

Leafy biofactories: producing industrial oils in non-seed biomass

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Consumers are a funny lot. We demand products with new and improved properties combined with lower price and sustainability. Most consumers remain unaware of the origin of the molecules that they use in everyday products and are often surprised to learn that many household items are derived from fossil fuels. Even more surprising is the realisation that plastics and lubricants are the high-value products in fossil fuels, and the remaining “waste stream” is sold for combustion. Although transportation could be powered by alternative means in the future, it remains an open question as to how high-value plastics and lubricants may be sourced at reasonable cost in a sustainable manner. Here, I argue that recent advances in the metabolic engineering of plant biomass are starting to address these questions.

Biology produces a fascinating array of lipid structures that would provide either direct replacements for petrochemicals or the basis for new materials. With next-generation sequencing providing a deluge of gene candidates, a major bottleneck in plant metabolic engineering has been an effective high throughput screening protocol to discriminate between gene candidates. This task might have traditionally fallen to yeast-based assays; however, plant metabolic engineers have developed their own assay format, which enables the rapid screening of complex transgenic metabolic pathways for oil synthesis in plant leaves [1]. These “leaf-based” assays allow single genes to be rapidly stacked into multicomponent pathways and assessed for function within a few days, rather than months. Furthermore, each gene component can be swapped for

another, allowing numerous alternative pathways to be built up rapidly. A tray of plants is able to test many dozens of such pathways in parallel, and so what once required months and significant glasshouse resources can now be done in a fraction of the time and effort. Recently, these leaf-based assays have been improved in key aspects. Extensive genomic resources for leaf-based assays [2,3] allow the engineer to accurately tinker with the host metabolism and better understand the plant’s response to transgenic interventions. Furthermore, a novel silencing/overexpression format has been developed that permits endogenous substrate pools to be efficiently shunted into transgenic pathways of interest [2]. These features allow plant-specific pathways to be rapidly refined and optimised to generate the maximum flux of host metabolism into newly engineered products.

So, you ask, how might this flexible system for metabolic engineering in plant leaves help in the supply of renewable oleochemicals? Firstly, numerous laboratories have already shown that leaf cells support transgene-derived enzymatic reactions that have applications as oleochemicals. These reactions modify the functionality of the lipids and oils in the plant cell and include epoxygenation [4], cyclopropanation [5], acetylenations [6] and elongations [2]. As more gene combinations are screened, it can be anticipated that leaf-based assays will expand the toolbox for the production of industrial oils into the future. One could also imagine a scenario where leaf-based assays could be used to build lipids with a combination of functionalities specifically tailored for unique products or processing protocols.

But can such exotic lipids be produced in plants at an industrially relevant scale? Logically enough, this question has usually led to transgenic engineering of oilseeds to produce industrial fatty acids. However, despite the decades of research, oilseeds have proven difficult to re-engineer for industrial oil pathways with modest successes in composition often coming at the expense of seed oil content and seedling vigour [7]. Although more research will help alleviate these problems in oilseeds, alternative locations for the production of exotic lipids may be required. Recently, plant biotechnologists have started to produce high levels of the common vegetable oils in leaves at levels comparable to oilseed crops [8,9]. Such results generally rely upon the simultaneous expression in leaves of pathways normally expressed in oilseeds, such as transcription factors (LEC2, WRI), oil biogenesis pathways (DGAT) and oil protection proteins (oleosins). Further increases in oily biomass seem inevitable as various transgenic approaches are combined and matched with the physiology of the host plant. The value of such “high oil” biomass is that some crops have so much vegetative tissue that the total yield per area provides as much oil as that harvested from oilseeds. Oil-rich biomass is an exciting prospect in its own right, but here I suggest that the expression of high-value oleochemical feedstocks is well-suited for this non-seed production platform. Industrial oils may be best produced in leafy biomass crops, in parts of the plant developmentally distinct from organs required for successful regeneration. Furthermore, the harvest of transgene-dependent oleochemicals from

leafy biomass prior to the onset of flowering and seed set should also be viewed as strengthening the gene containment strategies required for broadacre cropping.

Plant biotechnologists are developing a new option for the sustainable production of oleochemicals: the leafy biofactory. Such leafy biofactories could be built within the high biomass crops that are not considered part of the food chain, such as tobacco and miscanthus, to name but two. The notion of crops producing high-value industrial oils is not new, but the possibility of using leaves—not oilseeds—as the source of these feedstocks might be a surprise to many.

Consumers are a funny lot. We may one day marvel at a new range of products, available at a reasonable price and remain completely unaware that they are produced in a sustainable manner.

Conflict of interest

The author declares that he has no conflict of interest.

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