

Hydrangeas are one of my favorite shrubs. I enjoy cool palette gardens, and the muted pinks, purples, and blues of hydrangea flowers appeal to me. Moreover, I associate hydrangeas with my grandmother, whose house was surrounded with these lush shrubs. I have one lacecap and one mophead cultivar in my own landscape, both of which produce frothy masses of intensely blue flowers. Other hydrangea cultivars produce white flowers, or those in various shades of red or purple. There are even “chameleon” hydrangeas (*Hydrangea macrophylla* ‘Hovaria’) whose colors change several times throughout the growing season. The Internet is full of advice—often conflicting—on how to force color changes in your hydrangeas. Contrary to what you may have heard or read, it is neither a simple nor straight-forward undertaking to modify any flower’s color, especially in the real world (See “*Why no blue roses?*”).

In the 1940s, researchers began examining the hydrangea pigment puzzle by identifying the presence of red and blue anthocyanins in colored hydrangeas (white-flowered hydrangeas do not have these same pigments and are incapable of turning color). These pigments could apparently be transformed by adding or withholding plant nutrients, especially phosphorous and nitrogen—nutrient-rich conditions favor pink flowers, while low-nutrient soils produce blue flowers. Next, it was established that aluminum taken up from the soil and stored in the flowers was responsible for the deep blue color so prized by plant enthusiasts. Finally, acidic pH conditions in the soil were confirmed as a necessity for blue coloration. Since then, we’ve sharpened our understanding of these components and discovered the importance of co-pigments in determining floral color.

How these puzzle pieces fit together is an ongoing discussion. Let’s look at each part.

pH

In general, researchers have found that highly acidic soils (pH 3.5 to 5.5) produce blue hydrangeas, while slightly acid to slightly alkaline soils (pH 5.5 to 7.5) favor pink or red flowers. We can temporarily overcome soil pH limitations to influence hydrangea flower color; as every gardener knows, adding lime raises soil pH and might induce pink flowers, while ammonium sulfate can acidify the soil and enhance hydrangea bluing.

Interestingly, this pH relationship is reversed within the pigment-containing cells themselves, with red pigments requiring a much more acidic environment (pH 3.3) than blue pigments (pH 3.6 to 5.5). It’s been proposed that this higher pH range is necessary for color stabilization of the blue pigment complex, which we’ll discuss later.

Nutrients

Many of the early studies on hydrangeas explored the effects of nitrogen-phosphorus-potassium (NPK) fertilizers on flower color. Researchers generally found that phosphate stimulated pink and inhibited blue flowers. Increasing nitrogen, especially in the presence of phosphorus, decreases the intensity of blue coloring. Conversely, higher levels of potassium tended to improve bluing.

These earlier studies often inferred that plant nutrients could directly change pigment content, but this isn’t entirely accurate. However, the relative concentrations of phosphate, nitrogen, and potassium do have significant impacts on the uptake and activity of aluminum—an element that can drastically change the visual appearance of anthocyanin pigments.

Aluminum

Soil acidity appears to be directly related to the availability

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of certain heavy metals, most especially aluminum. Under alkaline conditions, aluminum is bound to the soil; as acidity increases, aluminum is released, taken up by hydrangea roots, and transported to floral tissues. Here it's stored in the vacuoles of the cells, where an acidic pH is also maintained.

Aluminum, a toxic heavy metal, is required for blue sepals in hydrangea. Experimentally, bluing is obtained using the various aluminum sulfates; aluminum chloride and aluminum nitrate are often toxic. There are some other metals—specifically calcium, cobalt, iron, nickel and silicon—that may be associated with flower color, but the evidence is largely circumstantial.

Like other metal elements, aluminum is naturally bound to clay particles in the soil. In alkaline soils, aluminum is bound quite tightly and is not easily taken up by plant roots. With increasing acidity, clay particles release aluminum which is readily taken up by some plant species, including hydrangeas. Soilless media, however, do not contain or retain aluminum, and growing blue cultivars in these mixes is challenging. Zeolite (found in non-clumping cat litter) and kaolite both contain aluminum and can be added to soilless media to promote bluing.

Though red hydrangeas also accumulate aluminum, they have much less of this metal

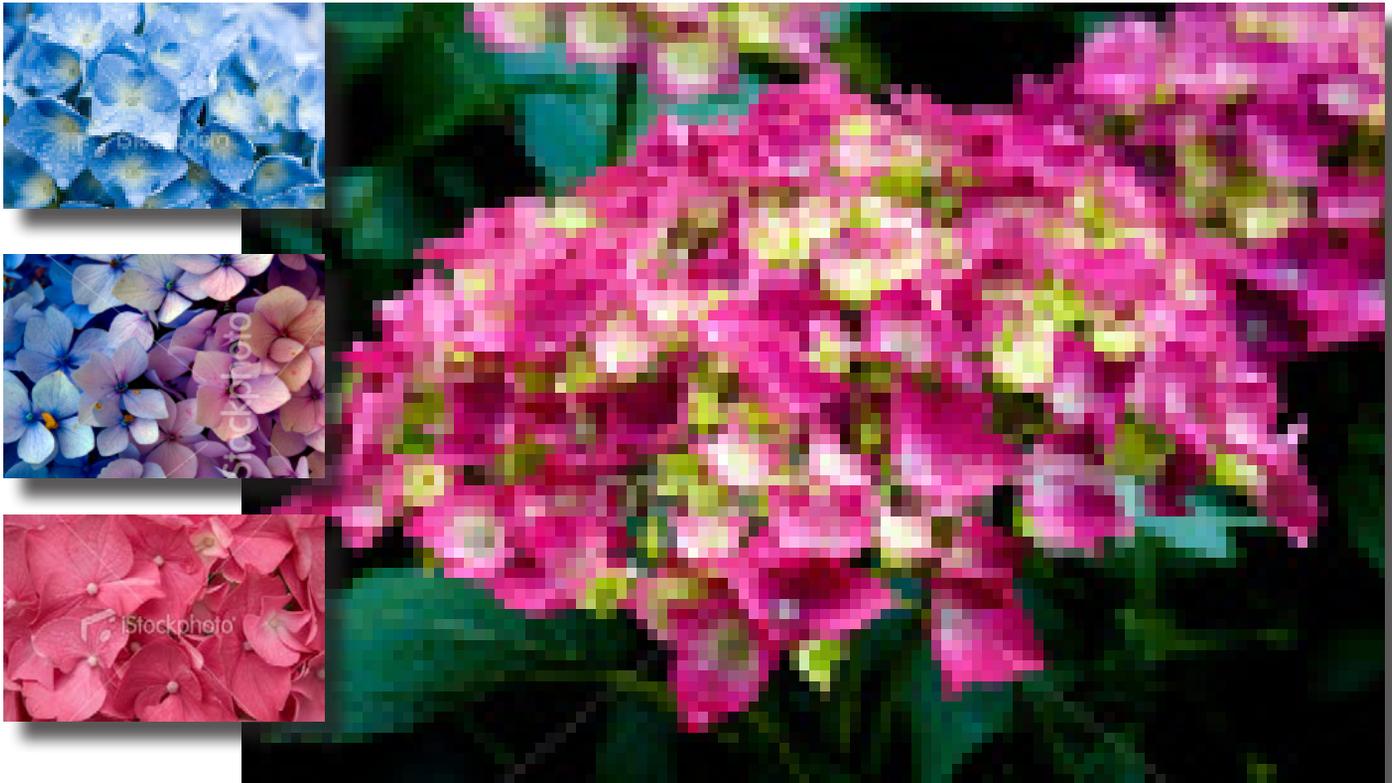
than the blue cultivars. Plant nutrition can influence aluminum accumulation and thus modify floral color. Addition of phosphate can tie up aluminum in acid soils, decreasing root uptake and inducing pinker flowers. Conversely, increasing potassium enhances aluminum uptake and accumulation. Such treatments are more effective in a container than in a landscape, since the root zone is restricted and more easily influenced.

Many plants are inhibited by aluminum and exhibit toxic effects; in high enough amounts, aluminum deactivates enzymes and shuts down metabolic pathways. Such plants protect their enzymes by excluding uptake at the roots, but hydrangeas actually accumulate aluminum in their flowers and leaves. They apparently can detoxify the element in their cells by binding it to citric acid, forming aluminum citrate. In fact, hydrangeas not only tolerate but may actually require aluminum to stimulate nutrient uptake and plant growth.

Accumulating a toxin like aluminum may also help protect hydrangeas from predators including insects, birds, and livestock (is it just coincidental that foliage and flowers of hydrangeas in the landscape rarely show signs of herbivory?). For considering its role in floral color, however, aluminum appears to be most important in stabilizing the anthocyanin pigment complex.



by Dr. Linda Chalker-Scott



Hydrangea coloration is determined by a complex relationship that is far more involved than simply regulating the soil's pH or choosing the species recommended to give a specific color. On opposite page, the hydrangeas seem to defy reason with a kaleidoscope of color.

WHY NO BLUE ROSES ?

Those of you who are chemistry geeks, this sidebar article is for you! And for those who are just about to turn the page—hang on! You'll be able to understand why the absence of blue flowers in some species isn't just a matter of bad luck in breeding.

The coloring responsible for bright red roses to vibrant purple lilacs to deep blue delphiniums is derived from anthocyanins (antho=flower and cyan=blue). These pigments are stored in cell vacuoles—miniature, water-filled balloons containing an assortment of organic acids, salts, minerals, and other dissolved chemicals. While all flowers in the red-purple-blue continuum contain some sort of anthocyanin in their vacuoles, the overall vacuolar contents vary dramatically among species:

Pigment type. Two of the most common are delphinidin, necessary for many blue flowers, and cyanidin, needed for many red flowers. Still others are known as well, and possibly many, many others not yet discovered and named.

Pigment modification. The basic pigment structures of delphinidin and cyanidin are modified when enzymes attach sugars and other organic compounds to them.

Pigment concentration. Many flowers contain more than one type of anthocyanin, and their relative concentrations are important in flower color.

Co-pigments. Flowers often contain other non-anthocyanin pigments.

Vacuole pH. Vacuoles are usually acidic, as they contain dissolved organic acids. However, the pH can vary significantly depending on chemical content, environmental conditions, or genetic disposition.

Metal content. Many anthocyanins are associated with metal ions, such as aluminum, and magnesium.

Genetic variability. It's often suggested that every plant species manufactures at least one unique biochemical, and that includes anthocyanins. Moreover, the relative concentrations of various pigments, co-pigments, and metals will differ among species.

Environmental variability. Soil mineral content, temperatures, light availability, and many other non-living and living factors strongly affect what plants store in their vacuoles.

Many researchers have investigated the genetic components of flower color; it turns out that roses lack part of the enzymatic pathway responsible for manufacturing delphinidin, the blue pigment. However, as a group of orchid researchers point out, developing blue flowers requires more than just inserting delphinidin genes into a plant's DNA. Ultimately, flower color is determined by what's inside the vacuoles, once thought to be nothing but cellular garbage dumps. It seems that the Rodney Dangerfield of plant cells gets the last laugh this time. ■

Pigments and co-pigments

Though anthocyanins were identified many decades ago as the pigments responsible for hydrangea coloration, researchers are still fine-tuning our understanding of how pigment color shifts when chemically modified. This modification could be an interaction with aluminum as just discussed, or a sugar molecule piggy-backed onto an anthocyanin, or an association with a co-pigment.

Based on research thus far, it is clear that blue hydrangea flowers depend on the formation of a complex among three partners: an anthocyanin called delphinidin with a sugar attachment, a phenolic acid co-pigment, and aluminum. Laboratory research

has found that neither aluminum nor the co-pigment mixed independently with delphinidin can produce the blue color; all three are required.

Other color outcomes have been determined as well; slight tweaking of the co-pigments will impart purplish hues to flowers. Substituting a cyanidin pigment for the delphinidin will impart a red color, even in the presence of aluminum and at acidic pHs.

Pigments, pH, aluminum, and nutrients are four parts of the color conundrum; still other factors include genetic and environmental influences. Fortunately, you don't need a degree in plant biochemistry to grow gorgeous hydrangeas—but now you should have a better idea of how they get that way. ■



Tips for growing great hydrangeas in your landscape

Test your soil pH before selecting hydrangeas; blue cultivars are best in strongly acid soils, while pink and white hydrangeas do well under weakly acid to weakly alkaline conditions. Adding lime will temporarily raise soil pH, while ammonium sulfate will lower it.

Hydrangeas flower poorly if exposed to low temperatures, particularly early fall or late spring freezes. Plant hydrangeas in locations where they are protected from low temperatures, or insulate them well during dormancy. Chicken wire enclosures filled with autumn leaves are a cheap and effective strategy.

Flower color will be more intense with direct sunlight. Alternatively, green flowers can often be produced by blocking sunlight after flowers have opened.

Hydrangeas are temperate species that need a lengthy cold period to flower; they will not flower well in warmer regions.

Aluminum is crucial for bluing; however, I would not

recommend adding aluminum to your landscape soil. This toxic heavy metal is tolerated by hydrangea, but other plants, plant consumers, and soil organisms can be harmed by excessive aluminum levels. If your landscape soils don't naturally contain enough aluminum to support blue hydrangeas (easily determined through an inexpensive soil test), grow them in large containers instead and add aluminum sulfate to this isolated system during the flowering stage. Since soilless media do not contain or retain aluminum, you'll need to add an aluminum source such as kaolite, zeolite or aluminum sulfate.

To promote blue flowers, avoid adding any phosphate and keep nitrogen at low to moderate levels; higher levels of potassium may help. Pink flowers can be encouraged by increasing both nitrogen and phosphorus but keeping potassium levels low. ■