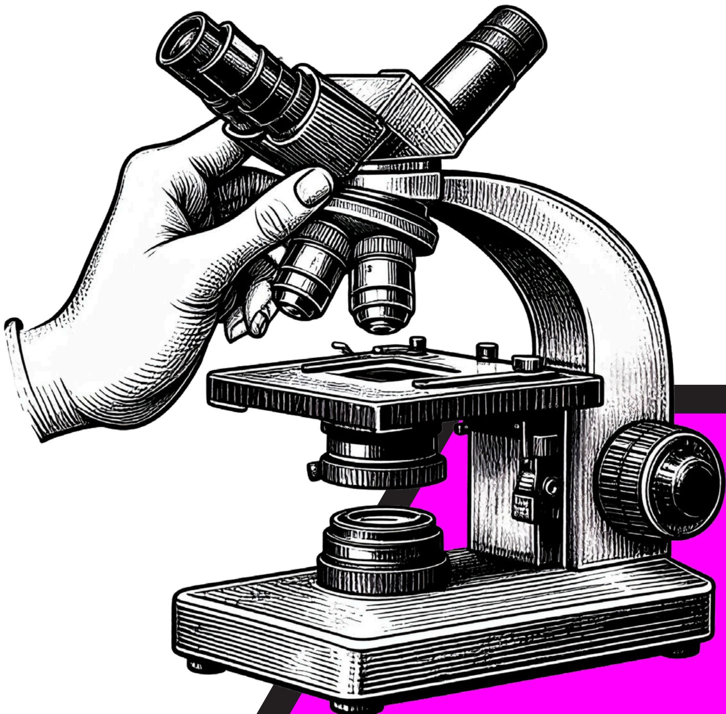

REAL WORLD CHANGES

SOCIETY FOR EXPERIMENTAL BIOLOGY AUTUMN 2025

BY FEDERICA BRANDIZZI, JENNY MORTIMER, AND KATHERINE DENBY

The Plant Journal

Plant genetic engineering has transformed our ability to study gene function and improve crop performance, enabling innovations in agriculture, synthetic biology, and biotechnology. Advances in plant transformation technologies have made it possible to introduce precise genetic modifications that enhance plant growth, stress tolerance, biosynthetic pathways, and reproductive strategies. However, the efficiency, scalability, and genotype flexibility of transformation techniques still limit the broad application of gene editing and synthetic biology tools, both in model species and in agriculturally important crops. A special issue of The Plant Journal, published earlier this year (https://onlinelibrary.wiley.com/doi/toc/10.1111/(ISSN)1365-313X.plant-engineering-advances), brought together a diverse collection of articles that explore the state of plant transformation technologies, strategies for overcoming current bottlenecks, and emerging opportunities in gene editing, synthetic biology, and alternative plant engineering approaches, all with a view to plant engineering contributing to global challenges, such as sustainable food production and a thriving bioeconomy.

One of the most critical aspects of plant engineering is the development of efficient and genotype-independent transformation systems. Tissue culture-free or minimal tissue culture transformation systems have the potential to revolutionize plant biotechnology, overcoming the time and labour required for tissue culture. These include in planta transformation methods from a variety of tissues, and the use of morphogenic regulators and small peptides can further enhance plant regenerative potential. Although Agrobacterium-mediated transformation has been the gold standard for delivering genetic material into plant cells, many crops and elite genotypes remain recalcitrant to Agrobacterium

[redacted]

infection, limiting its utility. An alternative approach to in planta transformation is the engineering of Agrobacterium to improve plant transformation and enhance Agrobacterium's ability to infect a broader range of plant species.

Genetic transformation is not the only way to engineer plants. The engineering of synthetic apomixis (enabling clonal seed production) could revolutionize crop breeding by preserving hybrid vigour across generations. Grafting also has a modern application, with mobile RNAs, graft hybrids, and graft chimeras being used to engineer plant development, stress tolerance, and hybrid traits without the need for direct DNA modification.

A key challenge to complex plant engineering (e.g. metabolic and regulatory pathways) is the size of DNA that can be effectively integrated into the genome at precise sites. Methods to do this include homologous recombination-based approaches, with programmable recombinases showing high potential. Alternatively, the creation of artificial chromosomes in planta enables

[redacted]

housing of large segments of foreign DNA without disrupting native gene function, and potentially enabling transferability between cultivars and species.

Beyond transformation, articles in the special issue explore synthetic biology and genome engineering approaches that push the boundaries of plant biotechnology. Efficient engineering of plants to produce specialized metabolites, or for complex regulatory pathway rewiring, requires design skills and the application of engineering techniques. Design can be supported by deep learning and/or mathematical modelling to drive precise spatio-temporal regulation of endogenous or transgene pathways.

PlantGENE (https://plantgene.sivb.org/) is a network designed to help realize the potential of plant engineering. PlantGENE facilitates knowledge exchange, offering both in-person and virtual training, and is building a global community. With over 1,000 members from 58 countries, this is a skilled and enthusiastic scientific network!

BY MAREIKE JEZEK

JXB (Journal of Experimental Botany)

Ricarda Jost, Oliver Berkowitz, Amelia Pegg, Bhavna Hurgobin, Muluneh Tamiru-Oli, Matthew T Welling, Myrna A Deseo, Hannah Noorda, Filippa Brugliera, Mathew G Lewsey, Monika S Doblin, Antony Bacic, James Whelan. 2025. Sink strength, nutrient allocation, cannabinoid yield, and associated transcript profiles vary in two drug-type Cannabis chemovars, Journal of Experimental Botany 76, 152–174, https://doi.org/10.1093/jxb/erae367

[redacted]

Few plants have been in the public eye and divided minds like cannabis – hailed, on the one hand, as a relaxing treat to boost creativity and take the edge off the daily grind, but stigmatized, on the other hand, as a dangerous, addictive gateway drug. Historically, strict drug policies have placed cannabis in the same category as heroin and LSD in many countries, and the illegal status of the plant has severely limited its research. Obtaining permits and funding to cultivate and investigate cannabis has long been a challenging endeavour for researchers. The first scientist to chemically isolate tetrahydrocannabinol (THC) from cannabis even relied on the police for their supply of plant material (Gaoni and Mechoulam, 1964). However,

the acceptance of cannabis has been rising both socially and politically in recent times, and many countries are easing restrictions on its use for medical or recreational purposes. This makes cannabis research easier and required more than ever.

Cannabis has been cultivated for thousands of years, and selective domestication has yielded two distinct forms: tall-growing hemp varieties, whose bast fibers and hurds are used to produce ropes, textiles, or building materials, and drug varieties with a high flower-to-leaf ratio and high levels of the phytocannabinoid tetrahydrocannabinolic acid (THCA), which can be converted into the psychoactive drug THC (Fig. 1) (Clarke and Merlin, 2016), for medical or mind-altering purposes. The predominant phytocannabinoid in hemp is cannabidiolic acid (CBDA), which gives rise to the non-intoxicating cannabidiol (CBD) (Fig. 1). CBD has been clinically proven to be effective in treating seizures in certain types of epilepsy (Franco and Perucca, 2019) and can also be found in wellness products such as soft drinks, chewing gums, and bathing salts. Due to an increased demand for CBD by the pharmaceutical and wellness industries, breeders aim to develop cannabis varieties with economically desirable traits, such as a compact plant build optimised for growth in controlled environments, high flower biomass and CBDA yield, and low levels of THCA. This has been achieved by introgressing genes from hemp into a drug-type genetic background, yielding new cannabis types (chemovars) whose unique combinations of phenotypic traits and underlying genetic makeup require detailed investigation to optimise growth and CBDA production, and for further selection of desired genotypes (Wee et al., 2024)

Jost et al. (2024) compared the performance of a THC-dominant with a CBD-dominant drug-type cannabis chemovar in a controlled environment setting that is typical for cultivation of medicinal plants. Their work revealed surprising differences that will affect breeding and cultivation of cannabis for commercial CBD production. The THC-dominant variety showed expected good performance with high inflorescence biomass and cannabinoid yield, with its stunted growth phenotype being well suited for indoor cultivation. The CBD-dominant chemovar, however, retained several features of its hemp parent, such as profuse vegetative growth and low flower production, which resulted in a decreased cannabinoid yield compared to the THC-dominant variety. Also, hemp is very efficient in nutrient uptake as it is well-adapted to growth on marginal soil that is poor in the main plant nutrients nitrogen and phosphate. The CBD-dominant chemovar seems to have retained this high nutrient uptake capacity which became detrimental to plant performance when grown with ample nutrient input as is common for the cultivation of drug-type cannabis. These plants showed a poor ability to sense and regulate the uptake of nutrients, especially phosphate, leading to its hyperaccumulation in leaves to toxic levels with adverse downstream effects such as low photosynthetic activity and early leaf senescence. Jost et al. (2024) found a number of genes involved in phosphate and nitrogen homeostasis that were differently expressed between the CBD- and the THC-dominant chemovars and which may contribute to the altered nutrient sensing, acquisition, or distribution of the former. Understanding the distinct nutritional requirements of different cannabis varieties and the underlying genetic regulation is an important step towards selective breeding of new drug-type varieties and improved performance. The findings also open up opportunities for the development of new sustainable cultivation strategies for chemovars with reduced nutrient input to optimise plant growth and cannabinoid yield.

Thanks to the newly formed interest as a medicinal plant, cannabis is outgrowing its image as a lifestyle drug of the hippie generation. With the change in cultural values and political restrictions comes the need for large-scale commercial cultivation. The work presented by Jost et al. (2024) highlights that further fine-tuning of cannabis genotypes and cultivation conditions is required to optimise performance and yields. Furthermore, the domestication history of cannabis leading to phenotypically diverse hemp- and drug-types provides an interesting model to investigate how trait selection has shaped its genetics and vice versa.

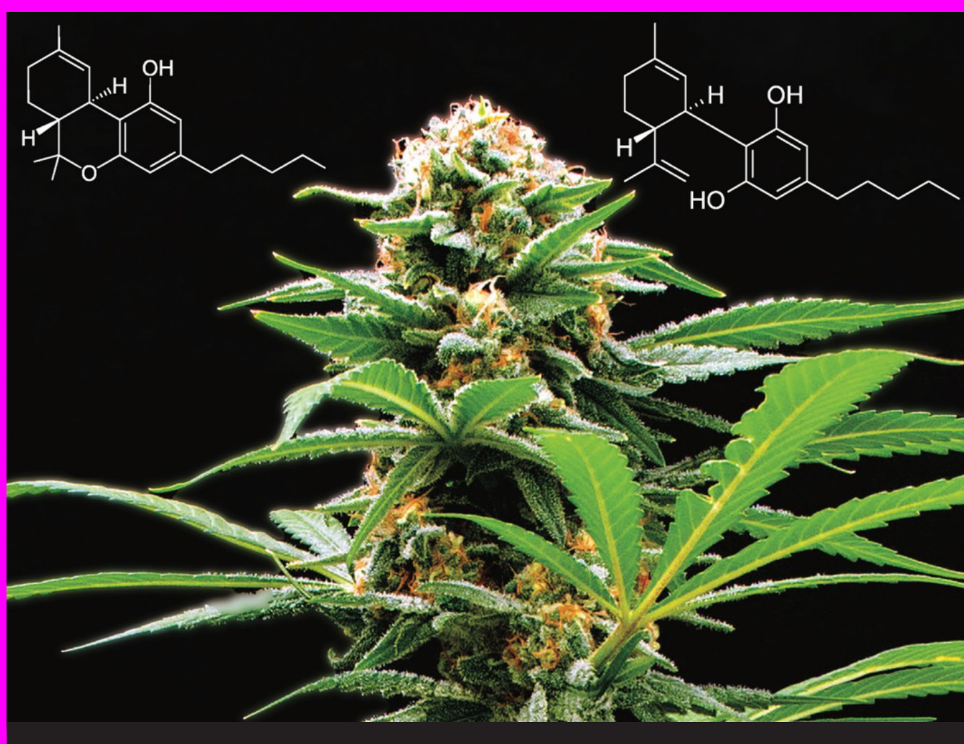

Figure 1: Terminal female inflorescence of a drug-type cannabis chemovar close to maturity and chemical structures of the major cannabinoids tetrahydrocannabinol (THC) (left) and cannabidiol (CBD) (right) (image courtesy of R. Jost and co-authors).