Organic Chemistry: An Indian Journal

Opinion |Vol16Iss9

Synthesis of Useful Organic/Inorganic Hybrid Materials Inspired by Biomineralization: Organic Molecular Control of Hybrid Self-Organization

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Received: September-05-2022, Manuscript No. tsoc-22-82504; **Editor assigned:** September-07-2022, PreQC tsoc-22-82504 (PQ); **Reviewed:** September-09-2022, QC No. tsoc-22-82504 (Q); **Revised:** September-14-2022, Manuscript No tsoc-22-82504 (R); **Published:** September-25-2022, DOI: 10.37532/0974-7516.2022.16 (8).1-2

Abstract

Biominerals are a class of organic/inorganic hybrid compounds produced by living things. They develop as a result of the self-organization of inorganic and organic components in an ambient environment.

Because of their exceptional physical and chemical capabilities, which cannot be achieved by the simple aggregation of their organic and inorganic ingredients, biominerals frequently exhibit highly ordered and hierarchical structures from nanoscale to macroscopic length scales. These findings inspire us to develop novel functional materials with qualities that outperform those of existing materials, both synthetic and natural. Here, we discuss recent developments in the molecular understanding of biomineralization processes and how these processes lead to the creation of organic/inorganic hybrid materials. We explicitly address material creation based on fundamental molecular investigations on silica, iron oxide, and calcium carbonate biomineralization.

Introduction

Biominerals are organic/inorganic hybrid substances that are vital parts of living things and provide support for critical processes. Mammal bones and teeth include hydroxyapatite (Ca_{10} $(PO_4)_6(OH)_2$), molluscan shells contain calcium carbonate (CaCO3), diatoms and marine sponges have amorphous silica (SiO_2), and chiton teeth contain magnetite (Fe3O4). 5 These biominerals have complex hierarchical structures that give them mechanical toughness and flexibility that standard synthetic materials cannot match. Single calcite crystals are a part of specialised photosensory organs that may serve as compound eyes and are present in the skeletal framework of brittle stars. 8 Some animals, including bacteria and birds, use magnetite nanocrystals as biological geomagnetic sensors to locate and survive in their terrestrial habitats. The intricate structures of biominerals, which are made up of both organic and inorganic components, are what give them their optical and mechanical capabilities. Most biominerals are created from plentiful materials found in the crust of the planet. Additionally, they are created in relaxed circumstances with ambient temperature

Citation: Roshan .E Synthesis of Useful Organic/Inorganic Hybrid Materials Inspired by Biomineralization: Organic Molecular Control of Hybrid Self-Organization. Org. chem.: Indian J. 2022; 16(9):1-2

and a pH that is close to neutral. The creation processes of biominerals have drawn a lot of study because of their intriguing characteristics, with the goal of understanding the mechanisms and using them to synthesise materials in industry. In the past three decades, a number of proteins that regulate biomineralization processes have been isolated and studied. These proteins include those that promote crystal growth and matrix-assisted crystal orientation, inhibit growth through face-selective surface adsorption, and regulate the crystal phase. Although it has long been thought that proteins are crucial to biomineralization processes, the majority of studies still focus on basic examinations of proteins like comparing amino acid sequences and biochemical characterisation. To date, very little is understood about the molecular functions of proteins. The use of a biomineralization protein in a sponge investigation led to a substantial advance in material production. The silicate in protein, which makes up the skeletons of marine sponges, was isolated from silica spicules. Unexpectedly, this protein demonstrates a direct catalytic function of silica bio mineralization and permits the creation of novel materials with a non-natural composition and a wide range of properties. Many proteins were identified from numerous biominerals in different animals after the detection of silicatein, which encouraged researchers to utilise them for material production. Silaffins extracted from diatoms have the ability to trigger and control silica precipitation. 3 The surface structure of magnetite nanoparticles is controlled by a tiny iron-binding protein called Mms6, which was identified from magneto tactic bacteria. Pif, a calcium-binding protein, controls how much nacre forms in pearl oysters. Fucata pinctada the bio-inspired synthesis of functional organic/inorganic hybrid materials with regulated micro- to nanoscale characteristics was made possible by these proteins, which were isolated from several biominerals. The functional sections of organic molecules have been used for biomimetic nanofabrication methods and the creation of bio-inspired materials as a result of these fundamental molecular research. We describe new developments in the fundamental molecular studies of biomineralization in a number of biological systems in this review. Here, we concentrate on research on calcium carbonate, iron oxide, and silica. We also emphasize the use of bio mineralization-related proteins in the carefully controlled synthesis of organic and inorganic functional materials. Using proteins purified from animals and/or macromolecules that resemble them, we have been able to create a variety of organic/ inorganic hybrid materials thanks to the findings of foundational research on bio mineralization. Although most biological systems have exceedingly complex bio mineralization pathways, contemporary biomimetic and bio-inspired syntheses are only based on specific elements of these mechanisms. The use of diverse synthetic methods involving many molecules will allow for the hierarchical organization of materials as well as the tuning of the crystal size, morphology, surface structures, composition, and crystallinity. These concepts will also make it easier to create ecologically friendly functional organic/inorganic hybrid materials with a variety of exceptional qualities like light weight, high flexibility, mechanical strength, dynamic function, and structural hierarchy.