Towards extracellular secretion of poly-β-hydroxybutyric acid (PHB) biodegradable polymer

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New in this version

Language and logical flow is improved in this version.

Conflicts of interest

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Abstract

Challenging disposal problems are associated with plastics use due to its poor biodegrability and emissions of hazardous chemicals during incineration. Poly-β-hydroxybutyric acids (PHB), a lipid based storage polymer in bacteria, is biodegradable, biorenewable and biocompatible, and thus, presents a tantalizing possibility for reducing the environmental impacts associated with plastics use. Progressive elucidation of PHB biosynthesis routes provides the understanding necessary for its production through recombinant microorganisms. Originally nature's solution for helping bacteria moderate fluctuations in nutrient availability, PHB biosynthetic pathway has multiple nodes at which contemporary genetic engineering efforts for overproducing the polymer can be focused. Other means for increasing cellular PHB concentration include optimizing fermentation conditions and growth medium composition. But, intracellular accumulation of PHB (principally as inclusion bodies) and difficulty of extracting it is the main reason for its high cost and lack of competitiveness. Hence, improving cost efficiency of extraction and purification are important for increasing PHB's market competitiveness vis-à-vis petroleum derived plastics. Additionally, use of toxic solvents and surfactants during PHB extraction also expands its environmental footprint while also contaminating the end-product. Thus, compared with increasing production titer, eliminating the extraction step would go further in reducing PHB's relative price (cost), and improves its environmental sustainability. However, high hydrophobicity induces PHB to aggregate into inclusion bodies, which points to the need for engineering microbes able to export PHB. Multiple pathways exist for protein export, but none exists for lipids. Hence, a variety of recognition proteins, carrier proteins and transporters, and crucially, their recognition motifs for energy mediated (i.e., hydrolysis of ATP or GTP) transport of PHB through the likely lipid based transport channel must be constituted for extracellular secretion of PHB. Such a goal would require rational engineering of recognition, carrier, transport and channel proteins or their derivation from existing ones through directed evolution. The above possibility set sights on the future, but what is in store at the moment or the foreseeable future? Creating "leaky" bacteria strains for facile "export" of PHB may be a feasible path forward. "Leakiness" can be realized by using current recombinant DNA technology for overexpressing PHB in cells: (i) without a cell envelope, (ii) one with a significantly weakened one, or alternatively, (iii) a cell envelope or peptidoglycan layer with a random/engineered pore structure. Casting glances further out into the future, research into extracellular PHB secretion would likely open up avenues into production and export of lipid biopolymer or macromolecular complexes from recombinant organisms.

Keywords: biodegradable polymer; polyhydroxyalkanoates; downstream processing; environmental sustainability; nutritional stress response; microbial fermentation; PHB granules; inclusion bodies; extracellular secretion; synthetic biology;

Subject areas: genetic engineering; biotechnology; metabolic engineering; protein engineering; rational protein design; biochemistry; chemical engineering; bioengineering; systems biology; computational biology; cell biology; synthetic biology;