

Plantindustrial

Linking Plant and Industrial Biotechnology

Evolution – Life on Earth evolved from a mélange of chemical compounds via microbial organisms and algae towards plants. During this process, evolutionary pressure has driven plants to develop an extremely efficient catabolic system, producing a huge variety of high value substances in their complex secondary metabolism. The very same natural laws are underlying chemical processes.



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reduce the ecological impact of chemical industry and improve economical rewards. Today, the chemical industry is still a raw material and energy intensive industry. Due to the scarcity of fossil resources, steadily increasing oil price and a need to reduce greenhouse gases, renewable resources from plants will be an increasingly important issue for the chemical industry over the coming years.

The usage of fermentation is only the first step to a sustainable chemistry and should be followed by an implementation of knowledge from plant science in a synergistic process to

Germany, fourth in the world for the production of chemicals, will take a leading role in these efforts because of the high investments of the chemi-

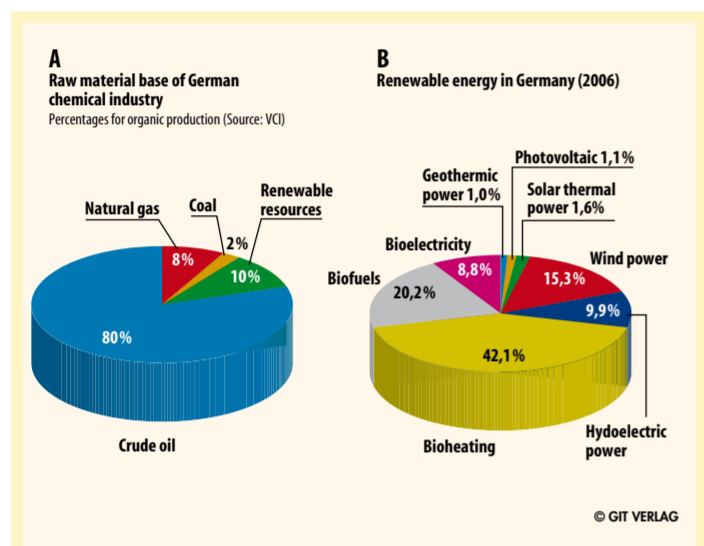


Fig. 1: A) Raw material basis of the German chemical industry; currently more than two million tons of renewable raw materials are used in German chemical industry. One third originates from home market. B) In 2006, about 200 TWh of German final energy consumption came from renewable, with 70% coming from bio sources.

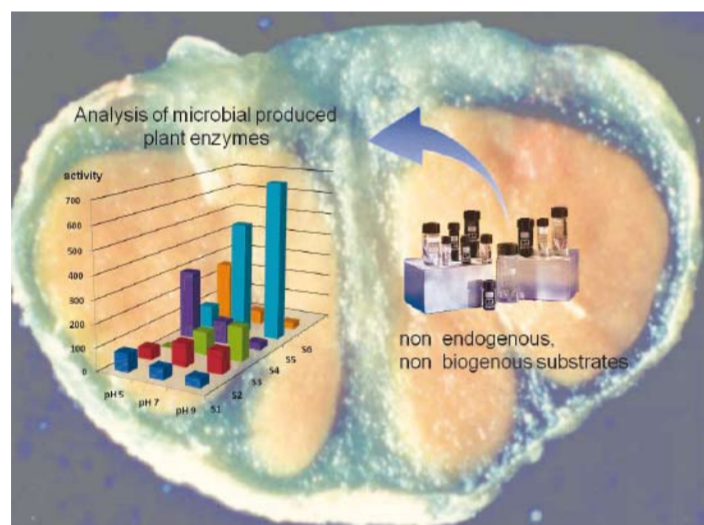


Fig. 2: Diversity of plant enzyme activities concerning substrate, co-factor and pH specificity. Shoot nodules of the leguminous plant *Sesbania rostrata* with the symbiotic bacterium *Azorhizobium caulinodans*.

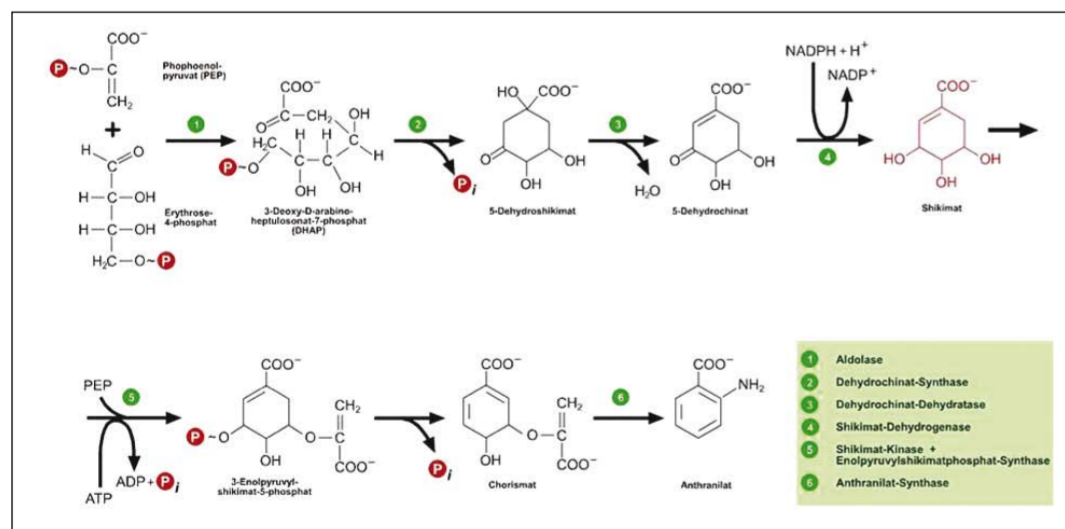


Fig. 3: Shikimi pathway in plants for the production of aromatic substances from sugars.

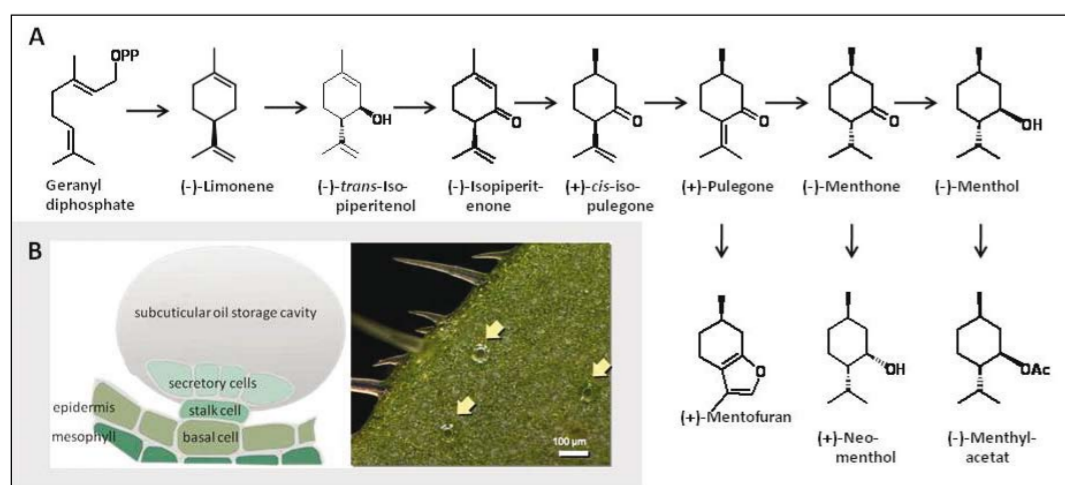


Fig. 4: A) Principal pathway of monoterpene biosynthesis in mint plants. Over several enzymatic steps the precursor geranylpyrophosphate is converted to menthol B) Trichomes of peppermint (mentha)

cal industry in R&D. Already around 10% of basic material for the chemical industry and 70% of the renewable energy in Germany stems from renewable resources, mainly plant material (fig. 1).

A World Of Enzymes

The sustainability of chemical processes, especially those where chiral products are synthesized, can be increased by the use of fermentation processes or direct biocatalytic steps. Unlike most chemical reactions, biocatalytically driven reactions are highly stereo-selective for the substrate and the resulting product due to the intrinsic properties of the involved enzyme activities resulting in particularly high substrate and reaction specificities (fig 2).

In addition, natural enzyme-based processes operate at lower temperatures and produce less toxic waste and fewer emissions than complex conventional chemical processes, e.g. the conversion of elemental nitrogen to ammonium is done by plants in symbiosis with bacteria at room temperature and normal pressure, whereas the chemical process demands high pressure and temperature, and metal catalysts (Haber-Bosch process).

The symbiotic process of nitrogen fixation is an example where nature leads the way to a strong collaboration between plant and microbial processes

solving hardy problems in an elegant way. This has been the model for our motto "plantindustrial – linking plant and industrial biotechnology" and is intended to result in a strong interdisciplinary collaboration with a high synergistic potential, e.g. to produce aromatic substances in a sustainable fermentation process.

The Shikimi pathway, in plants synthesizing Anthranilate out of Erythrose, serves as paradigm which waits to be converted into a fermentation process (fig. 3). Enzymatic reactions in fermentation or biocatalysis may also work effectively even using raw materials of lower purity because of the precise selectivity for the substrate structures. One of the best known examples is the production of vitamin B2 by BASF. The complex chemical synthesis of vitamin B2 requires eight steps and was replaced in 1990 by a fermentative one-step process using soya oil and enzymes of the fungus *Ashbya gossypii*. This process had considerable advantages over the traditional, petrochemical method in that it led to a 95% reduction of waste, a 30% reduction of CO₂ emissions and a 60% reduction in the amount of resources required. In total, the costs for the production of vitamin B2 could be reduced by 40%.

In another example where plant secondary metabolism and microbial fermentation is synergistically combined, steroid hormones are produced out of phytosterols. A fermentation process by Bayer-Schering uses a complex plant metabolite and converts it by a single step microbial fermentation into the desired end product.

New Pathways

Until now, microorganisms, such as fungi and bacteria were used as the main sources for enzymes. The growing complexity of reactions required for the production of fine chemicals, especially for the pharmaceutical industry, draws the attention of industrial biotechnology more and more to plants. The high complexity of plants' secondary metabolism – thus demonstrating the huge number and synthetic abilities of the plant enzymes – as well as the fact that most of today's small molecule drugs (SMDs) can be traced back to a plant metabolites as the basic structure, are certainly major reasons for this development. Moreover, nature has optimized plant enzymes to work best at relatively low temperatures. Their use therefore opens new chances for energy reduction in novel industrial applications. Besides their unmatched range of biosynthetic pathways and reaction mechanisms, plants have found during their long lasting evolution

on earth unique possibilities to produce, store and enrich even highly toxic substances by utilizing compartmentalisation, as well as specialized cell organelles or special tissues like trichomes in mint species (fig. 4 B).

In fact, compartmentalisation of biosynthetic reactions within plant cells is another key factor for solutions delivered by plants, e.g. for the synthesis of hydrophobic products and intermediates. Plants can be used as models to develop reaction compartments to produce a desired product at room temperature and normal pressure and have the blueprint for the required enzyme. Plants are especially potent in synthesizing a class of substances called terpenes e.g. carotinoids are well known representatives of this class. Another important class are monoterpenes produced by mint plants which have been utilised for industrial purposes for a long time (fig. 4).

The understanding of the underlying genetic and biosynthetic regulation, of the interaction of compartments and organelles, and of the sequen-

tial synthesis steps involving a multitude of different reaction conditions (oxidative, reductive, high or low pH) in mitochondria, plastids, peroxisomes, the cytosol or the ER will open new routes and possibilities to produce a vast amount of complex chemical products that until now have not been possible with classical chemical or enzymatic methods.

It is most important to note that usage of plant enzymes and their biosynthetic abilities is not restricted to the use of whole plant systems (e.g. as bioreactors). Through the targeted use of biotechnology and biodiversity, Phytowelt GreenTechnologies isolated plant genes and optimised their coding regions to produce enzymes in microorganisms with specificities and stabilities tuned to particular industrial purposes.

The Future

The formation of diversified clusters with partners from academia, large international corporations and SMEs are very important for further exploita-

tion of the hidden treasures of plants. Good examples for such activities are the Cluster Industrielle Biotechnologie 2021 (CLIB2021) and the European Technology Platform for sustainable Chemistry (SusChem) with its German affiliation SusChemD, a combined initiative of Dechema and VCI.

These clusters with a broad array of technologies and the implementation of substantial information available from plants will enable partners to generate value over the whole supply chain, improving sustainability and the impact of renewable resources, reducing cost and time to market by a synergistic approach of microbial and plant science as demonstrated by nature in symbiotic nitrogen fixation.

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