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NOTE ON THE COVER PHOTOGRAPH

Unseen beauty of flowers – hidden signals or spectacular by-product?

The picture on the cover of this issue shows the ultraviolet-induced visible fluorescence of the Caucasian Stonecrop flower *Phedimus spurius* (sometimes referred to as *Sedum spurium*) collected in Stockholm, Sweden. Under the sunlight, its small and rather unremarkable flowers are uniformly pink or pinkish-white, with only the anthers being distinctly darker. But when these flowers are placed in the total darkness and exposed to the ultraviolet light (UV-A), they completely transform in appearance. The central part of the flower where the bases of stamens and carpels join together and where ovaries are located produces intense blue fluorescence, which strikingly contrasts against the dark magenta fluorescence of the petals, while pollen attached to the anthers shine bright yellow or white. This property of flowers, and many other objects in nature, is a not uncommon but rather insufficiently understood process of ultraviolet-induced visible fluorescence.

Fluorescence plays a variety of functions in nature, and although it is widely present among different groups of plants and animals, its function is better understood in some organisms and completely unknown in others. For example, fluorescence was shown to contribute towards visual signalling (display or camouflage) in a variety of distantly related groups of animals: in mantis shrimp, jumping spiders, certain marine fish, one species of parrots, etc. (Arnold, Owens, and Marshall 2002; Lim, Land, and Li 2007; Mazel et al. 2004; Sparks et al. 2014). Its role can go beyond biocommunications. In corals, ultraviolet- and blue-induced visible fluorescence serves multiple functions, depending on the location depth of the corals: in shallow waters, it offers photoprotection due to scattering and converting damaging higher-energy ultraviolet and blue into safe green and red light; in deeper waters, it can enhance photosynthesis by wavelength transformation and back-scattering (Salih et al. 2000). On the other hand, the well-known fluorescence of scorpions is the most puzzling – numerous explanations have been proposed but none is unequivocally proven (Gaffin et al. 2012).

Ultraviolet-induced visible fluorescence in flowers is common and very variable, both in colours and in patterns: in some flowers, only pollen or anthers “shine” brightly against the weak red fluorescence of chlorophyll in petals; in others, the entire flower can glow. Sometimes the entire flower emits the same colour of light, and sometimes different flower parts are differently coloured. But despite considerable research efforts, the function of ultraviolet-induced visible fluorescence in the world of plants remains poorly understood. The fact that fluorescence produces light emission within the visible spectrum may lead some to focus on the visual aspect of it, and to consider it a signalling process of some sort. When fluorescence occurs in plants, the most attractive explanation would be to consider it a part of the mechanism of plant–insect interactions, that it plays the role as a visual signal in attracting pollinators, similar to iridescence and reflectance across the visible to pollinators part of the spectrum (ultraviolet-to-green or ultraviolet-to-red, Chittka and Kevan 2005). It has even been suggested that blue fluorescence of flower parts in wind-pollinated plants, together with observations of insects visiting these flowers, is a visual clue for pollinators collecting pollen (Baby et al. 2013). Unfortunately, there is no experimental support for these suggestions and it offers no benefit for flowers to attract insects and spare pollen to pollinators, which are unlikely to deliver it to female flower parts. It had also been suggested that fluorescence may contribute to visual appearance of flowers due to combination of fluorescence and reflectance of non-absorbed light (Gandía-Herrero, García-Carmona, and Escribano 2005). However, models that account for the percentage of ultraviolet radiation in sunlight; the efficiency of fluorescence (the amount of absorbed ultraviolet light and the percentage of its energy converted into visible light); the reflectivity of flowers in parts of the spectrum visible to pollinators; and the sensitivity of the eyes of prospective pollinators confirm that fluorescence is not strong enough to contribute substantially to the visual signalling under normal conditions (Iriel and Lagorio 2010). One more study that adds to the confusion showed experimentally that ultraviolet-induced blue fluorescence in pitcher plants plays important role in attracting prey insects, suggesting that fluorescence is visible under natural conditions to at least some animals (Kurup et al. 2013).

The next hypothesis states that ultraviolet-induced visible fluorescence produces light that may be used in photosynthesis in vegetative parts of plants, such as leaves and stems (García-Plazaola et al. 2015). It does make sense for organisms that live in the aquatic environment with narrow-band ultraviolet-blue illumination, which needs to be converted to green light before being absorbed by the chlorophyll. But would visible light produced through ultraviolet-induced visible fluorescence contribute enough energy for photosynthesis in plants illuminated by unfiltered sunlight? Besides, since photosynthesis is not the major function of flowers per se, a photosynthetic function of fluorescence in this case is even less likely.

The number of compounds in plants that emit visible fluorescence under the ultraviolet light is large (García-Plazaola et al. 2015), they are widely distributed among plants and tissues and many of them have vital functions that are not related to wavelength transformation. Even if in some species of plants, ultraviolet-induced visible fluorescence may indeed play some role in visual signalling, it is most probably not the only its function. Could the fluorescence in plants be simply the result of photoprotective mechanisms, which shield DNA in reproductive cells (pollen, ovules) from damaging effects of the ultraviolet radiation, by converting it into less harmful visible light, as suggested by some (Baby et al. 2013)? Finally, could it be just a by-product that does not really have a defined function of its own?

Disregarding its actual function in nature, ultraviolet-induced visible fluorescence of flowers may be a powerful visual signal for people. Although it cannot be observed without a few simple tools and key safety precautions, fluorescence presents ordinary, sometimes mundane flowers in an unusual and aesthetically pleasing way. The unseen beauty of flowers is revealed.

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