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Measuring Camellia Petal Color Using a Portable Color Sensor

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Abstract: The color of petals of flowering plants is often determined by comparing one or more of the petals to various Royal Horticultural Society (RHS) Colour Chart cards until a color match is found. However, these cards are susceptible to fading with age and can also provide inaccurate results if lighting is not optimal. The cards also rely on the human eye to determine a match, which introduces the possibility of human error. The objectives of this study were to determine camellia (*Camellia japonica* L.) petal color using the RHS Colour Chart, to determine camellia petal color with the Nix^{TM} Pro color sensor (Nix Sensor Ltd., Hamilton, Ontario, Canada), and to compare these measurements using different color measuring approaches. Color measurements of camellia flower petals using the Nix^{TM} Pro color sensor were compared to published CIELAB values from the Royal Horticultural Society (RHS) Colour Chart. Forty-five petal color samples were collected from fifteen different camellia shrubs. The RHS Colour Chart was used for each of the petals, and the RHS identifications were recorded. Measurements using the Nix^{TM} Pro color sensor were compared to RHS-provided CIELAB values that corresponded with the recorded identification for each petal to determine accuracy. The Nix^{TM} Pro color sensor's measurements were also compared to a mean of the values, multiple measurements on the same petal location, and multiple measurements on different petal locations to determine precision and variation. The Nix™ Pro color sensor's readings were precise in petal color determination and provided more nuanced differences between petals of the same plant and plants of the same variety in each of the color categories. The RHS Colour Chart provided an accurate depiction of most petals, but it was difficult to use with petals that had wide color variation over the entire petal. The Nix™ Pro color sensor's measurements appeared to have more variation in the b* color space. However, overall, the Nix™ Pro color sensor L*, a*, and b* values were highly correlated with the provided RHS values ($p < 0.01$), showing that the sensor can be used as an accurate and precise substitute for the RHS Colour Chart. The Nix™ Pro color sensor can be a useful, cost-effective tool to measure the petal color of camellia and other flowering plants and rectifies many of the problems associated with the RHS Colour Chart.

Keywords: flower; pigment; plant; Royal Horticultural Society (RHS); reflective sensing; remote sensing

1. Introduction

Color is crucial to the survival and reproductive success of many flowering plants because it dictates whether or not insects will be attracted to and ultimately pollinate the plant [1]. A flower's apparent color is governed by the selective absorption of specific wavelengths of light by the petals, as well as by light scattering in the petal's interior [1]. Although the specific variation and signaling of different petal colors are not well understood, all petals function in a similar sense, in that their purpose is to reflect sunlight in a way that attracts a pollinator's attention. However, there is a decreased return in light reflection for increased levels of color, and this fact is compounded by the energy required to produce more pigment [1]. For this reason, flower petals tend to be translucent rather than an energy-intensive solid, opaque color, as the higher rate of visible light reflection has been shown not to attract more pollinators, although petals that are too translucent would fail to attract pollinators [1]. Therefore, plants are in a constant act of balancing not attracting enough pollinators with spending too much energy on pigment production, causing variations in a petal's color value between plants [1].

With a wide variety of colors and conditions that can affect them, there are many different color standards in use. For this research, the CIELAB color space, also known as CIE L*a*b*, was used. The CIELAB color space is defined by planes of constant lightness, L*, in relation to a net of lines parallel to the a* (green to red) and b* (blue to yellow) axes [2]. By calculating color on three axes, the CIELAB standard is able to provide an accurate yet uniform color measurement standard [2]. Unlike the commonly used CMYK and RGB color models, CIELAB is designed to approximate human vision, with the L* value closely matching the human eye's perception of light [3]. It also has the advantage of being able to make minute color balance corrections by changing the a* or b* values, and to adjust the lightness contrast through the L* value [3]. Today, CIELAB is the most complete color space specified by the International Commission on Illumination (CIE) [3]. The L* value is measured on a scale from 0 to 100, where 0 is black and 100 is white [3]. The a* value is measured from −127, which is pure green, to 127, which is pure red [3]. Lastly, the b* value is measured from −127, which is pure blue, to 127, which is pure yellow [3]. This three-dimensional range between colors allows for distance to be calculated between colors, directly proportional to the difference between two colors in the human eye [3].

The color of flower petals is important for horticulturalists because, for ornamental plants such as camellias, petal color is one of the most critical characteristics and serves as a target and benchmark for plant breeding [4]. Petal color is a clear indicator of expressed genes that provides horticulturalists with a valuable pathway towards creating new varieties of ornamental plants, or visually understanding genetic interactions when breeding plants [4]. Furthermore, when some colors are distinctly lacking from ornamental plants (such as the lack of blue in Chinese roses and chrysanthemums), horticulturalists can profit if they breed new colors in popular ornamental plants, due to the novelty and visual appeal, highlighting the economic value that petal color can garner [5]. Petal color can also visually indicate pigments and chemicals present within certain species, as major flavonoid pigments such as anthocyanins and other crucial plant chemicals are directly related to a plant's color [5]. As a result, petal color serves as a trove of information for horticulturalists regarding a plant's genetic and chemical makeup, as well as serving as a visual indicator of genetic interactions from breeding. Thus, petal color provides horticulturalists with an invaluable amount of data, as well as the potential for economic success.

A wide array of physical and optical characteristics can dramatically alter a person's perception of color. Color refers to the part of the electromagnetic spectrum that is visible to the human eye. An object's color is defined by the visible light that is not absorbed, but instead is reflected into the human eye [6]. However, color is not absolute, as many physical conditions can alter the human perception of color. Two principal physical conditions are value, the relative lightness or darkness of a color, and gradation, the physical conditions of the contiguous surface [7]. Both of these conditions are relative, as the value of a color can change with the lighting (i.e., a rainy or sunny day) and the gradient of a color is relative to the surface it is covering. Consequently, human perception of a color can change dramatically just because of a different time of day or due to the presence of a different surface. Furthermore, optical illusions, such as the simultaneous contrast effect, can alter one's perception of a color due to a surrounding color [7]. This optical illusion is often seen when a color is placed on a bright background and the color also seems to become brighter in value, despite no change in the actual color.

The Royal Horticultural Society (RHS), the United Kingdom's leading gardening charity, is one of the oldest and most influential societies in horticulture [8]. The Society was founded in 1804 for the purpose of publishing scientific research, as well as bringing together the foremost researchers in horticulture. The RHS has expanded its collection of research and experimentation within its scientific gardens, however, its members, as well as gardeners around the world, have struggled with identifying and naming plant colors. Starting in the mid-1930s, the RHS addressed this issue by creating a comprehensive manual containing hundreds of defined colors [9]. Since then, the RHS Colour Chart has been constantly improved and is now in its sixth edition. In addition to new and refined colors, the chart has been updated from a book to a fan deck, for easier use in the field. Since its introduction, the RHS Colour Chart has been the universal standard for plant color classification.

The RHS Colour Chart works by arranging a spectral order of fully saturated and progressively less saturated colors, which are to be matched to the plant [10]. The chart functions only if it is used under a natural north light and cannot work with artificial light or direct sunlight. The plant is then placed within the holes of the color chart until a uniform color is formed, which indicates that a matching color and identification has been found. The color chart guide notes that measurements may become increasingly erroneous if the measurer's eyes become fatigued. Furthermore, flowers, which are not homogeneous in color, will not have an exact match and must be described as being close to the matched color. Once a proper match is found, the type of color can be universally described using the RHS Colour Chart naming system. If an exact match cannot be found, then the natural color of the petal cannot accurately be described [4]. This is problematic, as often there is not an exact match between a petal and the color chart, but rather the closest equivalent to the petal's color which is used.

Traditionally, color card matching methods like the RHS Colour Chart has been used as a standard reference for flower color classification. However, these traditional methods rely on human vision to assess color, which varies from person to person. Inexpensive color sensors, such as the Nix™ Pro sensor (Nix Sensor Ltd., Hamilton, Ontario, Canada), used in the present study, can potentially serve as a more reliable and accurate method of assessing color. The Nix™ Pro color sensor was developed to replace printed color charts used in interior design and has revolutionized the market by providing an inexpensive yet accurate color sensor within a mobile body [11]. The Nix™ Pro color sensor has been used in a wide variety of applications, from soil science [12] to meat quality checks [13]. The Nix™ Pro color sensor was used to identify soil color and predict soil organic carbon and total nitrogen [12,14] and soil samples have been compared to the Munsell Soil Color Chart (MSCC) [15]. The purpose of that study was to evaluate if the inexpensive Nix™ Pro color sensor could take accurate, consistent readings, potentially resolving issues with the MSCC's print quality variations and propensity to fade [15]. The study found that the Nix™ Pro color sensor provided repeatable readings that were similar to the much more expensive Konica Minolta CR-400 laboratory colorimeter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ) [15]. The study concluded that the Nix™ Pro color sensor was an excellent alternative to the MSCC method for in-field soil color determination. However, no previous research could be found that utilized the sensor for plant color evaluation.

A wide variety of species fit into the *Camellia* genus. It is home to more than 400 species, with a combination of white, pink, red, and yellow colors. Camellias were originally native to China and Japan's warm subtropical regions, but were introduced to Western gardens during the colonial period [16]. Camellia plants have a large economic value for multiple reasons. The primary reason is that camellia plants are harvested for their oil and tea leaves, with camellia oil fetching a significantly higher market price than other plant-based oils because of its nutritional and medicinal properties [17]. This does not include the large camellia gardening market, which is reliant on accurate color depiction to sell the aesthetically pleasing shrub. Camellias provide a sizeable economic value for their oil and tea yield, as well as through their sought-after beauty. This beauty primarily results from the plant's flowers, and research has found that petal color is the deciding factor in a majority of consumers' decisions when buying an ornamental plant [4]. However, the camellia industry still lacks a widely available and accurate color testing method. Due to the fact that camellias span a vast geographical area, varying environmental conditions can skew human-based color measuring methods. The Nix™ Pro color sensor could help to alleviate this problem by providing an inexpensive way to identify camellia petal color universally. Due to its patented design, which blocks out light and other environmental conditions, the Nix^{TM} Pro color sensor could provide uniform readings. This study compares the use of the Nix^{TM} Pro sensor for petal color classification by comparing it to the current universal RHS Colour Chart identification method. The specific objectives of this study were to: (1) determine camellia petal color with the RHS Colour Chart, (2) assess camellia petal color with the Nix^{TM} Pro color sensor, and (3) compare the measurements of camellia petal color using the Nix^{TM} Pro color sensor and 3rd party color equivalents of the RHS Colour Chart.

2. Materials and Methods

2.1. Site Description

The South Carolina Botanical Garden is an extensive 295-acre garden (Figure 1), founded in 1958 for the purpose of preserving a camellia collection on the Clemson University Campus [18]. Due to this mission, the botanical garden is home to one of America's largest and most diverse camellia collections with over 400 varieties of camellias [19]. The climate of the area is temperate and generally mild to warm year-round, with temperatures occasionally falling below freezing in the winter months. The area receives an average amount of rainfall of 1270 mm annually [20] and the South Carolina Botanical Garden has sizable ponds to act as water reserves. Located in the Piedmont region of South Carolina, the South Carolina Botanical Garden provides a significant variety of camellias to sample, allowing for a large and diverse sampling size.

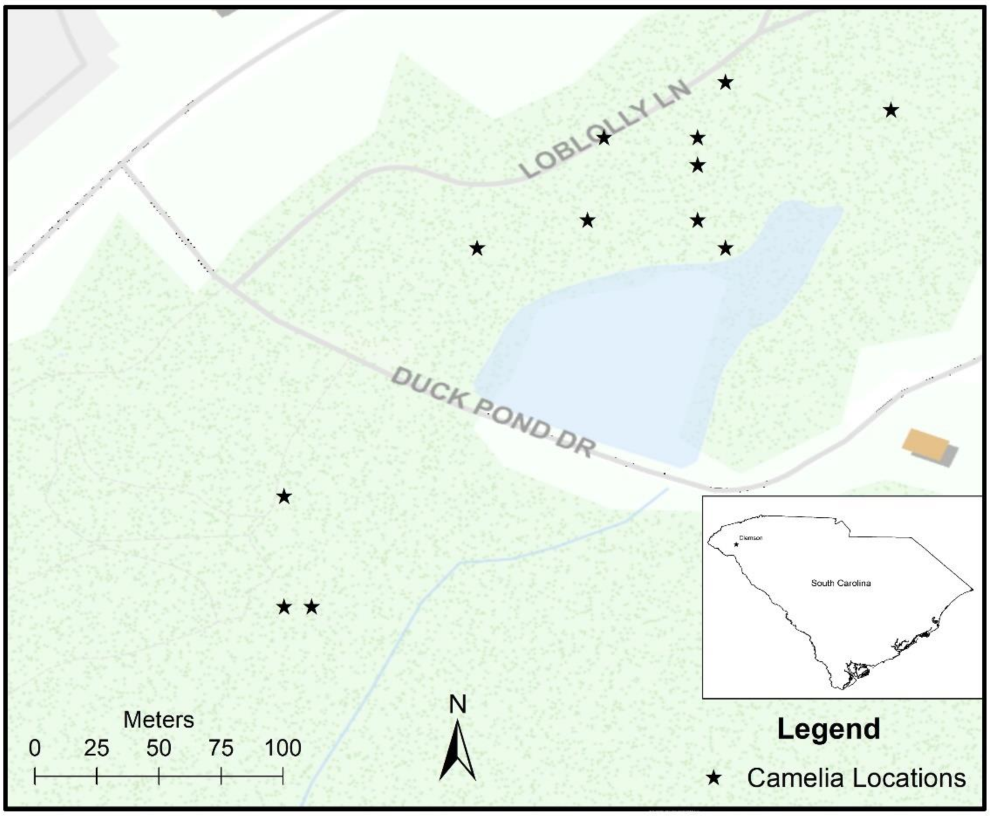


Figure 1. Map of the study area and sampling locations in the South Carolina Botanical Garden in Clemson, SC, USA.

2.2. Data Collection

As explained in more detail by Stiglitz et al. [15], the Nix^{TM} Pro Color Sensor has its own light-emitting diode light source and is controlled through a Bluetooth-connected mobile device. The sensor can output results in a variety of different color systems, including RGB, CMYK, and CIE

L*a*b*. The Nix^{TM} Pro Color Sensor is rechargeable, easily accessible because of its small size, can be recalibrated easily, and is relatively inexpensive (~$350). Data were collected during March of 2020 over several days to assure sampling uniformity among the various camellia shrubs, using steps outlined in the data collection flowchart (Figure 2). Figure 2 describes the general process behind the data collection, as well as the ways in which precision, variation, and accuracy were measured. For accuracy comparison, RHS provided CIELAB values for each of the color card identifications used in comparison to the Nix™ Pro color sensor readings [21].

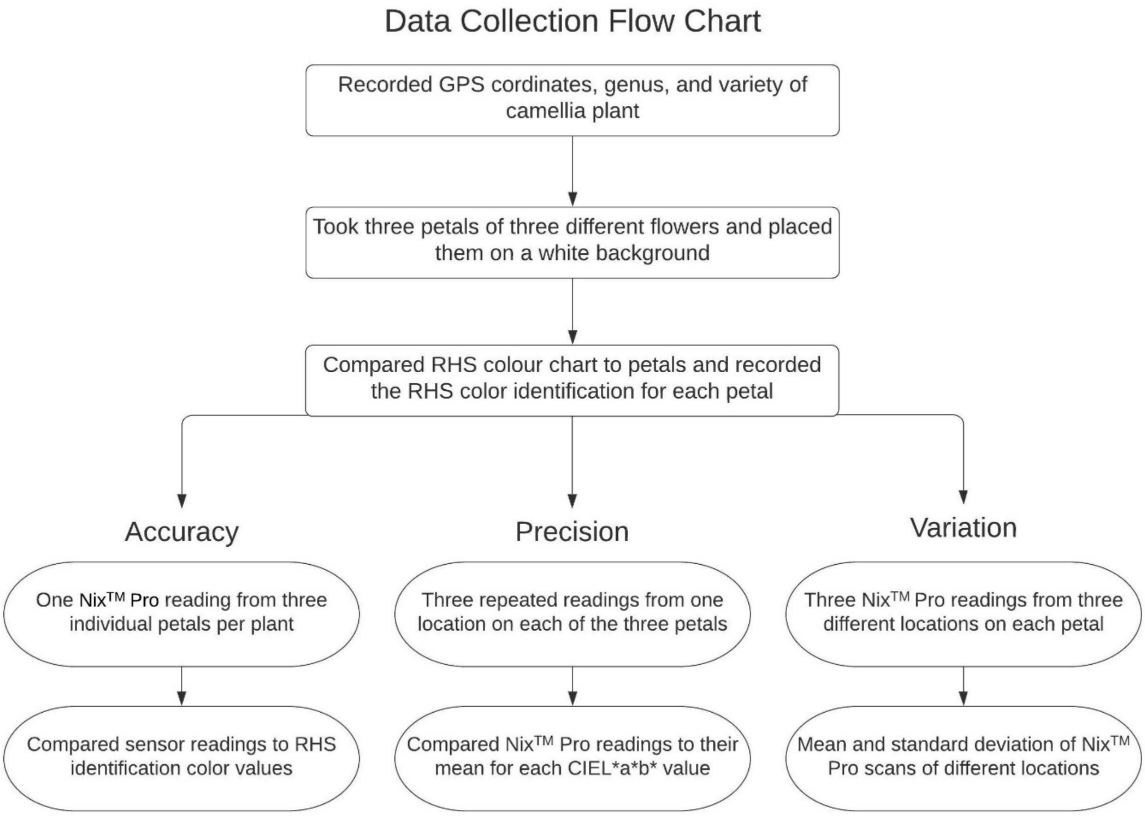


Figure 2. Flowchart of camellia petal color measuring methodology.

The first task was to find a camellia shrub that was in bloom yet had many fresh flowers. Shrubs that were at the end of their blooming cycle or which had browning flowers were avoided. Once a suitable shrub was found, a petal was removed from three different flowers on the same shrub to mitigate color variation between flowers. The petals were then placed on their respective identification number—either 1, 2, or 3 (for categorizing results)—on a white cardboard backing (Figure 3a,b). The RHS fan decks were compared to each petal by the researcher until a match, or the closest color, was found and then recorded (Figure 3a).

The color matching was performed in non-direct sunlight during mid-day to prevent any color skewing by the lighting conditions. Furthermore, a second researcher confirmed each of the RHS measurements as the closest color match to each petal's color. After the three RHS measurements were recorded, the Nix™ Pro color sensor was used on each of the petals and the results were also recorded (Figure 3b). This process was repeated for five white, five red, and five pink camellia shrubs, with a total of 45 different petals being measured with both the RHS and Nix™ Pro color sensor. Table 1 outlines the specific varieties that were sampled, according to their respective color category of white, pink, or red, and Table 2 provides RHS color identifications for each of the three petals for each variety.

(**a**) (**b**)

Figure 3. Example of measuring camellia petal color using: (**a**) the Royal Horticultural Society (RHS) Colour Chart [10], and (**b**) the Nix^{TM} Pro color sensor [11].

Table 1. Sampled camellia (*Camellia japonica* L.) in the South Carolina Botanical Garden with information from the International Camellia Society (2020) [22].

Variety	Information
Color: White	
Snow on the Mountain	Yashiro, Kôken, 1841, Kokon Yôrankô, vol. 310. Originated in Japan.
Chastity	Woodroof 1947, SCCS., Bulletin, vol. 8, No. 6, p. 4; Valley Garden Supply Catalogue,1946–1947.
Masterpiece	Yokoyama & Kirino, 1989, Nihon no Chinka, p. 26, colour photo and description.
Ivory Tower	SCCS., 1968, Camellia Nomenclature, p. 71.
Nuccio's Pearl	Nuccio's Nurseries Catalogue, 1978, p. 12: (N #730l).
Color: Pink	
Marie Bracey	American Camellia Yearbook, 1957, p. 301, Reg. No. 292.
In the Pink	Kramer Nursery Catalogue, 1971: Rose-pink formal double. American Camellia Yearbook, 1979, p. 107, Reg. No. 1541.
Ruth Lennon	American Camellia Yearbook, 1991, p. 80, Reg. No. 2214, colour photo between pages 80–81.
Celestina	Anonymous, Mar. 1832, Revue Horticole, p. 203–204: Double. Light rose, fine form. Originated by Cunningham, England.
Show Time	Nuccio's Nurseries Catalogue, 1978: Light pink semi-double. American Camellia Yearbook, 1979, p. 111, Reg. No. 1528.
Tiffany	Womak, 1962–1963, American Camellia Yearbook, p. 1.
Color: Red	
Scarlet Glory	American Camellia Yearbook, 1984, p. 181, Reg. No. 1953.
Barbara Morgan	Fruitland Nursery Catalogue, 1946–1947, p. 29; Fendig, 1952, American Camellia Catalogue.
Mathotiana	Anonymous, 1847, Gardeners' Chronicle, (27):434. Spae, 1847, Société Royale d'Agriculture et de Botanique de Gand, Annales (1847), 3:459–460, pl. 170.
Dr. Clifford Parks	American Camellia Yearbook, 1972, p. 128, Reg. No. 1210.
Dr. W. G. Lee	Gerbing Azalea Nursery Catalogue Supplement, 1943–1944 as 'Dr Lee's No. 43'.
Joe Holland	Magnolia Gardens and Nursery Catalogue, 1942–1943.

Table 2. The Royal Horticultural Society (RHS) Colour Chart [10] measurements for sampled camellia (*Camellia japonica* L.) in the South Carolina Botanical Garden with information from the International Camellia Society (2020) [22].

Variety	Petal 1	Petal 2	Petal 3
Color: White			
Snow on the Mountain	NN155A	NN155D	NN155D
Chastity	NN155A	NN155D	NN155D
Masterpiece	NN155D	NN155D	NN155D
Ivory Tower	NN155D	NN155A	NN155D
Ivory Tower	NN155D	NN155D	NN155D
Nuccio's Pearl	NN155D	N155D	N155D
Color: Pink			
Marie Bracey	58C	58C	58C
Marie Bracey	55A	55A	55B
In the Pink	47D	47D	52D
Ruth Lennon	55A	55A	55A
Ruth Lennon	55A	55A	55A
Celestina	58C	58C	58C
Show Time	62C	62D	62C
Tiffany	54C	54C	54D
Color: Red			
Scarlet Glory	45B	45B	45B
Scarlet Glory	53C	53B	53B
Barbara Morgan	53C	53C	53C
Mathotiana	53C	52A	53C
Dr. Clifford Parks	45B	45B	45B
Dr. W. G. Lee	46C	46C	46C
Joe Holland	50A	50B	50A

NOTE: RHS chip numbers with corresponding colors are NN155A = yellowish white, NN155D = white, N155D = yellowish white, 58C = strong purplish red, 55A = deep purplish pink, 55B = strong purplish pink, 47D = deep pink, 52D = strong pink, 62C = light purplish pink, 62D = pale purplish pink, 54C = strong pink, 54D = moderate purplish pink, 45B = vivid red, 53C = strong red, 53B = strong red, 46C = vivid red, 50A = strong red, 50B = deep pink.

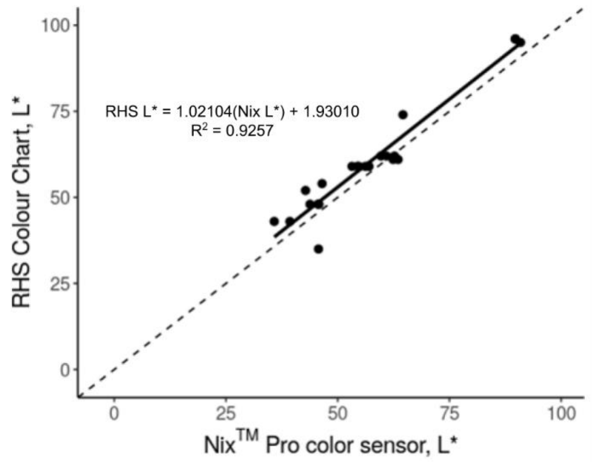
2.3. Statistical Analysis

Packages Lattice and GGplot2 within R Studio were used for the data analyses and graphs [23]. Lattice was used to produce some of the figures instead of GGplot2 due to its ability to easily incorporate multiple sets of data within a single graph [24]. However, GGplot2 was used to calculate *p*-values and R-squared values due to its ability to quickly provide a wide range of calculations [25]. GGplot2 was used to create figures, as well as for the analyses. All of the tables were created in Microsoft Excel, and the table statistics were also calculated in Microsoft Excel.

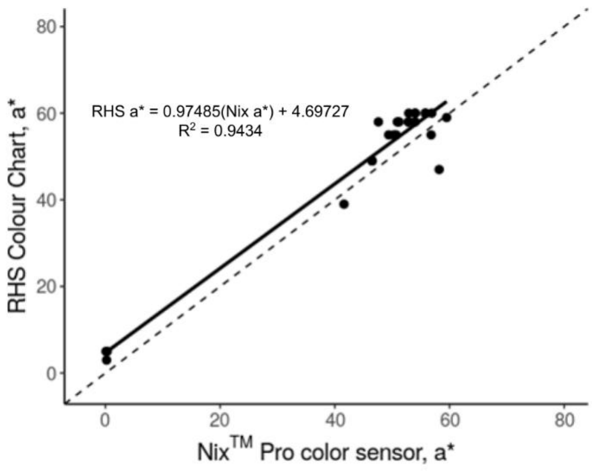
3. Results and Discussion

3.1. Accuracy

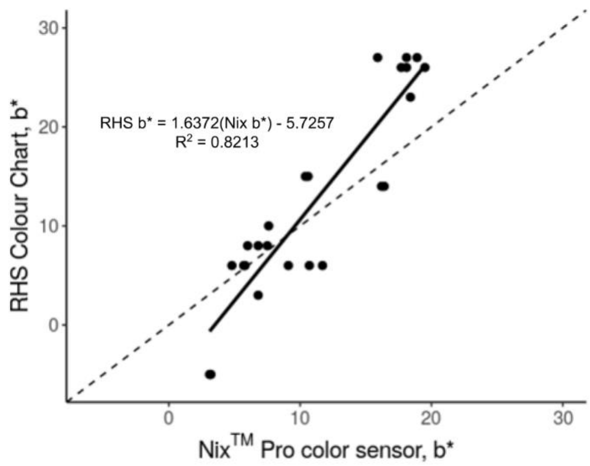
Accuracy was measured by comparing the Nix™ Pro color sensor L*, a*, and b* values of a petal to the provided corresponding L*, a*, and b* values of the RHS identification, and extraneous values were removed (Figure 4). The corresponding L*, a*, and b* values of the RHS identifications are contained in Table 3. Overall, there was a significantly low *p*-value and high R-squared value for each of the results. The L* value had a p-value < 0.01 and R-squared of 0.9257, a* value had a p-value of < 0.01 and R-squared of 0.9434, and b* value had a p-value of < 0.01 and R-squared of 0.8213. Overall, the *p*-value was less than 0.01; therefore, the null hypothesis (that there is no correlation between the Nix™ Pro color sensor's and RHS's measurements) can be rejected. The Nix™ Pro color sensor provides significantly similar results to the RHS values provided on the identification cards.



(**a**)



(**b**)



(**c**)

Figure 4. Comparison of Nix^{TM} Pro sensor color values to Royal Horticultural Society (RHS) Colour Chart published values for: (**a**) L* (darkness to lightness), (**b**) a* (redness to greenness), and (**c**) b* (yellowness to blueness). The dashed line represents perfect agreement.

Table 3. The Royal Horticultural Society (RHS) Colour Chart [10] identification and corresponding color measurements [21].

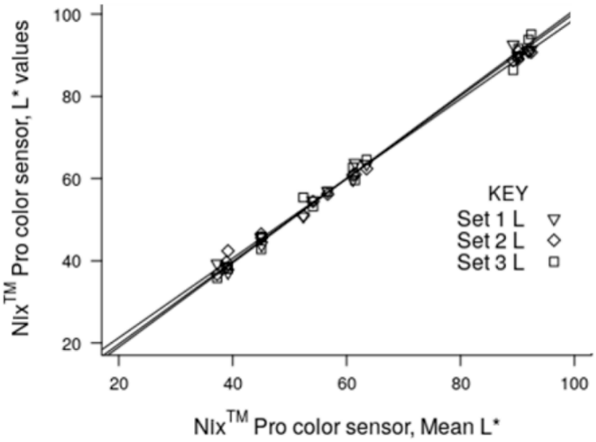
RHS Colour	L*	a*	b*
NN155A Yellowish White	95	3	3
N155D White	92	6	−1
NN155D White	96	5	−5
NN155B White	95	4	−1
N45B Moderate Red	35.3	56.6	18.1
N45C Moderate Red	39.5	54.6	17.5
53C Strong Red	46	56	14
58C Strong Purplish Red	59	58	6
62C Light Purplish Pink	80	29	−5
62D Pale Purplish Pink	86	17	−3
54C Strong Pink	68	37	3
54D Moderate Purplish Pink	78	28	3
55A Deep Purplish Pink	62	55	8
55B Strong Purplish Pink	69	43	−1
45B Vivid Red	43	60	27
46C Vivid Red	48	60	26
50A Strong Red	50	59	24
50B Deep Pink	57	53	18
51A Strong Red	52	55	14
52A Vivid Red	54	59	23
53C Strong Red	46	56	14
52D Strong Pink	74	39	10
47D Deep Pink	61	49	15
46D Deep Yellowish Pink	52	56	21

NOTE: L* (darkness to lightness), a* (redness to greenness), and b* (yellowness to blueness).

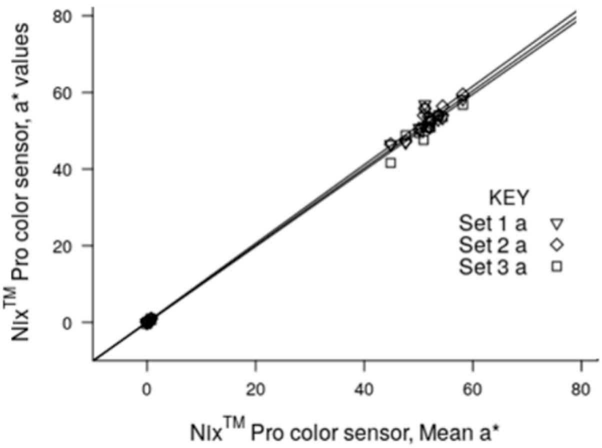
For the R-squared values, over 92% for the L* value, 94% for the a* value, and over 82% for the b* value observed variation can be explained by the model's inputs. Again, this demonstrates a high correlation between the CIELAB values taken by the Nix™ Pro color sensor and the values provided by the RHS Colour Chart identification. Consequently, the Nix™ Pro color sensor's results make a compelling case as a substitute for the RHS Colour Chart card system. Interestingly, the b* value varies more than the L* and a* values, which correlates with the Nix™ Pro color sensor's high standard deviation b* value in the precision section of the results. This may reinforce the earlier observation that the Nix™ Pro color sensor may have more difficulty processing the b* color range, leading to more variation in the results.

3.2. Precision

Precision of the Nix™ Pro color sensor was determined by comparing the individual values of L*, a*, and b* to their respective mean values (Figure 5). For the L* values, among the different data sets, the lowest R-squared value was 0.9938, indicating a low variation between the three L* value data sets and the mean (Figure 5a). For the a* values, the lowest R-squared value was 0.9944, reflecting a low variation between the three a* value sets and the mean (Figure 5b). For the b* values, the lowest R-squared value was 0.9647, suggesting a slightly higher but still low variation between the b* values and their mean (Figure 5c). These high R-squared values signify little difference between the individual measurements and their overall mean, indicating a high overall precision. However, there was slightly higher variation with the b* value (blue to yellow) among measurements, indicating that the color sensor may have a harder time precisely measuring this range. Another measure of precision is the variation between three repeated measurements on the exact same location of the petals (Table 4). The Nix™ Pro color sensor had a very high precision between measurements on the same location, with the highest standard deviation being 0.6 (Table 4).



(**a**)



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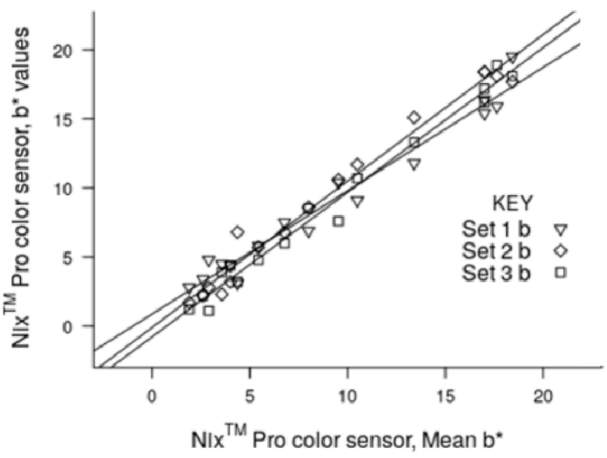

(**c**)

Figure 5. Comparison of Nix^{TM} Pro sensor color values to Royal Horticultural Society (RHS) Colour Chart published values for: (**a**) L* (darkness to lightness), (**b**) a* (redness to greenness), and (**c**) b* (yellowness to blueness).

Table 4. Mean (standard deviation) of three Nix^{TM} Pro color sensor readings from one location within each of three sampled petals from the same camellia plant for each sampled plant.

Variety	L*	a*	b*
Color: White			
Nuccio's Pearl			
- Petal 1	88.3 (0.1)	1.9 (0.0)	3.9 (0.0)
- Petal 2	87.3 (0.1)	1.0 (0.0)	9.0 (0.0)
- Petal 3	87.5 (0.0)	1.6 (0.0)	5.7 (0.0)
Color: Pink			
Show Time			
- Petal 1	73.2 (0.1)	34.8 (0.1)	5.1 (0.0)
- Petal 2	79.0 (0.0)	23.8 (0.0)	1.9 (0.0)
- Petal 3	66.3 (0.1)	33.9 (0.1)	3.3 (0.0)
Tiffany			
- Petal 1	69.1 (0.1)	38.9 (0.1)	5.3 (0.0)
- Petal 2	69.6 (0.1)	40.8 (0.0)	6.0 (0.0)
- Petal 3	65.7 (0.6)	41.9 (0.2)	7.8 (0.1)
Color: Red			
Scarlet Glory			
- Petal 1	38.0 (0.0)	46.1 (0.1)	12.7 (0.0)
- Petal 2	38.4 (0.0)	47.8 (0.0)	11.8 (0.0)
- Petal 3	44.1 (0.1)	55.0 (0.0)	17.8 (0.0)
Joe Holland			
- Petal 1	46.8 (0.2)	51.2 (0.1)	12.2 (0.1)
- Petal 2	50.1 (0.1)	49.4 (0.1)	10.6 (0.0)
- Petal 3	44.1 (0.6)	50.0 (0.0)	7.9 (0.0)

NOTE: L* (darkness to lightness), a* (redness to greenness), and b* (yellowness to blueness).

Camellias in the white category had almost no deviation with a maximum deviation of 0.1. Red and pink also had minimal deviation overall; however, the varieties 'Tiffany' and 'Joe Holland' had a higher L* value deviation of 0.6. This higher standard deviation does not imply a deficiency with the Nix™ Pro color sensor, as later results reflect that these varieties have a higher color variation over their petals.

3.3. Variation

Nix™ Pro color sensor variation was measured by the standard deviation of readings from three different locations on the same petal (Table 5). Although high, the standard deviation values between the three readings were almost all under 3.0 and most were closer to 1.0. Certain varieties, such as 'Tiffany' and 'Joe Holland', had a high standard variation of over 6.0, reflecting a higher color variation over the petal. This corresponds to the high standard deviation found for these varieties in the precision section of the results. The final measurement of variation was the difference between different measurements of petals from the same camellia plant (Table 6). Despite readings being taken from separate petals, the standard deviation between petals was quite low when outliers were excluded. Measurements for each variety were within a certain range, demonstrating the Nix™ Pro color sensor's ability to distinguish variety, even within the same color category, by their L*, a*, b* values. For example, when outliers were excluded, both 'Show Time' and 'Tiffany' are within the pink category, but 'Show Time' had an a* value range (green to red) of 17.3–23.8 and 'Tiffany' had an a* value range of 31.9–36.9 (Table 6). Each variety had its own unique green-to-red range, suggesting that varieties could be distinguished by their color range. Overall, the Nix™ Pro color sensor had high precision, with high R-squared values and relatively low standard deviations.

Table 5. Mean (standard deviation) of the Nix^{TM} Pro color sensor readings from three petals from the same camellia plant for each plant sampled.

Variety	L*	a*	b*
Color: White			
Snow on the Mountain	92.4 (2.4)	−0.1 (0.3)	4.0 (0.7)
Chastity	89.2 (3.1)	0.7 (0.4)	2.9 (1.9)
Masterpiece	91.9 (1.6)	0.8 (0.2)	1.9 (0.8)
Ivory Tower	90.1 (0.7)	0.2 (0.1)	4.4 (2.1)
Ivory Tower	90.1 (1.3)	0.03 (0.1)	3.6 (1.1)
Nuccio's Pearl	87.6 (0.8)	1.8 (1.0)	6.5 (3.5)
Color: Pink			
Marie Bracey	54.1 (0.8)	52.2 (1.1)	5.4 (0.6)
Marie Bracey	52.4 (2.6)	47.6 (1.0)	2.6 (0.7)
In the Pink	63.5 (1.1)	44.9 (2.8)	9.5 (1.7)
Ruth Lennon	61.1 (1.5)	50.1 (0.7)	6.8 (0.8)
Ruth Lennon	61.5 (2.1)	52.0 (1.2)	8.0 (0.1)
Celestina	56.7 (0.4)	50.9 (3.2)	10.5 (1.3)
Show Time	72.0 (7.1)	31.8 (6.9)	3.5 (1.7)
Tiffany	57.2 (6.1)	40.7 (2.4)	22.9 (13.2)
Color: Red			
Scarlet Glory	39.2 (2.8)	54.4 (1.7)	17.0 (1.5)
Scarlet Glory	39.9 (3.7)	48.3 (5.9)	13.2 (4.4)
Barbara Morgan	38.9 (0.7)	51.8 (1.6)	13.4 (1.7)
Mathotiana	45.0 (1.9)	58.2 (1.4)	17.0 (1.2)
Dr. Clifford Parks	37.3 (1.8)	53.6 (0.6)	17.6 (1.6)
Dr. W. G. Lee	45.1 (1.1)	56.2 (0.6)	18.4 (0.9)
Joe Holland	52.9 (6.1)	50.3 (1.1)	10.1 (1.8)

NOTE: L* (darkness to lightness), a* (redness to greenness), and b* (yellowness to blueness).

Table 6. Mean (standard deviation) of one Nix^{TM} Pro color sensor's readings from three locations within each of three sampled petals from the same camellia plant.

Variety	L*	a*	b*
Color: White			
Nuccio's Pearl			
- Petal 1	88.0 (3.2)	1.1 (1.1)	5.8 (2.8)
- Petal 2	86.8 (1.7)	1.3 (0.6)	7.4 (3.8)
- Petal 3	86.7 (1.2)	1.5 (1.5)	5.6 (1.3)
Color: Pink			
Show Time			
- Petal 1	74.8 (3.6)	30.0 (8.3)	4.7 (4.1)
- Petal 2	79.8 (2.7)	17.3 (2.6)	4.0 (2.2)
- Petal 3	77.0 (6.1)	23.8 (7.9)	3.7 (1.7)
Tiffany			
- Petal 1	69.7 (3.1)	36.1 (4.7)	7.0 (1.2)
- Petal 2	69.8 (4.5)	36.9 (3.0)	9.4 (1.3)
- Petal 3	71.7 (2.8)	31.9 (2.6)	7.1 (2.8)
Color: Red			
Scarlet Glory			
- Petal 1	36.8 (1.4)	46.7 (3.7)	12.3 (2.3)
- Petal 2	38.0 (1.0)	47.2 (1.9)	12.0 (0.7)
- Petal 3	44.8 (0.6)	55.3 (0.8)	17.1 (0.5)
Joe Holland			
- Petal 1	52.9 (2.2)	48.5 (2.2)	9.4 (3.3)
- Petal 2	53.4 (0.9)	48.4 (2.0)	8.2 (1.5)
- Petal 3	46.4 (2.2)	48.1 (1.9)	7.2 (0.8)

NOTE: L* (darkness to lightness), a* (redness to greenness), and b* (yellowness to blueness).

3.4. Sensor-Based Color Measurements in Horticulture

The technology used to measure plant color has undergone various stages of applications in horticulture. For example, an inexpensive Epson document scanner was previously used to accurately estimate leaf color [26]. The process used a combination of color and contrast to determine the amount of chlorophyll within a leaf [26]. When compared to a lab spectrophotometer, linear regressions between the readings were significant, at $p < 0.05$ [26]. However, the procedure to reach these results was laborious, requiring 43 individual steps [26]. Digital and smartphone cameras were evaluated to measure leaf and flower color [27]. Flower and leaf colors were measured repeatedly, and the results were accurate when plant and leaf parts were uniform in color [27]. However, color variations were found between the five cameras tested because of the differences in color sensors [27]. Variations in lighting conditions influenced the reported color values [27].

Consumer-level digital cameras were successfully modified to capture ultraviolet images and to take multiple images of varying wavelengths to provide an accurate depiction of a petal's color [28]. When compared to an Ocean Optics spectrophotometer equipped with a PX-2 pulsed xenon light source, the digital camera's results had a high correlation to the Ocean Optic's readings, highlighting the potential for this new color measuring technology [28]. The main limitations of that study were that it was difficult to standardize lighting conditions and each individual camera had its own specific color profile and space [28]. These digital camera limitations produced results that had a correlation with highly saturated yellow samples, but higher variation in red and green flower petals [28]. That technology required color calibration tools, expensive digital cameras, and multiple filters and ultraviolet camera modifications in order to produce accurate color results [28].

This study utilized the Nix™ Pro color sensor, which uses a standardized light source and is factory calibrated to accurately report object color by utilizing red, blue, and green filters, with a design which has the ability to block out exterior light [29]. This represents a readily adoptable technology, compared to the earlier attempts to use digital cameras and scanners. The Nix™ Pro color sensor is portable, accurate, and low-cost, and may represent an accessible innovation to standardize horticultural petal color measurements. Applications of sensor technology in plant color determination is critical for herbarium collections, landscaping, agriculture (e.g., mineral deficiencies in plants, chlorosis etc.) and other applications [30–32].

4. Conclusions

The Nix™ Pro color sensor's readings were repeatable and unique to specific camellia varieties, with high R-squared values and low standard deviation values for the precision tests. When outliers were removed, each variety of camellia fit within a specific range of L*, a*, and b* values, which was statistically significantly correlated to RHS classification values. The Nix™ Pro color sensor was considerably easier to operate, as it does not require specific lighting, does not fade with use, and does not require the time-consuming process of comparing different cards in order to find an exact match. However, the data did reflect a wider variation with the b* value (blue to yellow) color range between measurements. This may indicate that the Nix™ Pro color sensor produces values in this color range with a higher variation. Overall, the p-values less than 0.01 mean that there is a statistically significant correlation between the measurements produced by the Nix™ Pro color sensor and the values of the matching RHS identification. This high degree of correlation signifies that the Nix™ Pro color sensor can act as a highly accurate and precise substitute for the RHS Colour Chart card system. The application of the Nix™ Pro color sensor to measure petal color quickly, inexpensively, and effectively allows for a more convenient method of categorizing camellias. This provides a high value to horticulturists, as the Nix™ Pro color sensor can detect minute changes in values, detecting changes in genetic variation and enabling horticulturists to breed certain colors. The Nix™ Pro color sensor also potentially provides a value to consumers and sellers of camellias. This is because sellers can provide consumers with the exact color of their camellias rather than a category, allowing for more confidence in camellia transactions. The Nix™ Pro color sensor can provide digital readings within seconds while maintaining a high level of precision and accuracy, no matter of the lighting conditions, potentially providing a cost-effective tool to horticulturists, consumers, and sellers alike.

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