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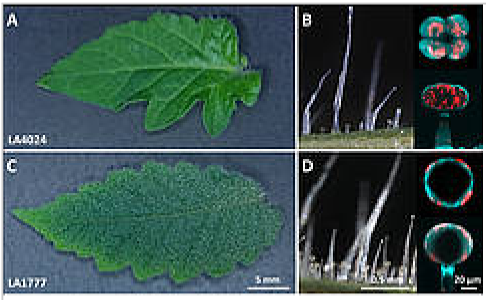
Energy for chemical barriers

Central carbon and energy metabolism of trichomes illuminated / IPB Press release, 13.6.2017



Glandular trichomes of cultivated tomato *Solanum lycopersicum* (**A**) and wild-growing tomato species, *Solanum habrochaites* (**C**). Also the respective microscopic images (**B and D**) show clearly: Wild tomatoes form more trichomes, which can also hold more volumes. Wild tomatoes also produce other types of defense metabolites and are therefore much more resistant to herbivores than their cultivated relatives.

The stinging nettle teaches a painful lesson: Plants can form numerous active substances to ward off herbivores and insects. In approximately 30 percent of all rooted plants, the biosynthesis of defense substances takes place in small glandular hairs on the leaves and stems called glandular trichomes. Glandular trichomes are highly effective plant factories for the production of bioactive compounds. They need a great deal of energy and a large pool of carbon compounds as raw materials for biosynthesis to produce their substances. Scientists at the Leibniz Institute for Plant Biochemistry in Halle (Saale), Germany have now illuminated the energy and metabolism flows in the glandular trichomes of tomato plants. The result of their work, recently published in *Plant Cell*, leads to an initial general model of the central energy and carbon metabolism in trichomes. Initial indications were also found of genetic differences between cultivated and wild tomatoes, apparently established in the course of breeding, that could explain the limited production of defensive substances in the trichomes of cultivated tomatoes.

Mint, rosemary, and sage along with numerous other plant species also possess the productive glandular trichomes. Many substances used by these plants as defense mechanisms are of high economic value for humans as pharmaceutical active ingredients, but also flavors and scents in the food and cosmetics industries. Since these bioactive substances are not essential for the immediate survival of the plant, they are considered secondary plant compounds and their biosynthesis accordingly takes place in a plant's secondary metabolism. All secondary compounds – including those produced in trichomes – exhibit large chemical diversity. The spectrum of the produced substances can vary greatly depending on the plant species.

While a few studies of the species-specific composition and synthetic pathways of secondary compounds produced in trichomes have already been conducted, the sources that the glandular trichomes draw on to obtain energy and the basic carbon components required for their extreme metabolic activity have never been clarified. This gap has now been closed by the plant experts in Halle under Professor Alain Tissier. The scientists in their comprehensive analysis found some circumstances specific to trichomes that do not apply for the rest of the plant.

General surveys of the activated genes (*transcriptomics*), the proteins that are present – primarily the required metabolic enzymes (*proteomics*) – and the corresponding substances that are produced (metabolites → *metabolomics*) were conducted in the experiment on isolated glandular trichomes of the tomato compared to normal leaf cells without trichomes. The result of this *multi-omics approach*: Most of the required energy is produced by the trichomes themselves through photosynthesis. Accordingly, the energy from sunlight flows directly into the biosynthesis pathways of the secondary and defense metabolism. In normal leaf cells on the other hand, the energy from photosynthesis tends to be used to integrate carbon dioxide from the air into the basic organic compounds of the primary metabolism.

Thus, green cells without trichomes use photosynthesis to produce sugar, starch, and cell wall components. As a consequence the plant produces biomass and grows. This contribution to growth, the production of the basic organic compounds sugar and starch, is considerably reduced in the trichomes. The plant experts in Halle were able to prove that the production of the required enzymes is significantly reduced in the glandular trichomes. However, sugar is urgently needed in trichomes as well: the trichome cells use it to obtain additional energy and all raw materials for the special biosynthesis pathways of their secondary metabolism. With the help of ^{13}C carbon isotopes, the scientists proved that the trichomes receive a steady supply of sugar from the adjacent leaf cells.

The increased formation of reactive oxygen species (ROS) that are highly reactive and therefore damage cells and membranes is also typical for cells with high metabolic activity. These oxidants are deactivated through the oxidation of very long-chained and polyunsaturated fatty acids that are produced in large quantities by glandular trichomes. This detoxification mechanism appears to be specific to glandular trichomes. A second neutralization mechanism using the central detoxification substance glutathione is known from both leaf cells and trichome cells. However, it is only activated after oxidative stress in leaf cells while it is always active in the trichomes.

Wild tomato *versus* cultivated tomato
In addition to the analyses of trichomes and normal leaf cells, the trichome metabolism of cultivated and wild tomatoes was compared. Wild tomatoes produce far more and somewhat different secondary metabolites in their trichomes than their cultivated relatives. They form fewer and smaller fruits than cultivated tomatoes, but are much more resistant against insect damage. It appears that cultivated tomatoes have lost the genetic material that leads to the production of certain defense substances in the course of breeding aimed at selecting for yield. Comparing the collected data revealed initial indications of corresponding genes that are present in wild tomatoes but no longer found or less active in cultivated tomatoes. These genes for example encode certain carrier proteins internal to trichomes that permit the timely delivery of raw materials to the biosynthesis site.

A better understanding of the trichome metabolism is the first prerequisite for breeding new cultivated varieties with greater resistance against aggressors and for the use of biotechnology to produce economically significant plant secondary compounds in bacteria or yeast.

Publication:
Gerd U. Balcke, Stefan Bennewitz, Nick Bergau, Benedikt Athmer, Anja Henning, Petra Majovsky, José M. Jiménez-Gómez, Wolfgang Hoehenwarter & Alain Tissier: Multiomics of Tomato Glandular Trichomes Reveals Distinct Features of Central Carbon Metabolism Supporting High Productivity of Specialized Metabolites, Plant Cell 2017, doi:10.1105/tpc.17.00060.

Contact:
Prof. Alain Tissier
Head of the Department Cell and Metabolic Biology
Phone.: +49 345 5582 1500
alain.tissier@ipb-halle.de