Extracellular extrusion of N-acetyl glucosamine nanofibers of unprecedented length by diatom algae through controlled silicon, nitrogen, and phosphorous delivery

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Abstract

Diatom algae possess unique biosynthetic pathways that produce a variety of materials, including nanostructured metal oxides, energy-dense lipids, bioactive compounds, and biopolymers. Diatoms possess a nanostructured, porous biosilica cell wall, and so require dissolved silicate as a required substrate for cell division. A few species of centri diatom algae within order Thalassiosirales biosynthesize and extrude N-acetyl glucosamine (NAGlc) biopolymer nanofibers of 50 nm diameter and unprecedented length exceeding 100 microns through specialized ports (fultoportula) lining the rim of its nanostructured silica cell wall, with each port releasing only one nanofiber at time. The poly N-acetyl glucosamine chains hydrogen bond in parallel array to form a rare beta-allomorph of chitin. The beta-chitin allomorph is much more readily functionalized and biodegradable than alpha-chitin sourced from the shells of invertebrate organisms. beta-chitin is finding many applications, particularly for biomedical materials, as it is strongly hemostatic (promotes blood clotting), and can be blended with other biomaterials to make engineered tissue scaffolds. Extracellular nanofiber extrusion is only triggered if the diatom cell has perceived that insufficient silicon is available for continued cell division. In an engineered system, the rate and yield of beta-chitin nanofiber formation is externally controlled by photobioreactor cultivation of the diatom Cyclotella with perfusion delivery of dissolved silicon and nutrients. We demonstrate that silicon-limited cultivation stimulates beta-chitin nanofiber formation, nitrate limitation limits beta-chitin nanofiber formation, and increasing phosphate delivery increases the selectivity of beta-chitin nanofiber formation over competing lipid production, resulting in nanofiber yields exceeding 15 wt% of dry cell mass.

Keywords: chitin, diatom, nanofiber, nanostructured silica, N, acetyl glucosamine biosynthesis, photobioreactor cultivation

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