as feeding deterrents (they impede the assimilation of nutrients from the ingested plant). They are common in seeds, which are usually a rich source of nutrients for phytophagous species.

Alkaloids are complex nitrogen bases with diverse molecular structure, occurring in many plants. Alkaloids are among the best-known toxins used for defence against insects. One of them – **nicotine** – has a long history as an insecticide. Another – **tomatine** – is the main alkaloid in tomatoes. The Colorado potato beetle is repelled by tissues containing tomatine and, if it feeds on them, mortality of the beetles is observed. The Colorado potato beetle usually does not attack tomatoes, but it heavily attacks the closely related potato, which, however, does not contain tomatine.

Terpenoids

Terpenoids are widespread and extremely diverse structurally and functionally. They function as attractants for pollinators, but also as feeding deterrents and as toxins. Geranium (*Pelargonium*) for example produces geraniol

in the petals for protection against beetles. About 30 minutes after ingestion the beetle is paralysed and remains so for several hours, during which time it falls prey to predators.

Resistance to noctuid moths of the genus *Heliothis* (cotton bollworm and others) is directly related to the content of **gossypol**.

The cotton leafhopper *Amrasca biguttula biguttula* shows 50% higher survival on susceptible cotton varieties and develops more rapidly. Although low-gossypol varieties have been bred for seed intended for food, in areas with heavy insect infestation varieties with high gossypol content should be preferred.

Cucurbitacins are triterpenoids that occur in the family Cucurbitaceae, impart a bitter taste and act as feeding deterrents for a large number of phytophages, but at the same time serve as attractants for cucumber beetles.

Other monoterpenes (pinene) provide protection for coniferous species against wood-boring insects and bark beetles. When the tree is attacked, the level of toxic or repellent monoterpenes in the resin increases.

Phenolics

Among the more important phenolics are the flavonoids. The isoflavonoid **rotenone**, which is extracted from the tree *Derris elliptica*, is used industrially as an insecticide. Other flavonoids are effective feeding deterrents because they have a bitter taste. **Tannins** are polymeric phenolic compounds that have strong protein-binding properties. **Proanthocyanidins** (condensed tannins) are feeding inhibitors and also reduce the digestibility of ingested food.

Protease inhibitors

Protease inhibitors suppress the action of proteolytic enzymes and reduce the amount of proteins that can be broken down and assimilated. On the other hand, they cause overproduction of digestive enzymes, which increases the loss of sulphur-containing amino acids. As a result, insects become weak, with suppressed growth and eventually die.

Protease inhibitors bind to the enzymes that cleave the peptide bonds of proteins and thus inhibit their proteolytic activity. In plants they are found in large quantities mainly in seeds and tubers, but are also present in leaves.

The level of protease inhibitors in potato plants increases when the plant is attacked by insects; even leaves distant from the site of attack respond. Leaves and other parts with increased levels of protease inhibitors are less digestible for phytophages. Some plants produce a variety of protease inhibitors, each with different specificity. Thus these plants have protection against a wide range of phytophages.

Growth regulators

Phytoecdysteroids are plant substances similar to ecdysone (the main hormone in insects). They were first discovered in the roots of ferns. The phytoecdysone content in some plants is surprisingly high. One gram of roots of oriental fern contains an ecdysone equivalent to 200 kg of pupae of the silkworm. Several dozen phytoecdysteroids have been isolated from more than 80 plant families.

The balsam fir *Abies balsamea* produces **juvabione** – a substance analogous to the juvenile hormone of insects. Other relatives of fir also release similar substances when attacked by aphids.

In the search for growth regulators from plants, W. Bowers isolated two interesting substances – **precocenes**, from the flower *Ageratum houstonianum*. When these precocenes come into contact with the insect's body surface, the cells of the corpora allata (the gland that produces the juvenile hormone) die. By destroying the source of the juvenile hormone, precocenes accelerate metamorphosis and result in premature, sterile adults.