What makes blueberries blue?

A new study reveals how the berries and some other waxy fruits look blue despite a lack of blue pigment.

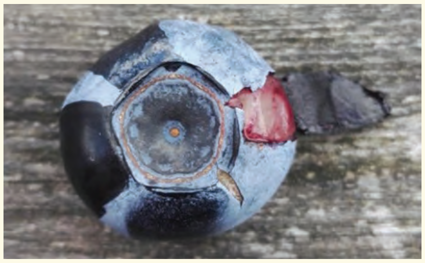
Blueberries are blue despite the dark red pigments in their skin. The same is true of other blue fruits like some plums, grapes, and juniper berries. Their color was strongly suspected to be a result of the structure of their waxy outer layer, which may play a role in holding in moisture and protecting the fruit. A research team led by Heather Whitney and Rox Middleton at the University of Bristol in the UK has investigated those waxy blue fruits to find out how they produce the color we see.

To begin, the researchers removed the wax of a blueberry to find how deep the blue goes. Removal of the outermost wax layer removed the brilliant blue color, leaving a very dark blue. But rubbing off the entire waxy covering showed that the underlying outermost skin cells are dark red. In fact, using microscopy, the only pigment found in the berry was observed to be red.

RIPENING BLUEBERRIES. (Photo by ChiemSeherin/Pixabay.)

That indicated that the blue color occurs in the outermost layer of the waxy covering.

The researchers used a scanning electron microscope to examine the morphology of the outermost layer of different blue fruits. Studying 14 fruit species, they found wax structures that they classified into four types of shape. The first type exhibits rings, the second rods, the third slabs, and the fourth tubes. The exception is the blueberry wax, which was classified differently than all the other species measured. Despite the different shapes of the crystals, they all produced a similar optical-reflectance spectrum. While other examples of both structural and pigmentary color show a clear reflectance peak corresponding with the dominant visual color, the bloom fruits studied by Middleton and colleagues have no peak in the spectrum, which continuously decreases with increasing wavelength. The fruit surfaces reflect the least light around 700 nm, the wavelength reflected by the underlying red pigment in the skin. Instead, the light is scattered from the random structure of the nanocrystals. Because shorter wave-



WHEN THE OUTER LAYER of wax coating is removed, a blueberry appears dark blue. When the entire coating is peeled off, the redder skin of the fruit is apparent. (Adapted from R. Middleton et al., *Sci. Adv.* **10**, eadk4219, 2024.)

lengths are scattered more, to our eyes the dominant color is blue.

To further confirm that the structure is the primary reason we see those fruits as blue, the researchers dissolved the fruit's wax using chloroform. When suspended in the solution, the wax was transparent in the visible wavelength range. After evaporating the chloroform around the dried wax, the wax crystals self-assembled into a structure similar to that of their natural state. The wax looked blue.

Color appearance without the corresponding pigment isn't unknown to science. Rainbows stretching across the sky or seen shimmering on a CD create colors by reflecting light as it interacts with structures. (For more on color due to structure, see the article by Ross McPhedran and Andrew Parker, Physics Today, June 2015, page 32.) The structural color of bloom fruits may also be advantageous by attracting the birds that eat them. The spectral signature allows the vibrant color to be seen in both UV and blue visual channels. (R. Middleton et al., *Sci. Adv.* **10**, eadk4219, 2024.)

Jennifer Sieben

Geologic evidence that volcanic lightning promotes life on Earth

Large quantities of fixed nitrogen found in ash and pyroclastic deposits confirm suspicions about a likely source of life's earliest building blocks.

Every protein molecule in every cell in your body contains nitrogen, but the abundant N_2 molecules in the atmosphere are useless to you. The triple bonds that hold them together are just too strong. Atmospheric nitrogen is made available to organisms by breaking apart that N_2 and bonding the free nitrogen with oxygen or hydrogen—a process known as fixation. Nitrogen fixing can be accomplished in a few ways, including biotic processing by bacteria and algae, high-energy industrial-fertilizer production, and lightning strikes.

Without fertilizer factories, algae, or bacteria around to provide the fixed nitrogen for life on Earth, its emergence would have required abiotic nitrogen fixation. Lightning has been the leading candidate for the source of that process. Lab experiments and theoretical models have suggested that volcanic lightning in particular could have played a vital role because ash and gas plumes promote the highest rates of lightning strike. Yet, until now, no significant quantities of abiotically fixed nitrogen have been found in the geologic record or from present-day eruptions.

Adeline Aroskay and Erwan Martin of Sorbonne University and their colleagues were looking in volcanic deposits for sulfates, which contribute to eruption-related climate change. They turned to rocks in arid environments in Turkey and Peru, where the soluble sulfate molecules would be preserved and not flushed away by water over time. Alongside the sulfur and chlorine compounds that they expected to find, they discovered a surprisingly high concentration of nitrates, a fixed form of nitrogen.

Looking at the stable isotopes of oxygen in the nitrates, the researchers found that they contained high concentrations of oxygen-17—as much as 17 parts per thousand—that would require contributions from ozone, which is rich in ^{17}O. The researchers concluded that the nitrates in the volcanic deposits must have been formed in the atmosphere. "We found natural samples in which we have the end product of this process," says Martin.

VOLCANIC LIGHTNING, like that seen in the ash plume of an eruption in Iceland in 2010, may be a significant source of abiotically fixed nitrogen. (Courtesy of Terje Sørgjerd/CC BY-SA 3.0 DEED.)

Using the nitrate concentrations in their samples and estimates of the volcanic deposit volume, they calculate that as much as 282×10^9 kg of nitrogen were deposited in one eruption. That's on the same order of magnitude as what is produced for industrial fertilizer in a year. But volcanic events large and explosive enough to fix so much nitrogen are rare—occurring perhaps once every 100 000 years—as are the arid conditions necessary to preserve the highly soluble nitrates. So it's not surprising that they hadn't been found in volcanic deposits before. (A. Aroskay et al., *Proc. Natl. Acad. Sci. USA* **121**, e2309131121, 2024.)

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