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Plant Phenolics: Important Bio-Weapon against Pathogens and Insect Herbivores

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Plants represent a rich source of nutrients for many organisms including bacteria, fungi, insects, and vertebrates. Although, immune system is absent in plants but they have structural, chemical, and protein-based defense system to detect invading organisms and stop them before they are able to cause extensive damage. In order to protect from disease and insects plants produce a large variety of secondary metabolites viz. phenolics, flavonoids, terpenes, and alkaloids. Phenols possessed a hydroxyl functional group on an aromatic ring. These compounds play an important role in plant defense system against pathogens and insect herbivores.

Introduction

The term "phenolic" or "polyphenol" can be chemically defined as a substance which possesses an aromatic ring bearing one (phenol) or more (polyphenol) hydroxyl substituents, including functional derivatives (esters, methyl ethers, glycosides, etc.): as a general rule, the terms phenolics refers to all secondary metabolites arising biogenetically from the shikimate-phenylpropanoids-flavonoids pathway, producing monomeric and polymeric phenols and polyphenols.

Phenolics are well known anti-fungal, anti-bacterial and anti-viral compounds occurring in plants. According to Matern and Kneusal (1988), the first step of the defense mechanism in plants involves a rapid accumulation of phenols at the infection site. Phenols by their simple structure penetrate the microorganisms cause considerable damage to the cell metabolisms. Besides their involvement in plant- animal and/or plant-microorganism relationships, plant phenolics have also key roles as the major red, blue and purple pigments, as antioxidants and metal chelators, as signalling agents both above and below ground between plant and other organisms. Plant phenolics may be divided broadly in two classes: (i) preformed phenolics; that are synthesized during the normal development of plant tissues and (ii) induced phenolics; that are synthesized by plants in response to biotic and abiotic stresses.

Pre-formed disease resistance

Phenolics present in healthy, uninfected plant tissues, as preformed antimicrobial compounds, that inhibit the growth of fungi may include simple phenols, phenolic acids, and flavonols (Table 1) that helps to limit pathogen attachment, invasion and infection. The cell wall is a major line of defense against fungal and bacterial pathogens. It provides structural barrier that also incorporates a wide variety of chemical defenses that can be rapidly activated when the cell detects the presence of pathogens. Beside the cellulose cell walls also contain lignin, a heterogeneous polymer composed of phenolic compounds that gives the cell rigidity. Lignin is the primary component of wood, and cell walls that become "lignified" are highly impermeable to pathogens and difficult for small insects to chew. Tannins are water-soluble flavonoid polymers produced by plants and stored in vacuoles. Tannins are toxic to insects because they bind to salivary proteins and digestive enzymes including trypsin and chymotrypsin resulting in protein inactivation.

The distribution of pre-formed antifungal phenolics within plants is often tissue specific and there is a tendency for many lipophilic compounds (*e.g.*flavone and flavonols methyl ethers) to be located at the plant surface (*e.g.* in leaf wax and bud exudates) or in the cytoplasmic fraction within the epidermal cells, suggesting that they may indeed act as deterrents to pathogens. In general, however, preformed antifungal phenolics are commonly sequestered in conjugated form, usually with glycosidic attachments, in vacuoles or organelles in healthy plants. Biotrophs may avoid the release of preformed antibiotics by minimizing the damage to the host, whereas necrotrophs are likely to cause a substantial release of these compounds.

Induced disease resistance

Induced response to fungal infection includes phenolic phytoalexins, isoflavonoids, pterocarpans, furocoumarins, flavans, stilbenes, phenanthrene. All these compounds originate through different branches of the general phenylpropanoid pathway, leading to the elaboration of various hydroxycinnamic acids and derivatives with antifungal activity. Confrontation of many of these compounds with fungi *in-vitro* revealed their effectiveness in reducing fungal growth. Various studies indicated that hydroxyl-cinnamaldehydes are more fungitoxic than hydroxycinnamic acids and hydroxycinnamyl alcohols (Barber et al., 2000). In resistant plants, phenolic based defense responses are characterized by the early and rapid accumulation of phenolics at the infection site resulting in the effective isolation of the pathogen.

Phytoalexins are low-molecular-weight isoflavonoids with antibiotic and antifungal properties that are produced in response to pathogen attack. These toxic molecules disrupt pathogen metabolism or cellular structure but are often pathogen specific in their toxicity. Examples include medicarpin produced by alfalfa (*Medicago sativa*), and camalexin, produced by *Arabidopsis thaliana*. Furanocoumarins are phenolic compounds produced by a wide variety of plants in response to pathogen or herbivore attack. They are activated by ultraviolet light and can be highly toxic to certain vertebrate and invertebrate herbivores due to their integration into DNA, which contributes to rapid cell death. In fact, grapefruit juice contains small quantities of furanocoumarins, which greatly increase the absorption of certain drugs into the bloodstream from the intestines. Some medicines carry warning labels cautioning people to avoid drinking grapefruit juice while taking the drugs in order to avoid an accidental overdose.

If pre-existing antifungal phenolics are not sufficient to stop the development of the infectious process, plant cells usually respond by increasing the level of pre-existing antifungal phenols at the infection site, after an elicited increased activity of the key enzymes (Phenylalanine ammonia lyase and chalcone synthase) of the biosynthetic pathway. The increased level of phenolics provides an adequate substrate to oxidative reactions catalysed by polyphenoloxidases (PPO) and/or peroxidase (POD) that, consuming oxygen and producing fungi toxic quinones, make the medium unfavourable to the further development of pathogens.

Table 1: Sources and uses of phenolics compound

Class	Compounds	Sources	Some Effects and Uses
Phenolic acids	caffeic, chlorogenic	All plants	Cause oxidative damage, browning in fruits and wine
Coumarins	umbelliferone	Carrots, parsnip	Cross-link DNA, block cell division
Lignans	podophyllin urushiol	Mayapple	Cathartic, vomiting, allergic dermatitis
Flavonoids	anthocyanin, catechin	Almost all plants	Flower, leaf color; inhibit enzymes, anti- and pro-oxidants, estrogenic
Tannins	gallotannin, condensed tannin	Oak, hemlock trees, birdsfoot trefoil, legumes	Bind to proteins, enzymes, block digestion, antioxidants
Lignin	lignin	All land plants	Structure, toughness, fiber

The role of phenolics in plant-insect interactions

The ecological relationship between plants and insects is a complex one with physical as well as chemical interactions. Plant constituents that make unpalatable a host are secondary metabolites in sufficient concentration to exert an undesirable physiological effect. Such a plant protected from the attacks of phytophagous insects, would in a sense have entered a new adaptive zone. Therefore, plant secondary compounds have received much attention as proximate and ultimate determinants of host-plant range in phytophagous insects.

The strategies employed by plants to attempt to resist or evade their insect herbivores are very diverse. Some species accumulate high levels of compounds which function as biochemical defences through their toxicity, or their physical properties; other plants do not commit resources to the accumulation of defensive compounds, but seek to minimise herbivore damage through rapid growth and development, dispersion, or choice of habitat.

Defence mechanisms can be described as ‘static’ or constitutive, in contrast to ‘active’ or induced mechanisms in which the synthesis of defensive compounds is induced in response to insect attack. A constitutive defence is often the causative factor in examples where specific plant hosts are fully resistant to attack by specific insect pests. The defence can act as a physical barrier, as in lignification or resin production, or can act as a biochemical signal perceived by the herbivore, as in deterrents of feeding or egg deposition, or can act as a toxin. The range of mechanisms of toxicity shown by different plant defensive compounds is very wide, and includes membrane disruption, inhibition of transport or signal transduction, inhibition of metabolism, and even disruption of hormonal control of developmental processes (Gatehouse, 2002).

It is also true that the effectiveness of phenolics as a resistance factors to insect feeding is enhanced by oxidation to polymers, which reduce digestibility, palatability and nutritional value. Thus high levels of PPO, the major phenolic oxidising enzyme of plants, can be correlated with plant resistance mechanisms against insects. Polyphenol oxidases, presumed an anti-herbivore and anti-nutritive enzymes that decrease the nutritive value of wounded plant tissues by cross-linking proteins or catalyzing the oxidation of phenolic toxic metabolites to reactive and polymerizing quinones.

Phenolic compounds and plant defence

Plants encounter numerous pests and pathogens in the natural environment. An appropriate response to attack by such organisms can lead to tolerance or resistance mechanisms that enable the plant to survive. Resistance mechanisms refer to traits that inhibit or limit attack, while tolerance strategies do not limit attack but reduce or offset consequences on the plant fitness by adjusting its physiology to buffer the effects of herbivory or diseases. Resistance strategies include physical and/or chemical barriers, mechanisms that rapidly clear infection or herbivory (hypersensitive response), and processes that limit the spread of damage within the host (such as localized cell death). Tolerance often involves some degree of compensation for disease damage. Plants can tolerate infection or herbivory by increasing the chlorophyll concentration in leaves, increasing the size of new leaves or the number of new branches, advancing the timing of bud break, delaying the senescence of infected tissues, and increasing the nutrient uptake (Dietrich *et al*., 2005) Most plants produce a broad range of secondary metabolites that are toxic to pathogens and herbivores, either as part of their normal program of growth and development or in response to biotic stress. Preformed antibiotic compounds that occur constitutively in healthy plants are likely to represent inbuilt chemical barriers to herbivorous and fungal enemies and may protect plants against attack by a wide range of potential pests and pathogens.

Conclusion

Plant Phenolics are secondary metabolites involved in the defence mechanisms against microbial pathogens, various environmental stresses and insect herbivores. Plants respond to diverse environmental enemies with a bewildering array of responses, which use constitutive and induced phenolic substances affecting the susceptibility/resistance characteristics of the host plant. Phenols by their simple structure penetrate the microorganisms cause considerable damage to the cell metabolisms. Plant phenolics act as detereent, repellent and enzyme inactivator for insect herbivores. The production of defensive compounds by plants carries a metabolic penalty, and the balance between induced and constitutive defences can be altered by both genotype and environment.

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