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Harnessing the Sun

Evolution in extreme environments has produced life forms with amazing abilities and traits. Beneath the waves, many creatures sport iridescent structures that rival any materials scientists can create in the laboratory.

A team of researchers from UC Santa Barbara and the University of Pennsylvania has now shown how giant clams use these structures to thrive, operating as exceedingly efficient, living greenhouses that grow symbiotic algae as a source of food. The findings appear today in the Journal of the Royal Society Interface.

In related research published last year in the Proceedings of the National Academy of Sciences and featured in The Scientist, members of the same team discovered the mechanism by which “reflectin” proteins quickly tune the flashing colors in the skin of squids for camouflage and underwater signaling. These same colorless proteins form the reflective nanostructures responsible for the brilliant, neonlike reflectance in the giant clam.

“Many mollusks, like squid, octopuses, snails and cuttlefish, have iridescent structures, but almost all use them for camouflage or for signaling to mates,” said co-author Alison Sweeney, assistant professor in the Department of Physics and Astronomy in Penn’s School of Arts & Sciences. “We knew giant clams weren’t doing either of those things so wanted to know what they were using them for.”

Giant clams are uniquely recognized by the brilliant neonlike reflectance from cells in their epithelium, which creates striking patterns in colors from deep azure blues or turquoises to greens, golds and reds. Scientists have long thought these reflective cells acted as a kind of sunscreen, protecting the animal's tissues from damage by the intense solar irradiation to which they are exposed in the shallow tropical seas.

"We discovered a second function of the biophotonic behavior of these cells in which they redirect solar photons deeper and laterally into the clam tissue, providing gentle but uniform illumination to the millions of symbiotic unicellular algae that supply nutrients to their animal host by photosynthesis," said Daniel Morse, professor emeritus in UCSB's Department of Molecular, Cellular and Developmental Biology and director of the campus's Marine Biotechnology Center. "This discovery might even provide a blueprint for improving the design of low-cost, flexible, polymer-based solar cells in which efficiency can paradoxically be reduced by excessive sunlight."

While the true purpose of the giant clams' iridescent structures, cells known as iridocytes, was not known, the team had a strong hypothesis. Like their coral neighbors, giant clams are home to symbiotic algae that grow within their flesh. These algae convert the abundant sunlight of the clams' equatorial home into a source of nutrition but are not particularly efficient in the intense sunlight found on tropical reefs. Sunlight at the latitude where these clams live is so intense that it can disrupt the algae's photosynthesis, producing potentially fatal concentrations of reactive oxygen rather than energy for growth.

The researchers began their study hypothesizing that the clams' iridocytes were being used to maximize the usefulness of the light that reaches the algae inside. Originally they were confounded by the relationship between the iridocytes and the algae, until they realized that they had an incomplete picture of their geometry. More precise cross-sections of the clams showed that the algae were organized into pillars, with a layer of iridocytes at the top.

"When we saw the complete picture, we understood that the pillars are oriented exactly the wrong way if you want to catch sunlight," said Sweeney. "That's where the iridocytes come into play."

The team relied on Amanda Holt, a postdoctoral optical physicist formerly at UC Santa Barbara and now at Penn, and Sanaz Vahidinia of NASA's Ames Research Center to model exactly what was happening to the light once it passed through the iridocytes. The degree of disorder within these cells bore a resemblance to structures Vahidinia studies at NASA: the dust of Saturn’s rings.

Their analysis suggested that the iridocytes would scatter many wavelengths of light in a conelike distribution pointing deeper into the clam. Red and blue wavelengths, the most useful to the algae, spread the widest, impacting the sides of the pillars in which the single-celled plants were stacked.

To test this model, the team constructed fiber-optic probes with spherical tips the size of an individual alga. Threaded through a section of clam flesh alongside the native algae, this spherical probe was able to detect the angled light scattered by the iridocytes, whereas a flat-tipped probe, able to sense light only shining straight down, detected nothing.

“At any vertical position within the clam tissue the light comes in at just about the highest rate at which these algae can make use of photons most efficiently,” Sweeney said. “The entire system is scaled so the algae absorb light exactly at the rate where they are happiest.”

“This provides a gentle, uniform illumination to the vertical pillars consisting of the millions of symbiotic algae that provide nutrients to their animal host by photosynthesis,” Morse added. “The combined effect of the deeper penetration of sunlight (reaching more algae that grow densely in the three-dimensional volume of tissue) and the ‘step-down’ reduction in light intensity (preventing the inhibition of photosynthesis from excessive irradiation) enables the host to support a much larger population of active algae producing food than possible without the reflective cells.”

Mimicking the micron-scale structures within the clam’s iridocytes and algal pillars could lead to new approaches for boosting the efficiency of photovoltaic cells without having to precisely engineer structures on the nanoscale. Other alternative energy strategies might adopt lessons from the clams in a more direct way: Current bioreactors are inefficient because they must constantly stir the algae to keep them exposed to light as they grow and take up more and more space; adopting the geometry of the iridocytes and algal pillars within the clams would be a way of circumventing that issue.

“All of our alternative energy sources are expensive when it comes to surface area, just like a clam,” Sweeney said, “so it makes sense to try to solve that problem the way evolution has.”

The research team also included Yakir Luc Gagnon of Duke University.

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About UC Santa Barbara

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