Characterization of *Hydrangea macrophylla* Cultivars by the Anthocyanin Content in their Sepals

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**Abstract**

In order to ascertain the role of anthocyanin content on the color and brightness of *Hydrangea macrophylla* sepal, anthocyanin contents of different colored sepal were measured for numerous commercial cultivars. Anthocyanin contents were primarily determined by extraction of the pigment, then measurement by differential spectrophotometry. Concentrations ranged from about 25 to over 400 μg delphinidin-3-glucoside per g of fresh sepal, with the magnitude roughly proportional to the perceived intensity of sepal coloration for that *Hydrangea macrophylla* cultivar. However, the anthocyanin content was independent of the sepal color, being the same for red, purple, or blue sepal of the same cultivar. Even though significant sepal-to-sepal variation in color intensity existed within a single inflorescence, the extractable anthocyanin content was constant for a specific cultivar. Accordingly, *Hydrangea macrophylla* cultivars were classified in terms of their color brightness or anthocyanin content in sepal as blush (very light colored, 25 to 60 μg·g⁻¹), cold-hardy (light colored, 80 to 120 μg·g⁻¹), classic (medium colored, 140 to 190 μg·g⁻¹), vivid (deep colored, 230 to 270 μg·g⁻¹), or vibrant (very deep colored, >300 μg·g⁻¹) at peak bloom. The anthocyanin content of the sepal steadily increased as the inflorescence approached peak bloom, remained constant for a week or more, then decreased. The cultivar-dependent anthocyanin contents of the sepal can be used, in part, to rationalize the relative bluing capability of the various *Hydrangea macrophylla* cultivars.

**Index words:** anthocyanin, hydrangea, sepal, cultivar classifications, bluing, delphinidin-3-glucoside.

**Species used in this study:** *Hydrangea macrophylla*.

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**Significance to the Nursery Industry**

The brightness of the red, purple, and blue colors in the sepal of inflorescences on *Hydrangea macrophylla* cultivars is controlled by the anthocyanin content unique to each cultivar. This study has quantified the anthocyanin content of each cultivar, and has thus categorized the cultivars in terms of the brightness or intensity of color in their sepal. If one assigns a scale from very light colored to very deep colored for sepal brightness, examples of representative cultivars range from the very light colored of ‘Blushing Bride’ and ‘Regula’, to the light colored of ‘Penny Mac’ and ‘Endless Summer’, to the medium colored of ‘Red Star’ and ‘Blue Danube’, to the deep colored of ‘Hamburg’ and ‘Pia’, and finally to the very deep colored of ‘Forever Pink’ and ‘Kardinal’. Sepals of a specific cultivar show the same color intensity or anthocyanin content regardless of its red, purple, or blue color. This quantification allows nurseries to market specific *Hydrangea macrophylla* cultivars by the plant’s color intensity of sepal, as customer or landscaper preferences for hydrangea inflorescences may range from pale or pastel color intensity to dark or vibrant brightness.

The anthocyanin content of the sepals may also, in part, help define the threshold aluminum content of soil needed to change the sepals of *Hydrangea macrophylla* inflorescences from red to blue. Gardeners want to avoid adding more aluminum sulfate than necessary for sepal bluing, because of potential toxicity to neighboring plants. Bluing requires the aluminum content in the sepal to be in a specific molar excess of the anthocyanin content (12, 27). Indeed, this study argues that different cultivars may require different levels of aluminum sulfate to change sepals from red to blue depending on their anthocyanin content.

**Introduction**

*Hydrangea macrophylla* is a landscape shrub that continues to grow in popularity with the introduction of commercially-available remontant and cold-hardy cultivars, as well as cultivars with interesting or novel sepal colors. With a profusion of color from its many and showy inflorescences, *Hydrangea macrophylla* is often the focal point...
Aluminum, as Al\(^{3+}\), complexes with this anthocyanin (34). Sepals change color to blue when 
Hydrangea macrophylla 
cultivars is the anthocyanin del-
phinidin-3-glucoside (34). The sepals comprising the in-
termediate pH can lead to a continuous spectrum of sepal 
colors from lavender to purple to violet, enhancing the charm 
of many summer gardens. Gardeners can even control the 
color of these inflorescences, as the sepal colors on many 
Hydrangea macrophylla 
cultivars are sensitive to the soil pH. The sepals comprising the inflorescences are red for plants 
grown in basic soils, but blue for those in acidic soils. Soils of 
intermediate pH can lead to a continuous spectrum of sepal 
colors from lavender to purple to violet, enhancing the charm 
of 
Hydrangea macrophylla with its color variability.

The pigment providing the red color to sepals of all 
Hydrangea macrophylla 
cultivars is the anthocyanin del-
phinidin-3-glucoside (34). Sepals change color to blue when 
hydridenin-3-glucoside, which then forms a complex with 
the aluminum complex with delphinidin-3-glucoside in 
its red form. The cation of delphinidin-3-glucoside (TOP) and 
the aluminum complex with delphinidin-3-glucoside in 
its blue quinoidal base anion (BOT-

Although the role of Al\(^{3+}\) in the bluing of Hydrangea 
macrophylla 
sepal colors have been established (14), some have 
questioned whether aluminum is the sole cause for bluing 
(21). For example, the vacuolar pH (35) and co-pigment 
profiles (12) for red sepals differ from those of blue sepals. 
Other studies (2, 24) have also reported that the concentra-
tion of delphinidin-3-glucoside is lower in blue than in red 
sepal colors. Nevertheless, recent studies (12) have measured about 
the same concentrations of this anthocyanin in both red and 
blue sepals. In order to model this red to blue transition, 
yet other studies (14, 27) have assumed the concentration of 
delphinidin-3-glucoside to be about the same in sepals of both colors.

A preliminary study (21) has identified unique antho-
cyanin contents in sepals of specific cultivars of Hydrangea 
macrophylla, leading to the potential to classify the various 
hydrangea cultivars by their sepals’ anthocyanin content. 
Such a systematic ordering of the Hydrangea macrophylla 
cultivars with respect to delphinidin-3-glucoside content 
in their sepals may define a subsequent ordering of these 
cultivars with respect to ease of bluing. The cultivars with 
lower anthocyanin contents might be expected to be easier 
to change their sepal color from red to blue than those with 
higher anthocyanin contents, as less Al\(^{3+}\) would be neces-
sary to have an appropriate molar excess of Al\(^{3+}\) over the 
anthocyanin.

The principal objective of this study was to determine 
the delphinidin-3-glucoside content of red, blue, and purple 
sepal colors of representative Hydrangea macrophylla 
cultivars in order to ascertain whether specific cultivars or particular 
colors can be characterized by their sepals’ anthocyanin 
contents. In addition, we investigated certain characteristics of the sepal coloration; that is, the variation of anthocyanin 
content from sepal-to-sepal within an inflorescence as well as 
the changes in anthocyanin content with bloom stage.

Materials and Methods

Most Hydrangea macrophylla 
cultivars were obtained from Hydrangeas Plus® (VanHoose Enterprises LLC, Auro-
ra, OR), although some were acquired from Wayside Gardens (Hodges, SC) and the Center for Applied Nursery Research 
(Dearing, GA). Some inflorescences were harvested from stock planted in containers using Sta-Green Nursery Blend 
Tree and Shrub Planting Mix (soil pH ≈ 7.0). Sepal colors 
were adjusted by chemical additives such as lime (20 g Ca 
per kg dry soil, soil pH ≈ 7.5), aluminum sulfate (650 mg Al 
per kg dry soil, soil pH ≈ 6.0; 1300 mg Al per kg dry soil, 
soil pH ≈ 5.2), and equimolar aluminum sulfate – citric acid 
mixes (soil pH ≈ 0.5 unit lower than that with just aluminum 
sulfate additions). Other inflorescences were harvested from 
mature Hydrangea macrophylla 
shrubs of various ages 
grown in the gardens (soil pH ≈ 6.0 to 6.5) at BackCountry 
Research (Rockbridge County, VA). Osmocote® was used as a fertilizer for all hydrangea plants, whether grown in 
container or garden. Samples of inflorescences were obtained 
during the summers of the seven-year period from 2004 through 2010.

The extractable anthocyanin content of Hydrangea mac-
rophylla 
sepal colors were analyzed by a procedure (21) based 
on a standard method of differential spectrophotometry 
(10). After the anthocyanin was extracted into an acidi-
cified methanol solution, the peak and baseline absorbances (at 
553 nm and 700 nm, respectively) of extract aliquots in two 
phosphate buffers (pH 1 as 0.025 M KCl and pH 4.5 as 0.400 
M NaC\(_2\)H\(_3\)O\(_2\)) were measured. This differential absorbance 
was then related to the anthocyanin content, expressed as 

![Fig. 1. Red flavylum cation of delphinidin-3-glucoside (TOP) and the aluminum complex with delphinidin-3-glucoside in one resonance form of its blue quinoidal base anion (BOTTOM).](http://meridian.allenpress.com/jeh/article-pdf/29/3/131/1757336/0738-2898-29_3_131.pdf)
studies to rapidly measure anthocyanin contents (28). Calibrated meters have been used in the content of accurate non-destructive measurements of the anthocyanin not only in the reported determinations by the extraction/ship. Nevertheless, the calibrations provide con results in Fig. 2 indicate some curvature in these relation-
a prior study (28) showed linear calibrations, the cumulative content of red and blue sepals, respectively (Fig. 2). Whereas index (BACI), were calibrated to the extractable anthocyanin content (RACI) and one the blue anthocyanin content Two separate meters, one measuring the red anthocyanin ly adapted to measure the relative anthocyanin content (28). Content Meters (OptiSciences, Tyngsboro, MA), appropriate-
also determined using (31) or a fully-open color intensity), or alternatively de
anthocyanin contents of
μ delphinidin-3-glucoside per g of fresh sepal. Extraction efficiency of the anthocyanin from the sepals was assumed to be 100%, with the assumption confirmed by standard delphinidin and cyanidin additions. The extractable anthocyanin content was always determined from sepals of delphinidin and cyanidin additions. The extractable anthocyanin content was 110 ± 20 μg·g⁻¹ fresh sepal for four ‘Endless Summer’ inflorescences harvested from pots during summer 2010, and 115 ± 20 μg·g⁻¹ fresh sepal for seven ‘Endless Summer’ inflorescences harvested from the garden during the same time period. The soil pH only controlled the color of the sepal, not the anthocyanin content, regardless of the

Prior to extracting the anthocyanin from the sepals, the anthocyanin contents of Hydrangea macrophylla sepals were also determined using field-portable CCM-200 Chlorophyll Content Meters (OptiSciences, Tyngsboro, MA), appropriately adapted to measure the relative anthocyanin content (28). Two separate meters, one measuring the red anthocyanin content index (RACI) and one the blue anthocyanin content index (BACI), were calibrated to the extractable anthocyanin content of red and blue sepals, respectively (Fig. 2). Whereas a prior study (28) showed linear calibrations, the cumulative results in Fig. 2 indicate some curvature in these relationships. Nevertheless, the calibrations provide confidence not only in the reported determinations by the extraction/measurement methods but also that the meters are capable of accurate non-destructive measurements of the anthocyanin content of Hydrangea macrophylla sepals. Accordingly, the calibrated meters have been used in the field in this and prior studies to rapidly measure anthocyanin contents (28).

Results and Discussion

Extractable anthocyanin content. Table 1 summarizes the extractable anthocyanin contents of the selected Hydrangea macrophylla cultivars with red/pink, purple, and blue inflorescences. For a specific cultivar, the sepals’ anthocyanin content did not vary with plant source, whether grown in a container or in the garden. For example, the anthocyanin content was 110 ± 20 μg·g⁻¹ fresh sepal for four ‘Endless Summer’ inflorescences harvested from pots during summer 2010, and 115 ± 20 μg·g⁻¹ fresh sepal for seven ‘Endless Summer’ inflorescences harvested from the garden during the same time period. The soil pH only controlled the color of the sepal, not the anthocyanin content, regardless of the

Table 1. Extractable anthocyanin content (μg delphinidin-3-glucoside per g of fresh sepal) of sepals for Hydrangea macrophylla cultivars. The number of separate inflorescences analyzed of a specific color is provided in parentheses. The average value includes analyses of all colors. Average standard deviation in all analyses is ± 20 μg·g⁻¹. Variation from inflorescence-to-inflorescence of a particular cultivar is about the same as the year-to-year variation shown in Table 2.

| Cultivar                 | Pink-red | Purple | Blue | Avg. |
|-------------------------|----------|--------|------|------|
| Lanarth White           |          |        |      | 4    |
| —— blush (very light colored) ↓ |          |        |      |      |
| Blushing Bride‘         | 27 (1)   | 27     |      | 27   |
| Regula‘                 | 50 (2)   | 50     |      | 50   |
| VanHoose White‘         | 50 (1)   | 50     |      | 50   |
| Lilacin‘                | 60 (3)   |        |      | 60   |
| —— remontant and cold-hardy (light colored) ↓ |          |        |      |      |
| Penny Mac               | 70 (13)  | 90 (3) | 100 (8) | 80   |
| Nikko Blue              | 80 (8)   | 100 (1) | 80 (6) | 80   |
| Dooley                  | 70 (1)   | —      | 120 (2) | 100  |
| Endless Summer™         | 115 (18) | 90 (11) | 100 (17) | 105  |
| David Ramsey            | 100 (1)  | —      | 110 (4) | 110  |
| General Vicosmesse de Vibraye | 80 (1) | 120 (5) | 130 (8) | 120  |
| All Summer Beauty       | 100 (4)  | —      | 130 (8) | 120  |
| Forever and Ever        | 120 (2)  | —      | —      | 120  |
| —— classic (medium colored) ↓ |          |        |      | 140  |
| Bottstein               | 140 (5)  | —      | —      | 140  |
| Blue Danube             | 140 (13) | 190 (8) | 150 (9) | 160  |
| Red Star                | 160 (2)  | 160 (1) | —      | 160  |
| Blauer Zwerg            | 190 (5)  | —      | 120 (1) | 180  |
| Mathilda Gugutes        | 200 (3)  | 150 (1) | 200 (1) | 190  |
| Tovelit                 | 190 (3)  | —      | —      | 190  |
| —— vivid (deep colored) ↓ |          |        |      |      |
| Eisvogel                | —        | 210 (2) | —      | 210  |
| Alpengluehen            | 230 (2)  | —      | —      | 230  |
| Hamburg                 | 230 (1)  | 220 (2) | 250 (1) | 230  |
| Pin                     | 240 (4)  | —      | —      | 240  |
| Masja                   | 270 (4)  | 230 (3) | —      | 250  |
| Enziandom               | 270 (2)  | —      | 270 (2) | 270  |
| —— vibrant (very deep colored) ↓ |          |        |      |      |
| Marechal Foch           | 340 (3)  | 260 (4) | —      | 300  |
| Leuchtfeuer             | 330 (4)  | —      | —      | 330  |
| Forever Pink            | 360 (6)  | —      | —      | 360  |
| Glowing Ember‘          | 420 (5)  | —      | —      | 420  |
| Kardinal                | 420 (2)  | 410 (3) | 480 (2) | 430  |
| Monteforte Pearle‘      | 700 (5)  | —      | —      | 700  |

‘Pink blush phase of ‘white’ inflorescence.‘
‘Measured by RACI calibrated to extractable content.
The sepal anthocyanin content was also independent of the vendor. Likewise, the anthocyanin contents of sepal for a specific cultivar at peak bloom were similar over the seven summers of measurements (Table 2).

Anthocyanin contents among red, purple, and blue sepal were similar for the same cultivar with neither a systematic increasing nor decreasing trend (Table 1). In most cases, the anthocyanin contents for all colors overlap within experimental error. Evidently, the amount of anthocyanin controls only the intensity of the sepal color rather than the hue or color itself.

Other factors such as climate, temperature, fertilizer (for example; nitrogen availability), and sunlight may also affect the anthocyanin content of the sepal of a specific Hydrangea macrophylla cultivar. However, these variables were kept relatively constant in this study, although the contents reported in Table 1 are specific to the Rockbridge County VA (USA) climate. That anthocyanin contents were similar over the seven summers of this study (Table 2) provides evidence for minimal effect of these environmental factors.

Characteristics of anthocyanin content. Interestingly, the sepal within a single inflorescence varied greatly in anthocyanin content. Such analyses had at least 10 to 30% standard deviation, representative of the variation in the color intensities of the individual sepal. Even though an inflorescence appeared to be a homogeneous color, upon closer inspection sepal-to-sepal variation was visually obvious. An example of the actual heterogeneous nature of a typical inflorescence is shown in Fig. 3. Despite this sepal-to-sepal variation in anthocyanin content noted in the inflorescences in numerous cultivars, the average anthocyanin content for a particular cultivar always tended to vary constant.

Anthocyanin content of the sepals of a blue ‘Penny Mac’ inflorescence changed as a function of its stage of blooming (Fig. 4), similar to a red ‘Masja’ inflorescence followed in a previous study (28). Hydrangea macrophylla blooming stages have been defined previously (31). The anthocyanin content of the sepals first rises in the inflorescence’s approach (stages I and II) to full bloom, remains relatively constant for about a week or so at peak bloom (stage III), and then steadily falls once the inflorescence passes its prime (stage IV). The results of this study are consistent with other reports (33) of a threefold decrease in the anthocyanin content of the sepals from stage III to stage IV blooms. The exact length of time for which Hydrangea macrophylla remains at peak anthocyanin content is likely dependent on environmental conditions such as sun and rain. Table 1 lists anthocyanin contents of the sepals when the Hydrangea macrophylla inflorescences were at peak bloom.

Classification of Hydrangea macrophylla cultivars. The Hydrangea macrophylla cultivars are different in terms of their inherent, genetically-controlled delphinidin-3-glucoside

![Fig. 3. Heterogeneity in anthocyanin content of the sepal in a single inflorescence of ‘Forever Pink’ at peak bloom. The number of sepal with a specific RACI (red anthocyanin content index) is plotted as a function of that RACI (with a value of ±1) for the sepal. The RACI mean value for the sepal of this particular ‘Forever Pink’ inflorescence represents an extractable anthocyanin content of ~400 µg g⁻¹ fresh sepal.](http://meridian.allenpress.com/jeh/article-pdf/29/3/131/1757336/0738-2898-29_3_131.pdf)

| Year | Penny Mac | Endless Summer | Blue Danube |
|------|-----------|----------------|-------------|
| 2004 | 75 ± 15   | 90 ± 20        | 145 ± 20    |
| 2005 | 80 ± 10   | 95 ± 15        | 180 ± 20    |
| 2006 | 75 ± 15   | 110 ± 10       | 170 ± 15    |
| 2007 | —         | 105 ± 20       | 180 ± 20    |
| 2008 | 80 ± 15   | 100 ± 20       | 180 ± 30    |
| 2009 | 80 ± 20   | 90 ± 20        | 155 ± 30    |
| 2010 | 85 ± 15   | 115 ± 25       | 175 ± 20    |
content in sepals (Table 1). That one can classify the cultivars by their sepals’ anthocyanin content is somewhat expected, especially in light of fruit and vegetable cultivars being categorized similarly. For example, the various cultivars of blueberries (6, 22), raspberries (7, 13), potatoes (4, 25), and cherries (9) have all been shown to have unique anthocyanin contents.

Even if environmental factors such as light intensity and quality (17), temperature (8, 29), magnesium content (18), and water availability affect the exact anthocyanin content (19) of the hydrangea sepals, the ordering of the cultivars as shown in Table 1 would be expected to remain about the same. However, the anthocyanin content of some floral cultivars of *Hydrangea macrophylla* has been shown to be unresponsive to such environmental effects (30). In addition, changes in anthocyanin content of *Hydrangea macrophylla* sepals for specific cultivars were unrelated to changes in nitrogen, potassium, and phosphorous content of the soil (2). Thus, anthocyanin data in Table 1 may be equally valid for other growing environments and climates.

Suggested classifications of the *Hydrangea macrophylla* cultivars in terms of sepal anthocyanin content or intensity of color are the ‘blush’ (very light colored) cultivars with 25 to 60 μg delphinidin-3-glucoside per g fresh sepal, the ‘remontant and cold-hardy’ (light colored) cultivars with 80 to 120 μg·g⁻¹, the ‘classic’ (medium colored) cultivars with 140 to 190 μg·g⁻¹, the ‘vivid’ (deep colored) cultivars with 230 to 270 μg·g⁻¹, and the ‘vibrant’ (very deep colored) cultivars with 300 and higher μg delphinidin-3-glucoside per g fresh sepal. Such categories allow quantification and description of the intensity of the sepal coloration of the various cultivars.

Within the limits of the sample pool of this study, the remontant (blooms form on new wood) and cold-hardy cultivars always tended to possess the lowest sepal anthocyanin contents of the cultivars with red or blue sepals. Thus, this study may provide a basis for breeding programs trying to enhance the intensity of the coloration, and thus the sepal anthocyanin content, of the remontant cultivars (11). That all remontant and cold-hardy cultivars have similar anthocyanin contents of their sepals is evidence that all are probably genetically related (20). Further, that ‘Penny Mac’, ‘Dooley’, and ‘Nikko Blue’ form one sub-group and ‘Endless Summer’ and ‘David Ramsey’ another sub-group in terms of sepal anthocyanin content is consistent with their genetic relationships (16, 23). However, the representative cultivars in the classic, vivid, and vibrant classifications of sepal color intensity and anthocyanin content do not appear to directly correspond to their reported genetic relationships (23).

*Hydrangea cultivars and bluing of sepals*. Those cultivars that are anecdotally resistant to sepal bluing tended to have the higher anthocyanin contents. For bluing to occur, Al³⁺ has to be in molar excess of anthocyanin in the sepals (27, 31). For example, sepals on cultivars such as ‘Forever Pink’ and ‘Kardinal’ may be difficult to change to blue because ten times more aluminum on a molar basis must be incorporated in the plants to achieve the same aluminum excess over anthocyanin in the sepals than do cultivars such as ‘Penny Mac’ and ‘Nikko Blue’. In fact, the sepals of all remontant and cold-hardy cultivars should be relatively easy to change to blue because of their low anthocyanin content. The ease of bluing of the sepals of these cultivars appears to be generally consistent with observations in the field.

However, the process of sepal bluing may be less than straightforward. For example, ‘Marechal Foch’, ‘General Vicomtesse de Vibraye’, ‘Domotoi’, ‘Enziadom’, and ‘Nikko Blue’ are all reported to be easy to change from red to blue with aluminum sulfate (3, 15, 32) despite their wide variation in anthocyanin content. The cultivars with a higher anthocyanin content in their sepals, nevertheless, result in more intensely colored blues. Just as each *Hydrangea macrophylla* cultivar has its own unique sepal anthocyanin content, perhaps each likewise has its own unique sepal co-pigment content or profile which also contributes to the cultivar’s bluing capability (12). Alternatively, the cultivars with sepals that are easier to change to blue may accommodate the uptake of aluminum more easily from the soil, similar to differential uptake of metal ions by olive cultivars (5). Thus, the list established in Table 1 may be less than a perfect match for bluing capability, as other factors must also be considered; but, the classifications provide a first approximation in bluing capability.

**Anthocyanin content and bloom stage.** The anthocyanin content of *Hydrangea macrophylla* sepals increased to peak bloom, then decreased. The length of the peak flowering or stage III is shown in Fig. 4. The anthocyanin content meter can readily be used to non-destructively monitor this length of peak bloom (28). Interestingly, the Al³⁺ content continues to steadily increase through the bloom stages for blue sepals but remains a constant low value for red sepals (31). Accordingly, the molar ratio of Al³⁺ to anthocyanin is continuously changing with bloom stage. This change may help explain why pink sepals fade to blue as the bloom stage advances to stage IV with the concomitant production of an even richer crescento of colors.

In summary, the anthocyanin content of the *Hydrangea macrophylla* sepals is a measure of the sepals’ color bright-
ness, regardless of the red, purple, or blue coloration. For a particular inflorescence, the anthocyanin content of the sepals steadily increases until peak bloom, then stays constant for more than a week, and finally steadily decreases after peak bloom. Even at peak bloom, there exists a heterogeneous distribution among sepal color intensities, but on the average the anthocyanin content for a specific Hydrangea macrophylla cultivar is constant. The anthocyanin content is used to categorize the cultivars in several groups according to the lightness or deepness of their sepal colors.

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