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A Review Article On Bioluminescence

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Abstract: Bioluminescence is the natural emission of light by living organisms. It results from biochemical reactions involving the enzyme luciferase and the substrate luciferin. Found in a range of different taxa including algae, fungi, bacteria, insects, fishes, it serves various ecological functions like defense, prey attraction and communication. This study illustrates the mechanism of bioluminescence in Dinoflagellates. Further, this study enlists the various functions of bioluminescence in a diverse range of organisms.

Introduction:

Bioluminescence is light produced by an organism using a chemical reaction. Bioluminescence is the inherent ability of an organism to emit light. Most Bioluminescent organisms are found in the ocean. Light is produced by a chemical reaction in the presence of oxygen involving a substrate termed “luciferin” and the enzyme “luciferase”¹. The deep-ocean environments are mostly devoid of sunlight. Thus, bioluminescence may provide a survival advantage in the darkness of the deep sea, helping organisms find food, assisting in reproductive processes, and providing defensive mechanisms. Bioluminescence can be stimulated chemically by a change in water pH by adding specific chemicals, electrically by applying a voltage to the water volume, or mechanically by disturbing the flow². Mechanical stimulation is achieved when hydrodynamic external forces, e.g., waves, eddies, feeding currents of filtering organisms, etc., exert local stress on the cellular membrane, enabling an action potential and the bioluminescent chemical reaction to occur³. Mechanically stimulated bioluminescence can be observed due to the rise and fall of waves and moving of boats and ships.

Bioluminescence Emissions:

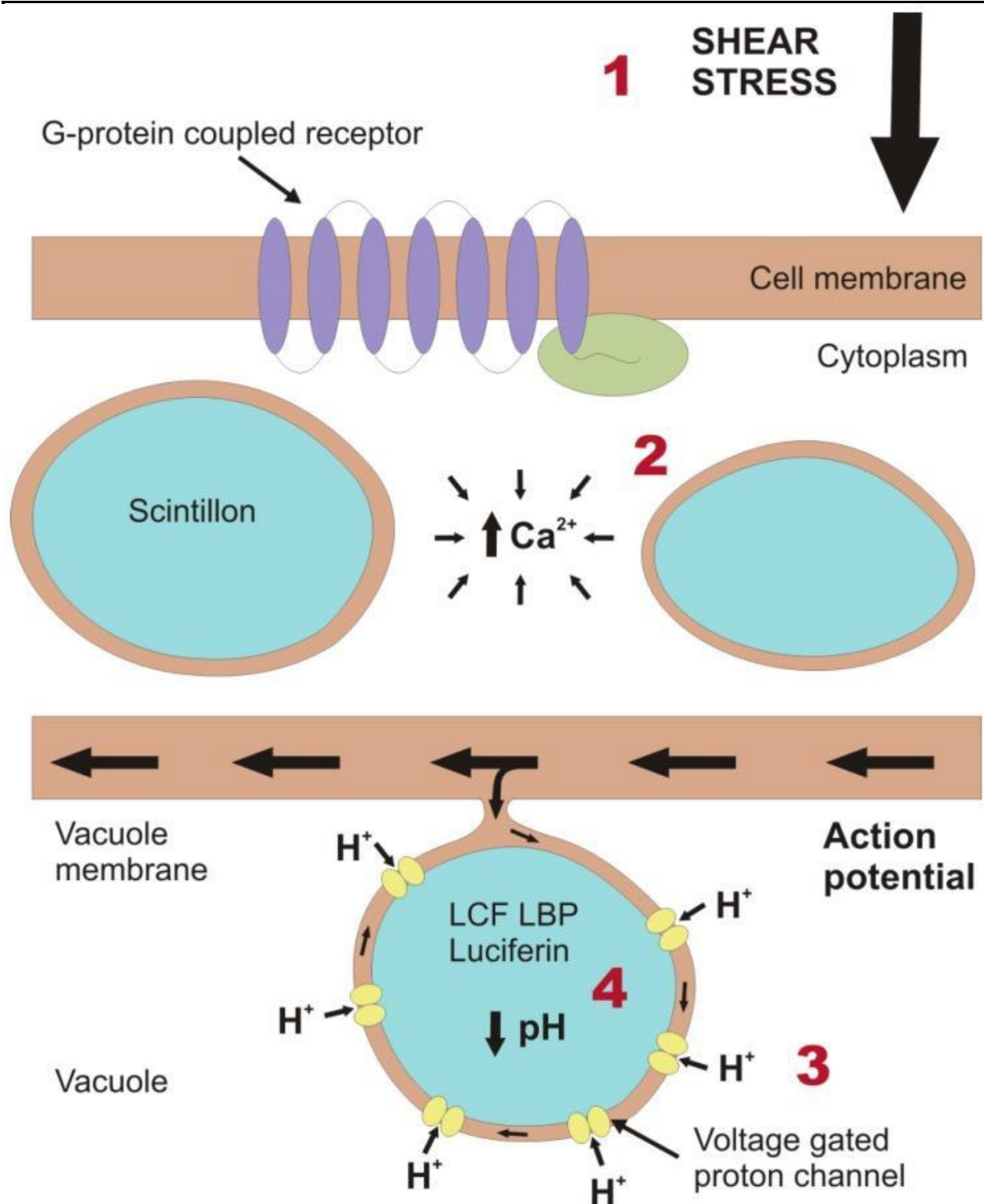
Mechanically stimulated bioluminescence (MSB) in marine organisms is a way of survival by luring prey or intimidating predators⁴. MSB can either be intrinsic, semi-intrinsic or extrinsic⁵. Intrinsic bioluminescence occurs when an organism produces both the luciferin and the luciferase needed for the chemical reaction. Inversely, an organism that obtains these molecules through predation and diet will display extrinsic bioluminescence. An individual with semi-intrinsic bioluminescence will obtain one of the components through their diet, sometimes facultatively.

Light Production In Cell:

Dinoflagellates are eukaryotic protists that are capable of producing light. In Dinoflagellates, the production of light occurs in organelles termed scintillons⁶, which contain the substrate luciferin, the luciferase enzyme (LCF) and luciferin binding protein (LBP)⁷. Scintillons are dense vesicles approximately 0.5-0.9 μ m in diameter⁸ which during darkness are found abundant in the periphery of the cell⁹. Light is mainly emitted in response to mechanical stress upon contact with grazers or by breaking waves¹⁰. The chemical reaction to produce light is

pH dependent, requiring the acidification of scintillons. For this reason, some scintillons protrude into the acidic vacuole. The shear stress exerted on the cell membrane triggers a mechanotransduction pathway to generate an action potential across the vacuole membrane and the associated scintillons¹¹. This involves the activation of GTP-binding protein coupled receptors in the plasma membrane. The next step of the process is mediated by an increase in cytosolic Ca^{+2} , mainly by release from intracellular stores and partially from extracellular sources. The action potential produced by these processes leads to an influx of protons from the acidic vacuole into the scintillons, decreasing their internal pH from 8 to 6¹². When acidification of the scintillons is achieved it causes structural changes in LCF leading to its active conformation and making the luciferin binding sites available¹³. In species that contain LBP, this protein binds the luciferin at neutral to alkaline pH, protecting it from autoxidation, and releases it by means of conformational change below pH 7, at which LCF also becomes active. Luciferin is oxidized by LCF to form oxyluciferin, which results in the emission of photons in the form of a brief flash of blue light¹⁴.





Schematic representation of part of a dinoflagellate cell, depicting the cellular processes that take place to generate a bioluminescence flash.

The steps are depicted as follows:

- 1) Initially, a force is exerted on the outer cell membrane. Transduction involves the activation of a G-protein coupled receptor¹⁵ which typically consists of a receptor (purple) comprising seven transmembrane domains and the G-protein (green) on the inner side of the cell membrane. Subsequent to transmission of the mechanical signal from the outside to the inside of the cell, the signal must be translated to an electrical signal on the vacuole membrane.
- 2) This is achieved by increasing the concentration of Ca^{+2} in the cytoplasm, mainly from sources within the cell but also from the external medium¹⁶. This causes the vacuole membrane to depolarize and generate an action potential. In this illustration, one of the scintillons protrudes into the vacuole and is connected to the vacuole membrane. Thus, the action potential can travel across the membrane of the scintillon.
- 3) This results in the activation of voltage gated proton channels, which we here assume to be concentrated on the membrane of the scintillon rather than on the remaining vacuole membrane.
- 4) The influx of protons from the acidic vacuole rapidly lowers the pH of the scintillons and activates the bioluminescence chemistry. While some of the protons may be sequestered by the production of water as a by-product of bioluminescence, the fate of the rest of these protons and the mechanism by which the scintillons return to the original pH values are unknown.

The Function of Bioluminescence:

In Dinoflagellates, bioluminescence acts as defense against predation¹⁷. Shear due to close proximity of zooplankton or grazers stimulates bioluminescence¹⁸. A widely accepted theory is that bioluminescence protects dinoflagellates indirectly by acting as a “burglar alarm” that is when a flash is stimulated by contact with a grazer, it will attract a higher-level predator that will then consume the grazer¹⁹. Some studies have shown that even if the dinoflagellate which flashes (i.e., the bioluminescent genotype) dies, the population as a whole will still benefit because blooms form asexually and therefore the organisms are genetically highly similar. Some species show bioluminescence to confuse attackers. Many species of squid, for instance, flash to startle predators, such as fish. With the startled fish caught off guard, the squid tries to quickly escape. Some insect larvae (nicknamed “glow worms”) light up to warn predators that they are toxic. Toads, birds, and other predators know that consuming these larvae will result in illness and possible death. Few fishes like the anglerfish and dragon fish use bioluminescence to attract prey. A few species use bioluminescence to communicate with other species.

Conclusion:

Bioluminescence is a fascinating natural phenomenon that highlights the incredible adaptations of life in the deep sea. This represents a remarkable evolutionary trait with diverse ecological functions, ranging from communication, prey attraction to predation and defense. Continued research into bioluminescence not only enhances our understanding of biology but also opens new doors in technology, medicine and environmental science.

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