Carmichael's Concise Review

More Colorful than Ever!

Stephen W. Carmichael
Mayo Clinic, Rochester, MN 55905

carmichael.stephen@mayo.edu

In nature, color can be imparted to a feature either by a pigment or a structure that selectively reflects a part of the visible spectrum. The latter is called structural color, and it may be brighter than a pigment. Structural color is often used by animals for signaling, mimicry, and/or mate choice. In plants, mainly fruits, structural color is probably used for mimicry. Silvia Vignolini, Paula Rudall, Alice Rowland, Alison Reed, Edwidge Moyroud, Robert Faden, Jeremy Baumberg, Beverley Glover, and Ullrich Steiner described the anatomical arrangement within the outer layers (epicarp) of a blue fruit found in equatorial Africa that results in a blue color more intense than that of any previously described biological material [1]! Although this fruit (Figure 1) has no nutritional value, by imitating the appearance of a fresh nutritious fruit, it avoids the energy cost of producing pulp yet can be dispersed by birds. And not only can it imitate a food source, it is probably also dispersed by birds who use it to decorate their nests in order to attract mates.

Figure 1: Photograph of the fruit of *Pollia condensata*.

Vignolini et al. could not extract any blue pigment from the blue fruit of *Pollia condensata* by conventional means, leading them to think the metallic blue color is due to the anatomy of the cells of the epicarp. The strong gloss of the fruit is produced by the flat transparent cuticle. Scanning electron microscopy and transmission electron microscopy (TEM) revealed that the epicarp consists of three to four layers of thick-walled cells. The cell walls in this layer create a periodic multilayer envelope, and a blue iridescence originates from these cells. An underlying layer of cells pigmented with tannin absorbs most of the light transmitted through the epicarp, which increases the purity of the structural color. TEM revealed individual cellulose microfibrils oriented in helicoid structures (technically left-handed [LH] and right-handed [RH] helicoids) within the cells of the epicarp. The parallel helically arranged fibrils create a difference in which circularly polarized light of opposing handedness interacts with the helical stack. Color-selective transmission and reflection of light arises from this difference in the propagation of light with a wavelength (λ) that matches the helical pitch of the stack-structure. The orientation of the fibrils in the epicarp of the *Pollia* fruit predicts a λ of about 445 nm, corresponding with blue coloration.

Further studies of the *Pollia* fruit with RH and LH circular polarization filters of non-polarized light confirmed that the reflected color arises from the stacks of fibrils (an arrangement known as Bragg stacks) in the cell wall. Interestingly, RH polarization revealed a few red-colored cells. Additional studies with light passing through a tunable liquid crystal color filter revealed an even smaller amount of green reflected. Whereas blue reflectance is dominant, the sparse distribution of green- and red/purple-reflecting cells gives the fruit an intriguing pixellated (pointillist or "metallic")

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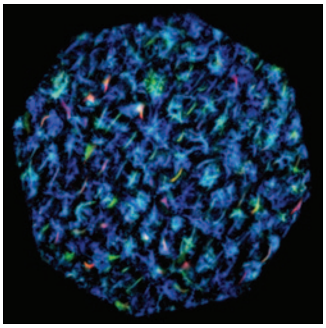

Figure 2: Polarized reflection of an isolated *Pollia condensata* fruit under epi-illumination, imaged between crossed polarizers with a 10× objective. The diameter of the fruit is about 5 mm.

appearance that has not been recorded in any other organism (Figure 2).

Finally, the brightness of the structural color is impressive, providing a total (unpolarized) reflectivity of about 30% compared to a silver mirror. This is very high, considering the fruit is only reflecting part of the visible spectrum compared to a mirror. In fact, this is the highest reported reflectivity of any terrestrial organism. Furthermore, this structural color does not fade with time, so fruits on the dimly lit forest floor remain an attractive food source or nest decoration for years!

References

[1] S Vignolini, PJ Rudall, AV Rowland, A Reed, E Moyroud, RB Faden, JJ Baumberg, BJ Glover, and U Steiner, *Proc Nat Acad Sci* 109 (2012) 15712–15.

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