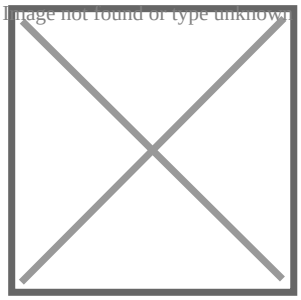
Mother Nature? More like ‘Mad Scientist Mama’—creator of chemicals good and bad for humans

We frequently see a contrast drawn between what is “natural” and what is “chemical.” Sometimes products are described as “chemical-free” even though every physical object is made of chemicals. As much as this suggests a problem with our science education, it speaks to a missed opportunity for wonder. Nature is not some sort of cosmic mother figure; on the contrary, nature is composed of diverse biological and physical processes, including some pretty amazing examples of chemistry continually taking place. If we indulge the human personification of nature and its “children” a bit, we could say the following about these “chemists”:

- They are extremely creative.
- They can make really complex molecules.
- Some of their chemicals last a really long time – which is sometimes good and sometimes bad.
- They are really good at making polymers.
- They make some extremely toxic things.

I’ll give a few examples below.

Creative natural chemistry



Steve Savage

The diversity of naturally-occurring chemicals is staggering. Humans regularly take advantage of this, particularly when we need ideas for things like pharmaceuticals or crop protection products. Sometimes we extract the chemicals from a plant or other living thing. Often we grow tanks of microbes to harness their ability to make a chemical we find useful. In cases where the amounts of the chemical are too small to be practical from the natural source, human chemists can synthesize the same compound to fulfill the quantity needed. An example of this is a new potato sprout inhibitor. In many other instances, a natural chemical serves as the inspiration for human chemists to experiment with similar structures leading to the discovery of particularly useful drugs, fungicides, etc.

nature ideas

Taxol structure image by Calvero. Pacific Yew tree image by Jason Hollinger via creative commons. Azoxystrobin fungicide structure by

Yikrazuul. Strobilurus tenacellus mushroom picture by Tatiana Bulyonkova at Mushroom Observer.

Complex natural chemistry

Some of the most abundant chemicals in nature are simple. Nearly 80% of the air we breathe is nitrogen in the form, N_2 – just two nitrogen atoms bonded together. Nitrogen goes through natural cycles that are important to all living things but often stays in relatively uncomplicated forms like ammonia (NH3) or nitrate (NO3). On the other hand, natural chemicals can be complex, so much so that it would be challenging for even a skilled human chemist to make them.

One of these complex examples is called *spinosad* and it is produced by a microbe called an *actinomycete* . We have found this to be a particularly effective insecticide for use on crops yet quite benign for the environment and not toxic to people. The chemical company that produces this for farmers relies on the natural microbe to produce this complicated bit of chemistry.

spinosad

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Structure of Spinosyn image by Capaccio via creative commons.

Long-lived natural chemicals

Most naturally-occurring chemicals are part of a cycle in which chemicals combine, making a material, but then eventually break back down into basic constituents to begin the cycle again. Some naturally-produced chemicals are relatively long-lived. This can be a good thing in the case of the chemicals that are found in the organic matter of a healthy, undisturbed soil. These are not just any plant or microbial product; they are specific compounds that slowly cascade through a series of breakdown products.

For instance, plants make a group of complex, phenolic chemicals, called *lignin*, which are important for strengthening their cell walls. Lignin is quite resistant to microbial breakdown, although some fungi can

and do destroy it, even as they decompose wood. Lignin is a major component of what is termed *humus* – the component of soil that helps to buffer nutrients and retain moisture. When soils are converted from wild land to cultivation, there is a dramatic increase in the rate of breakdown of these chemicals and thus the release of the carbon dioxide.

Some long-lived, natural chemicals, however, are less desirable. Under low oxygen conditions, soil-dwelling microbes can interconvert forms of nitrogen (e.g. ammonia to nitrate or nitrate to nitrogen gas). In that process, they "accidentally" make some nitrous oxide (N_2O). Nitrous oxide is around 300 times more potent than carbon dioxide as a greenhouse gas because it lasts longer in the atmosphere. Unfortunately, human activity can exacerbate the production of this naturally-generated chemical from farmed soils. Adjustments in farming practices can lead to a better balance of the production of natural chemicals that help or hurt greenhouse gas levels.

Fancy polymeric natural chemicals

In the 1967 movie *The Graduate*, the character played by Dustin Hoffman is lectured about how the future is going to be all about plastics. Indeed, many people were excited in that era about polymers that chemists were developing, like nylon and polyester. These are based on long chains of *monomers* attached end to end.

Many of the most abundant natural chemicals on earth are also *polymers*, which are long chains made of simple sugar molecules. Depending on which sugar and how the sugars are linked together, the polymers result in anything from the cellulose that makes cotton fiber to wood or even the alginate from seaweed we use for thickening foods or the starch that is the primary energy source in foods like pasta, bread, rice or potatoes. Increasingly, we are tapping in to the enzymatic tools found in microbes in order to make polymers from renewable resources.

Toxic chemistries

Most people associate the term *natural* with the terms *safe* and *wholesome*. This impression has been created by decades of marketing, not by any understanding of the chemicals in nature. Many natural chemicals are perfectly benign; however, nature's assortment of chemicals also includes many that are toxic by various mechanisms. Lots of plants make chemicals to protect themselves from being eaten or otherwise bothered. We have all heard about nasty plants like poison ivy or even lovely plants like the Colorado Columbine which are dangerous to eat.

nature toxic

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Cut Granny Smith apple image from Wikimedia. Cauliflower image from Calliope via creative commons. Hot pepper image by Andre Karwath via creative commons. Capsaicin structure by Jurgen Martens. Nicotine structure by NEUROtiker. Cyanide structure via Wikimedia.

Food plants also make some fairly toxic chemicals. The seeds of many familiar crops, including apples, cherries and peaches to name a few, contain a chemical storage component called a *cyanogenic glycoside*. When the seed is damaged, enzymes release hydrogen cyanide from the glycoside. Hydrogen cyanide is very toxic! It is a good reason not to eat those seeds, although it would take a lot of such seeds to hurt a person. The capsaicin that we enjoy in hot sauce is an insect protection chemical made by the pepper plant to defend itself. It is moderately toxic to us but not at the doses we normally consume. Quite a few plants make nicotine to ward off insects including tomatoes, cauliflower and eggplant. Nicotine is very toxic but not at the doses these crops produce. As with any toxic chemical, natural toxins are only an issue to humans at a certain dose.

Some natural chemicals, however, are extremely dangerous and we don't want those in our food. *Mycotoxins* are a particularly nasty category of natural chemicals produced by certain fungi. One such chemical, called *aflatoxin*, is among the more toxic chemicals in existence and is also a potent carcinogen. Unfortunately, under certain circumstances, fungi can produce aflatoxin in food crops. In the developed world, a system of controls and testing keeps us well protected from this; in the developing world, though, aflatoxin is a major cause of death both through acute and chronic effects because it contaminates staple foods like corn or groundnuts.

nature aflatoxin

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Aspergillus infected groundnut image from International Institute of Tropical Agriculture. Aflatoxin structure by Ju

Some natural chemicals are elegantly selective in their toxicity. A soil bacterium, called *Bacillus* thuringiensis (usually called “Bt”), makes proteins that are specific in their toxicity to only certain categories of insects. One strain of Bt makes proteins that only effect beetles while another’s toxin only affects caterpillars. None of these Bt proteins are toxic to humans or almost anything else. We have made excellent use of these natural chemical toxins as sprayable insect controls and by genetically engineering plants to make their own supplies of the protein resulting in the plant being insect resistant.

Conclusion

Yes, nature does a great deal of chemistry. For us, these chemicals can be a source of good things, a source of good ideas, and sometimes a hazard or problem.

A version of this article appeared on the GLP on March 23, 2017 after appearing on the Putting Pesticides In Perspective blog. It was reposted with permission.

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