Metabolites: Primary vs Secondary

Metabolites are compounds synthesized by plants for both essential functions, such as growth and development (primary metabolites), and specific functions, such as pollinator attraction or defense against herbivory (secondary metabolites).

Metabolites are organic compounds synthesized by organisms using enzyme-mediated chemical reactions called metabolic pathways. Primary metabolites have functions that are essential to growth and development and are therefore present in all plants. In contrast, secondary metabolites are variously distributed in the plant kingdom, and their functions are specific to the plants in which they are found.

Secondary metabolites are often colored, fragrant, or flavorful compounds, and they typically mediate the interaction of plants with other organisms. Such interactions include those of plant-pollinator, plant-pathogen, and plant-herbivore.

**Primary Metabolites**

Primary metabolites comprise many different types of organic compounds, including, but not limited to, carbohydrates, lipids, [proteins](http://lifeofplant.blogspot.com/2011/01/proteins-and-amino-acids.html), and [nucleic acids](http://lifeofplant.blogspot.com/2011/03/nucleic-acids.html). They are found universally in the plant kingdom because they are the components or products of fundamental metabolic pathways or cycles such as glycolysis, the Krebs cycle, and the Calvin cycle.

Because of the importance of these and other primary pathways in enabling a plant to synthesize, assimilate, and degrade organic compounds, primary metabolites are essential.

Examples of primary metabolites include energy rich fuel molecules, such as sucrose and starch, structural components such as cellulose, informational molecules such as DNA (deoxyribonucleic acid) and [RNA](http://lifeofplant.blogspot.com/2011/01/rna.html) (ribonucleic acid), and pigments, such as chlorophyll. In addition to having fundamental roles in plant growth and development, some primary metabolites are precursors (starting materials) for the synthesis of secondary metabolites.

**Secondary Metabolites**

Secondary metabolites largely fall into three classes of compounds: alkaloids,terpenoids, and phenolics. However, these classes of compounds also include primary metabolites, so whether a compound is a primary or secondary metabolite is a distinction based not only on its chemical structure but also on its function and distribution within the plant kingdom.

Many thousands of secondary metabolites have been isolated from plants, and many of them have powerful physiological effects in humans and are used asmedicines. It is only since the late twentieth century that secondary metabolites have been clearly recognized as having important functions in plants.

Research has focused on the role of secondary metabolites in plant defense. This is discussed below with reference to alkaloids, though it is relevant to many types of secondary metabolites.

**Alkaloids**

Alkaloids are a large group of nitrogen-containing compounds, examples of which are known to occur in approximately 20 percent of all flowering plants. Closely related plant species often contain alkaloids of related chemical structure.

The primary metabolites from which they are derived include amino acids such as tryptophan, tyrosine, and lysine. Alkaloid biosynthetic pathways can be long, and many alkaloids have correspondingly complex chemical structures.

Alkaloids accumulate in plant organs such as leaves or fruits and are ingested by animals that consume those plant parts. Many alkaloids are extremely toxic, especially to mammals, and act as potent nerve poisons, enzyme inhibitors, or membrane transport inhibitors.

In addition to being toxic, many alkaloids are also bitter or otherwise bad-tasting. Therefore, the presence of alkaloids and other toxic secondary metabolites can serve as a deterrent to animals, which learn to avoid eating such plants.

Sometimes domesticated animals that have not previously been exposed to alkaloid-containing plants do not have acquired avoidance mechanisms, and they become poisoned.

For example, groundsel contains the alkaloid senecionine, which has resulted in many recorded cases of livestock fatalities due to liver failure. More frequently, over time, [natural](http://knowaboutcats.blogspot.com/2010/12/all-natural-extermination.html) selection has resulted in animals developing biochemical mechanisms or behavioral traits that lead to avoidance of alkaloid-containing plants.

In other, more unusual cases, animals may evolve a mechanism for sequestering (storing) or breaking down a potentially toxic compound, thus “disarming” the plant.

For instance, caterpillars of the cinnabar moth can devour groundsel plants and sequester senecionine without suffering any ill effects. Moreover, the caterpillars thereby acquire their own weapon against predators: the plant-derived alkaloid stored within their bodies.

Over [time](http://knowaboutcats.blogspot.com/2010/11/alphabet-soup-time.html), plants acquire new capabilities to synthesize additional defense compounds to combat animals that have developed “resistance” to the original chemicals. This type of an “arms race” is a form of coevolution and may help to account for the incredible abundance of secondary metabolites in flowering plants.

**Medicinal Alkaloids**

Many potentially toxic plant-derived alkaloids have medicinal properties, as long as they are administered in carefully regulated doses. Alkaloids with important medicinal uses include morphine and codeine from the opium poppy and cocaine from the coca plant. These alkaloids act on the nervous system and are used as painkillers. Atropine, from the deadly nightshade plant, also acts on the nervous system and is used in anesthesia and ophthalmology.

Vincristine and vinblastine from the periwinkle plant are inhibitors of cell division and are used to treat cancers of the blood and lymphatic systems. Quinine from the bark of the cinchona tree is toxic to the Plasmodium parasite, which causes [malaria](http://insectspedia.blogspot.com/2010/08/malaria.html), and has long been used in tropical and subtropical regions of the world.

Other alkaloids are used as stimulants, including caffeine, present in coffee, tea, and cola plants (and the drinks derived from these plants), and nicotine, which is present in tobacco. Nicotine preparations are, paradoxically, also used as an aid in smoking cessation. Nicotine is also a very potent [insecticide](http://insectspedia.blogspot.com/2010/09/insecticides.html).

For many years ground-up tobacco leaveswere used for insect control, but this practice was superseded by the use of special formulations of nicotine. More recently the use of nicotine as an insecticide has been discouraged because of its toxicity to humans.

**Terpenoids**

Terpenoids are derived from acetyl coenzyme A or fromintermediates in glycolysis. They are classified by the number of five-carbon isoprenoid units they contain. Monoterpenes (containing two C5- units) are exemplified by the aromatic oils (such as menthol) contained in the leaves of members of the mint family. In addition to giving these plants their characteristic taste and fragrance, these aromatic oils have insect-repellent qualities.

The pyrethroids,which are monoterpene esters from the flowers of chrysanthemum and related species, are used commercially as insecticides. They fatally affect thenervous systems of insects while being biodegradable and nontoxic to mammals, including humans.

Diterpenes are formed from four C5-units. Paclitaxel (commonly known by the brand name Taxol), a diterpene found in bark of the Pacific yew tree, is a potent inhibitor of cell division in animals. At the end of the twentieth century, paclitaxel was developed as a powerful new chemotherapeutic treatment for people with solid tumors, such as ovarian cancer patients.

Triterpenoids (formed from six C5- units) comprise the plant steroids, some of which act as plant hormones. These also can protect plants from insect attack, though their mode of action is quite different from that of the pyrethroids.

For example, the phytoecdysones are a group of plant sterols that resemble insect molting hormones. When ingested in excess, phytoecdysones can disrupt the normal molting cyclewith often lethal consequences to the insect.

Tetraterpenoids (eight C5- units) include important pigments such as beta-carotene, which is a precursor of vitamin A, and lycopene, which gives tomatoes their red color.

Rather than functioning in plant defense, the colored pigments that accumulate in ripening fruits can serve as attractants to animals,which actually aidthe plant in seed dispersal.

The polyterpenes are polymers that may contain several thousand isoprenoid units.[Rubber](http://lifeofplant.blogspot.com/2011/01/rubber.html), a polyterpene in the latex of rubber trees that probably aids in wound healing in the plant, is also very important for the manufacture of tires and other products.

**Phenolic Compounds**

Phenolic compounds are defined by the presence of one or more aromatic rings bearing a hydroxyl functional group. Many are synthesized from the amino acid phenylalanine.

Simple phenolic compounds, such as salicylic acid, can be important in defense against fungal pathogens. Salicylic acid concentration increases in the leaves of certain plants in response to fungal attack and enables the plant to mount a [complex](http://trytostayhealthy.blogspot.com/2010/12/vitamin-b-complex.html)defense response.

Interestingly, aspirin, a derivative of salicylic acid, is routinely used in humans to reduce inflammation, [pain](http://trytostayhealthy.blogspot.com/2011/02/pain.html), and fever. Other phenolic compounds, called isoflavones, are synthesized rapidly in plants of the legume family when they are attacked by bacterial or fungal pathogens, and they have strong antimicrobial activity.

Lignin, a complex phenolic macromolecule, is laid down in plant secondary cell walls and is the main component of wood. It is a very important structural molecule in all woody plants, allowing them to achieve height, girth, and longevity.

Lignin is also valuable for plant defense: Plant parts containing cells with lignified walls are much less palatable to insects and other animals than are nonwoody plants and are much less easily digested by fungal enzymes than plant parts that contain only cells with primary cellulose walls.

Other phenolics function as attractants. Anthocyanins and anthocyanidins are phenolic pigments that impart pink and purple colors to flowers and fruits. This pigmentation attracts insects and other animals that move between individual plants and accomplish pollination and fruit dispersal.

Often the plant pigment and the pollinator’s visual systems are well matched: Plants with [red](http://lifeofplant.blogspot.com/2011/01/red-algae.html) flowers attract birds and mammals because these animals possess the correct photoreceptors to see red pigments.