Autumn Leaf Color: The Majesty & Mystery

Stephen G. Saupe, *College of St. Benedict/St. John's University, Biology Department, Collegeville, MN*

Everyone is certainly familiar with the spectacular colors of maple in the autumn. As a final hurrah to the growing season, maple leaves turn brilliant shades of yellow, orange and red. Though leaf-peepers have long marveled at these majestic color changes, the biological purpose for these changes is still a mystery.

Figure 1. Sugar maple leaf in the early stage of chlorophyll loss, exposing the carotenoids.

To better understand this mystery, let's first discuss the pigment chemistry underlying the color changes. Maple leaves are green during the growing season because they contain lots of chlorophyll. This green pigment, which occurs in specialized sub-cellular structures called chloroplasts, is the predominant pigment in the leaf. The function of chlorophyll is to capture light that will be used to power photosynthesis.

The chloroplasts also produce another group of pigments, the carotenoids. The function of these yellow and orange pigments is to assist chlorophyll in capturing light. In addition, they act like a sunscreen to protect the relatively unstable chlorophyll molecules from photodegradation in too much light.

During the growing season, there is usually much more chlorophyll than carotenoids. In a green sugar maple leaf, there is as much as 10x times more chlorophyll. This means that leaves are green, even though they have yellow pigments. The carotenoid colors are masked by the more abundant chlorophyll.

So, why do maple leaves change color in the autumn?

In response to shortened days and cooler temperatures, the leaf stops making chlorophyll and the existing chlorophyll molecules begin to break down. The resultant byproducts are processed into sugars and other materials. The recycled molecules are transported out of the leaf and ultimately stored in the stem and roots to be used the next season.

As the chlorophyll molecules disappear the carotenoids, which are more stable, become visible. This initiates the color transition from green to yellow. One common misconception is that this process is entirely responsible for autumn coloration.

The autumn color of about 30% of our deciduous trees is due strictly to carotenoids unmasked after the breakdown of chlorophyll. For example, this explains the leaf color changes we observe in paper birch, quaking aspen, basswood and elm.

In the majority of our deciduous trees, something else is afoot. The most spectacularly colored fall leaves, like those of red maple, sugar maple, northern red oak, and sumac, are colored by another group of pigments called anthocyanins.

There are many kinds of anthocyanins. The one that is mainly responsible for maple leaf color in the autumn is cyanidin-3-glucoside. This red pigment comprises about 80% of the anthocyanin in the leaf.

The same conditions that trigger the breakdown of chlorophyll, stimulate the accumulation of anthocyanins. In green sugar maple leaves there are only trace amounts of anthocyanin during the growing season. In autumn, the anthocyanin concentration skyrockets and increases by more than 40-fold. As the chlorophyll disappears, anthocyanins appear.

Thus, the color of a leaf in the autumn is determined by the relative amounts of chlorophyll, carotenoids, and anthocyanins. Consider the color changes of a sugar maple leaf throughout the course of the year: they progress from green to yellow to orange and finally red.

During the growing season chlorophyll predominates, so the leaves are green. Autumn conditions trigger the degradation of chlorophyll exposing the carotenoids and the leaves now appear yellow. As this senescence process continues, the red anthocyanins accumulate. In combination with the yellow carotenoids, the leaf appears orange. Carotenoids, though more stable than chlorophyll, slowly disappear during senescence so that by the end of the season, the anthocyanins predominate, and the leaves look red.

Back to the mystery.

The puzzle is why anthocyanins should be produced in leaves that will soon be discarded. Plants, like all organisms, are usually very conservative with their resources. It doesn't make sense that a maple would waste energy creating molecules soon to be shed with their leaves. From a Darwinian evolution point of view, the production of colorful pigments should serve some survival function.

Many hypotheses have been suggested, though none seem to fully explain this mystery. In general, we know that anthocyanins are induced by various environmental stresses including low temperature, nutrient deficiencies, ozone, UV, pathogens and water stress. This suggests that perhaps the anthocyanins are helping to protect against the stress of senescence. Another idea is that the anthocyanins may serve as a heat sink to warm leaves for additional photosynthesis in the autumn. Or, perhaps the anthocyanins, like the carotenoids during the growing season, protect the chlorophyll molecules from being destroyed too quickly, or they are anti-oxidants.

Still another hypothesis suggests that the red-colored leaves could signal that the leaves are toxic or unpalatable so that insects lay fewer eggs that would hatch the following spring to eat the leaves. Or, perhaps the brightly colored leaves make herbivores more visible to their predators.

Figure 2. Sugar maple leaves in late stage pigmentation showing lots of anthocyanin production.

Whatever the reason for the colorful displays, as you admire the dazzling majesty of our maples touched by Jack Frost, consider this colorful mystery. What is your hypothesis?

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