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Evolution of Autumn Leaf Coloration of *Torminalis glaberrima* Grown in Isparta, Türkiye

Isparta-Türkiye'de Yetişen Torminalis glaberrima'nın Sonbahar Yaprak Renklenmesinin İncelenmesi

Candan KUŞ ŞAHİN[1], Ebru Hatice TIĞLI KAYTANLIOĞLU[2], Hüseyin FAKİR[3], Uğur ÖZKAN[4]

[1]Doç. Dr. Süleyman Demirel University, Architecture Faculty, Dept. of Landscape Architecture, Isparta, Turkiye
[2]Res. Assist. Isparta University of Applied Sciences, Forestry Faculty, Dept. of Forest Engineering, Isparta, Turkiye
[3]Prof. Dr. Forestry Faculty, Dept. of Forest Engineering, Isparta, Turkiye
[4]Res. Assist. Isparta University of Applied Sciences, Forestry Faculty, Dept. of Forest Products Engineering, Isparta, Turkiye

ORCID: C.K..S. 0000-0002-0413-2380; E.H.T.K. 0000-0002-9165-6675; H.F. 0000-0002-6606-8011; U.Ö. 0000-0003-0147-9976

ABSTRACT
The fall coloration of temperate tree leaves is a phenomenon of nature that ranges in color from pale yellows, oranges, and purples to dark reds. Although some evolutionary forces and weathered mechanisms (e.g., light and frost protection) cause variations in leaf color within and among species, no full explanation is found regarding fall coloration. This study phonologically monitored Torminalis glaberrima leaves from May until at the end of November in terms of fall coloration and senescence properties. The study presents the average color coordinate values of Torminalis glaberrima leaves, starting from May and continuing through November. Torminalis glaberrima leaves show an intense green color from May to June. We have used CIE L*a*b (1976) color space to determine discoloration intensity. As the seasons change, however, the leaves become darker into November (L = 25.67), with leaf discolorations becoming clearly distinguishable. We selected color values of leaves of Torminalis glaberrima at May as control, and as vegetation continues, compared to color changes throughout study (end of November). Accordingly, we measured total color differences (ΔE). The highest change in coloration was found in November (ΔE = 56.86) followed by October (ΔE = 44.71), September (ΔE = 42.32), August (ΔE = 15.37), July (ΔE = 5.86), and June (ΔE = 2.14). Notably, the highest color difference ΔE = 44.56 was found from August to September, and the lowest from May to June (ΔE = 2.14). Except for the leaves' GE brightness values, which show very low correlations over time, all other color coordinate values for CIE L*a*b* and hue values show some color level correlations over time.
Keywords: CIE L*a*b*, *Torminalis glaberrima leaves*, autumn coloration, leaf senescence

ÖZ
Ilıman iklim bölgelerinde yetişen ağaçların yaprakları, sonbaharda bir olgu olarak parlak sari renkten turuncu, pembe ve koyu kırmızı renge kadar karmaşık renklenme göstermektedir. Hernekadar bazı evrimsel güçler ve dış atmosferik şartlar (ışık ve don koruması) yapraklarda renk değişimine sebep olmakla birlikte, bu durum türler arasında farklılık göstermekte ve hala tam olarak açıklanabilmiş değildir. Bu çalışamda, torminalis glaberrima yapraklarının sonbahar renklenmesi ve yaşlanma durumu, fenolojik olarak Mayıs ayından Kasım sonuna kadar izlenmiştir. Torminalis glaberrima yapraklarının renk değerleri, Mayıs ayından başlayarak Kasım ayı sonuna kadar karşılaştırmalı olarak sunulmuştur. Torminalis glaberrima'nın yaprakları Mayıstan Haziran sonuna kadar koyu Yeşil renk tonunda gözlemlenmiş ve zaman ilerledikçe Kasımda daha koyu renge dönmüştür (L: 25.67 nümerik). Zamana bağlı olarak oluşan yapraklardaki renk değişimi kolaylıkla gözşlemlenebilmiştir. En yüksek renk değişimi, Kasımda (ΔE: 56.86), devamında Ekimde (ΔE: 44.71), Eylülde (ΔE: 42.32), Ağustosta (ΔE: 15.37), Temmuzda (ΔE: 5.86) ve Haziranda (ΔE: 2.14) ölçülmüştür. Fakat en yüksek renk farklılığı ise ΔE: 44.56 numerik olarak, Ağustostan Eylüle kadar olan periyotta en düşük ise Maytıstan Hazirana kadar (ΔE: 2.14) olan periyotta oluşmuştur. GE parlaklık değeri zamana bağlı olarak çok düşük korelasyon göstermekte ve istisna oluşturmakta, fakat diğer tüm renk koordinasyon değerleri olan CIE L*a*b*C* ve h nin, zamana bağlı olarak bir şekilde korelasyon gösterdiği anlaşılmıştır.
Anahtar kelimeler: CIE L*a*b*, torminalis glaberrima, sonbahar renklenmesi

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Corresponding author/Sorumlu yazar: Ebru Hatice TIGLI KAYTANLIOGLU / ebrukaytanlioglu@isparta.edu.tr

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INTRODUCTION

Many variables besides maturity, geographic location, and atmospheric conditions have impacts on the physicochemical properties of plants, even those in the same species. However, seasonal factors have been reported as one of the most effective on plant species' growing conditions (Archetti et al., 2009; Chiba et al., 1996; Junker & Ensminger 2016; Lee et al., 2003). Therefore, determining such changes such as chemical content and color variations plays an important role in plant species' properties and constituents. While numerous studies are found to have investigated the constituents and contents of pigments, evaluating certain physical parameters (i.e., color) may be necessary to determine the aesthetic value of a plant species (Archetti et al., 2009; Bozdoğan, 2016; Chiba et al., 1996; Field et al., 2001; Junker & Ensminger 2016; Lee et al., 2003; Lehrer & Brand 2010). Certain color pigments, particularly those that appear in autumn, have already been well presented for user who is too impersonal for aesthetics (Archetti et al., 2009; Chiba et al., 1996; Junker & Ensminger 2016; Lehrer & Brand 2010).

According to more recent study on International Plant Names Index (IPNI) 2022, *Sorbus torminalis* have called to be called *Torminalis glaberrima* (Gand.) Sennikov & Kurtto (Akyıldırım Beğen and Eminağaoğlu, 2022). *Sorbus torminalis*, commonly known as the wild service tree, is a deciduous tree widely distributed throughout the lower elevation temperate and Mediterranean zones of Europe, extending eastwards into the Caucasus Mountains and northern Iran (Jeran et al., 2017; Bednorz & Urbaniak 2005). The species is tolerant to direct sunlight and short periods of drought and therefore suitable for afforestation in warm arid sites. However, the species is particularly noted for its attractive form, shaggy bark, white spring flowers, edible berry-like fruits, and lobed maple-like leaves (Jeran et al., 2017; Bednorz & Urbaniak, 2005; Bekçi et al., 2010). The leaves are glossy green on top and light green underneath, often turning vivid yellow, orange, and red in the fall. The leaves are reported to show autumn coloration in mid-September to October, with leaf fall occurring from early October to mid-November (Bednorz & Urbaniak, 2005). Moreover, several phenolic compounds have been isolated from the leaves of *Sorbus torminalis*, including caffeic acid, p-coumaric acid, flavonoids (i.e., vitexin, apigenin, luteolin, quercetin, and torminaloside), sterols (i.e., cholesterol, campesterol, stigmasterol, and sitosterol), and fatty acids (i.e. myristic, palmitic, palmitoleic, stearic, oleic, linoleic, and linolenic acids; Olszewska & Roj 2011; Hasbal et al., 2015). A recent report proposed that *Sorbus torminalis* has a smooth trunk shape, white flowers, light brown berries, and autumn coloration properties, which makes it a useful plant in landscape design practices as an allée, wind curtain, and erosion control (Bekçi et al., 2010) Regarding the expected changes in global climate, the wild service tree should substitute well for some tender woody plants with higher sensitivity to drought in landscape practices. The *Sorbus* species has also been proposed for its decorative attributes, as well as its therapeutic value that is well-known in folk tradition (Jeran et al., 2017; Bednorz & Urbaniak 2005; Bekçi et al., 2010).

Many investigators have reported on the variations in the leaf senescence properties of plant species in terms of quantity and quality (Archetti et al., 2009; Bozdoğan, 2016; Chiba et al., 1996; Field et al., 2001; Lehrer & Brand, 2010). Recent studies have presented evidence for *Sorbus torminalis* leaf color changes to occur in autumn (Hasbal et al., 2015; Jeran et al., 2017; Bednorz & Urbaniak 2005), but no work is yet found to have investigated its autumn coloration properties in Türkiye. Therefore, the present study aims to study and discuss the autumn senescence of *Torminalis glaberrima* leaves based on experimental findings to determine their color properties.

The purpose of this paper is to give an overview of *Torminalis glaberrima*, the autumn coloration properties of the species' leaves, and their value in landscaping. The paper assumes native *Sorbus* species to present itself as a quality multifunctional species applicable for use in landscaping.

MATERIALS AND METHODS

The study has selected to evaluate the autumn leaf coloration characteristics of *Torminalis glaberrima* which is in the *Rosaceae* family, and to represent its ornamental value in the field of landscaping. The study conducted phonological observations at different stages of coloration from May 2022 through end of November 2022 in in-situ growing conditions. The *Torminalis glaberrima* leaves were collected from stands in the Egirdir region of Türkiye's Isparta Province in the last weeks of each month. However, healthy mature trees were randomly selected, from which approximately 10 representative leaf samples were collected from all sides of the crown. The region in which the samples were collected is a forestland managed by the Regional Directorate of Forestry authorities. Figure 1 shows the general maps of the geographic regions from which the samples were collected. The supplied leaves were manually cleaned of contaminants then stored in standard containers at 4°C until analyzed. The experimental procedures were conducted in the

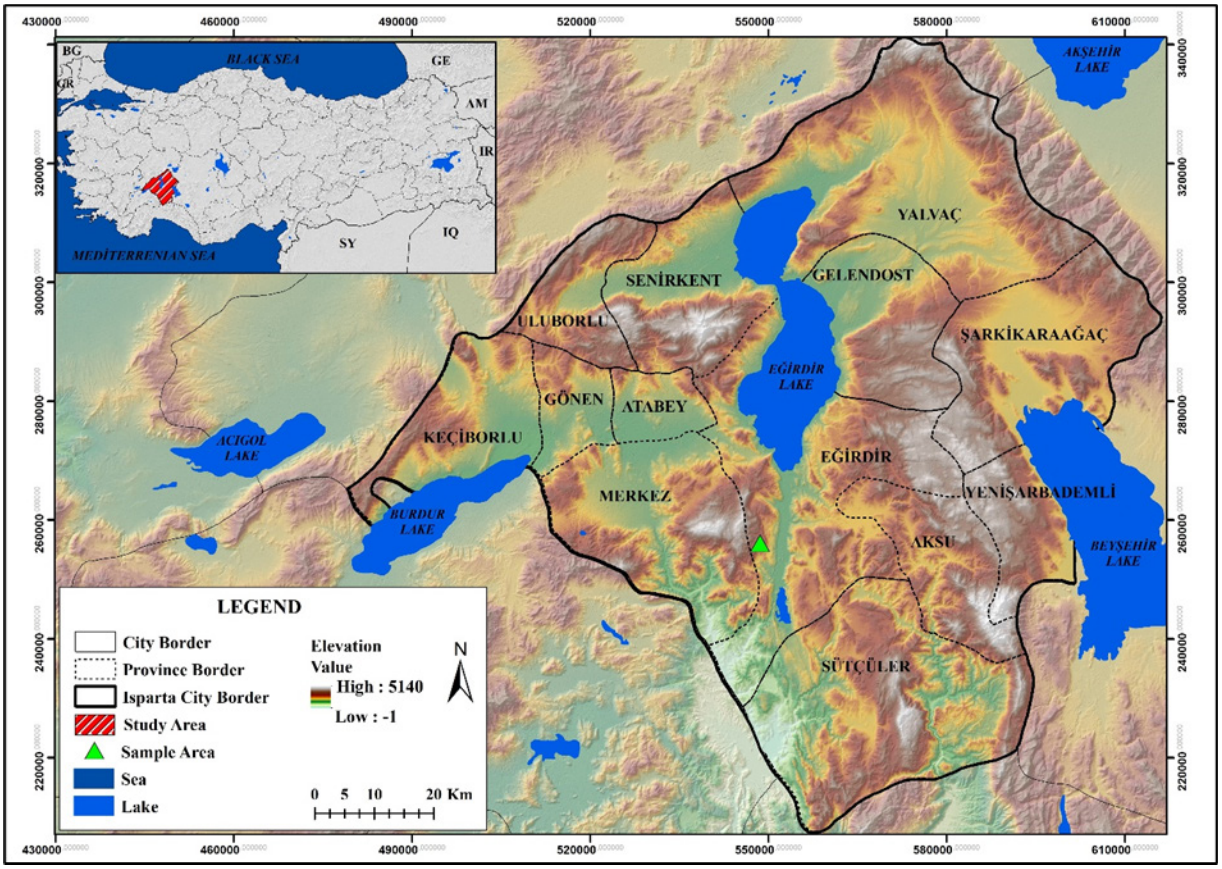

Figure 1: The geographic location of Torminalis glaberrima trees.

botanic laboratory of the Forest Engineering Department of Isparta University of Applied Sciences Faculty of Forestry in Türkiye.

The leaves of *Torminalis glaberrima* were found to be initially green in spring; the color then senesces to yellows, oranges, and reds in the fall. The study assumed that mid-to-late May to the end of November would be an appropriate observation period. The selected trees' in-situ and collected leaf samples were carefully monitored at different stages of discoloration by photographing to conduct a visual evaluation. The study obtained numerous photos that effectively reflect the leaf coloration of the *Torminalis glaberrima* species, some of which are presented in Figure 2.

To track and photograph fall discoloration, the observation was divided into five coloration periods:

- the pre-coloration period (late May to mid-July),
- early coloration period (late July to mid-September),
- middle coloration period (late September to mid-October),
- late coloration period (late October to mid-November),
- final coloration period (late November to mid-December).

Technical Association of the Pulp and Paper Industry (TAPPI) standard (i.e., GE brightness) measurements require a special instrument that employs a 45° illumination and 0° viewing geometry so that translucent materials are evaluated on an arbitrary but specific scale. This method is considered to be useful for determining *Torminalis glaberrima* leaf brightness. The GE brightness measurements were made according to TAPPI brightness (T452 om-98) and the *Commission Internationale de l'Eclairage* (CIE) L*a*b* and CIE L*C*h color coordinate measurements were made according to CIE L*a*b* (1976) using the X-Rite 938 handheld spectrodensitometer (X-Rite, Grand Rapids, MI).

The spectrodensitometer was calibrated with a standard white calibration plate, and color was measured as L*, a*, b* coordinate values. A single measurement was recorded for each sample, and 10 replicate leaves were measured for each sampling. The value of L* describes the degree of darkness/lightness with L = 0 being black and L = 100 being white. Before analysis, the a* and b* coordinates were transformed into chroma (*C**) and hue angle (*h*°) using the equations: $C^* = (a^{*2} + B^{*2})^{1/2}$ and $h° = \tan^{-1}(b^* / a^*)$. Richness of color is represented by C*, and *h*° represents the dominant color wavelength where 0° =

Figure 2: The general appearance of Torminalis glaberrima trees and their collected leaves.

red–purple, 90° = yellow, 180° = bluish green, and 270° = blue. The data were evaluated statistically using the program SPSS 19.0 and the one-way analysis of variance (ANOVA) method.

FINDINGS AND RESULTS

The variation in leaf color during autumn may serve an ornamental appearance. A vast literature of reports has already been suggested for using the CIE L*a*b* color measurement method, which is based on the mathematical quantification of color, for evaluating the impact of environmental factors on leaves and fruit (Bahreini, 2022; Post & Schlautman 2020; Tan et al., 2021; Ochmian et al., 2012; Nowakowska et al., 2017).

In this regard, the average color coordinate values of *Torminalis glaberrima* leaves, starting in May a continuing through November, are presented comparatively in Table 1. The individual months appear to have a considerable influence on all color coordinates. Initially, the lightness value of L = 36.56 was found for May and to go as high as L = 45.20 in September, before decreasing to L = 25.67 in November. As expected, the leaves still show a deep greenish shade initially (May to June), with the hue ranging from h = 124.91º to h = 119.54º which is in the green (-a values) and yellow (+b values) of the color chart. The darkest leaves were found in November (L = 25.67). Timely atmospheric changes (i.e., temperature, light) were able to be determined to have had a clear impact on leaf coloration and color intensity. The highest greenish value of a = -16.37 was found in August, but the highest reddish value of a = 43.32 was found in November. After August, the leaves were shown to turn to a deep reddish-to-brown color (+a values), while the chromaticity and hue increased.

To simply quantify all color values is a very complicated process that includes many phenomenological variations. Therefore, the total color difference (ΔE), which in this study may be useful for determining leaf coloration properties, can be used to provide an estimation of how time (i.e., the month) affects the natural color of *Torminalis glaberrima* leaves.

As for the deep green color in May, the assumption is to use these values as the control and then monitor coloration changes throughout the end of the study in November. The total difference in the leaves measured color values (ΔE) compared to the control (i.e., May) are given in Figure 3**.** Leaf coloration clearly continues as maturation and senescence throughout the dormant period of November. Meanwhile, the highest change in coloration was found in November (ΔE = 56.86), followed by October (ΔE = 44.71), September (ΔE = 42.32), August (ΔE = 15.37), July (ΔE = 5.86), and June (ΔE = 2.14). In the literature, ΔE values between 2.0-3.0 are thought to present an observable color difference to observers (Muller et al., 2003; Sahin & Mantanis, 2011).

The method chosen in this study involves the visual (Figure 2) and mathematical (Table 1, Figure 3) evaluations of *Torminalis glaberrima* leaves starting in May and continuing through to November and has clearly confirmed the information in the literature (Archetti et al., 2009; Bozdoğan, 2016; Chiba et al., 1996; Field et al., 2001; Junker & Ensminger 2016; Lee et al., 2003; Lehrer & Brand, 2010) in terms leaf coloration changes.

Table 1. The Monthly Color Properties of Torminalis glaberrima Leaves

	L	a	b	c	h	Brightness (GE)
May	36.56 (1.39) B	-11.35 (0.98) B	16.32 (2.26) B	19.93 (2.22) A	124.91 (2.56) F	5.05 (0.26) B
June	35.36 (1.51) B	-9.80 (1.58) B	15.45 (1.53) B	18.37 (1.80) A	122.64 (4.29) EF	4.83 (0.30) B
July	39.14 (1.94) C	-9.53 (1.76) B	21.26 (2.18) C	23.35 (2.32) B	114.14 (3.95) D	4.99 (0.38) B
August	42.94 (3.36) D	-16.37 (1.43) A	29.38 (4.80) D	33.72 (4.29) C	119.54 (4.49) E	4.60 (0.25) B
September	45.20 (3.37) D	28.13 (3.13) C	28.88 (4.06) D	40.58 (1.69) E	45.65 (6.82) C	5.60 (0.87) C
October	39.85 (2.04) C	33.18 (4.20) D	18.62 (5.11) BC	37.80 (3.71) D	28.23 (5.94) B	6.19 (0.49) D
November	25.67 (3.52) A	43.32 (2.53) E	4.92 (3.44) A	43.72 (2.58) F	6.44 (4.49) A	3.91 (0.52) A

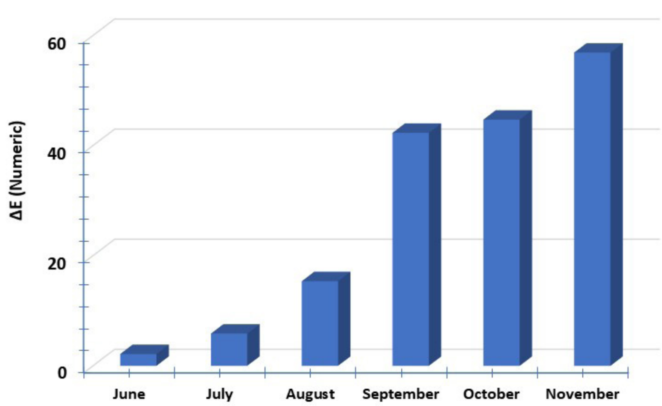

Figure 3: Monthly change in coloration properties of *Torminalis glaberrima* leaves with May as the control.

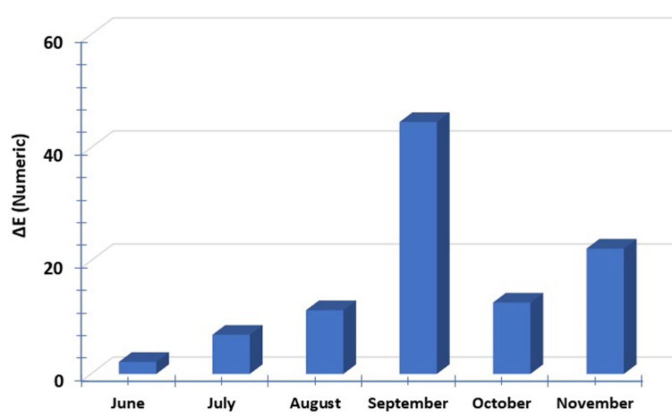

Figure 4: The monthly coloration differences of *Torminalis glaberrima* leaves beginning in May.

Another approach involved evaluating coloration changes from one month to the next starting in May, with the color difference (ΔE) values calculated and plotted in Figure 4. Just as in Figure 3, a more-or-less similar trend was also observed of maturation and senescence that continuously increased until the end of the study in November. Yet the highest change in coloration (ΔE = 44.56) occurring from August to September and the lowest occurring from May to June (ΔE = 2.14) are interesting to note. This may be an estimation time for the intense fall coloration of *Torminalis glaberrima* leaves. This approach may also be used to predict peak time for plant coloration in fall. As mentioned above and shown in Figure 2, a visual distinction in leaf color had also become apparent after July.

The measured color coordinate values were plotted against time (in months) to further evaluating the change in the coloration properties of *Torminalis glaberrima* leaves (Figure 5). Apart from the GE brightness properties' very low correlation coefficient (R^2 = 0.11), which means brightness values are practically independent when measured over time, all other measured color values appear to show some level of acceptable correlations. However, the highest correlation was found with hue angle ($R_{h°}^2$ = 0.91), followed in order by chromaticity (R_{C*}^2 = 0.89), the greenish-reddish color space (R_{a*}^2 = 0.85), yellow-blue color space (R_{b*}^2 = 0.77), and lightness (R_{L*}^2 = 0.68).

Cold weather's impact on temperate species' leaf discolorations, usually referred to as autumn/fall colorations, have been well presented. Although the visual appearance of

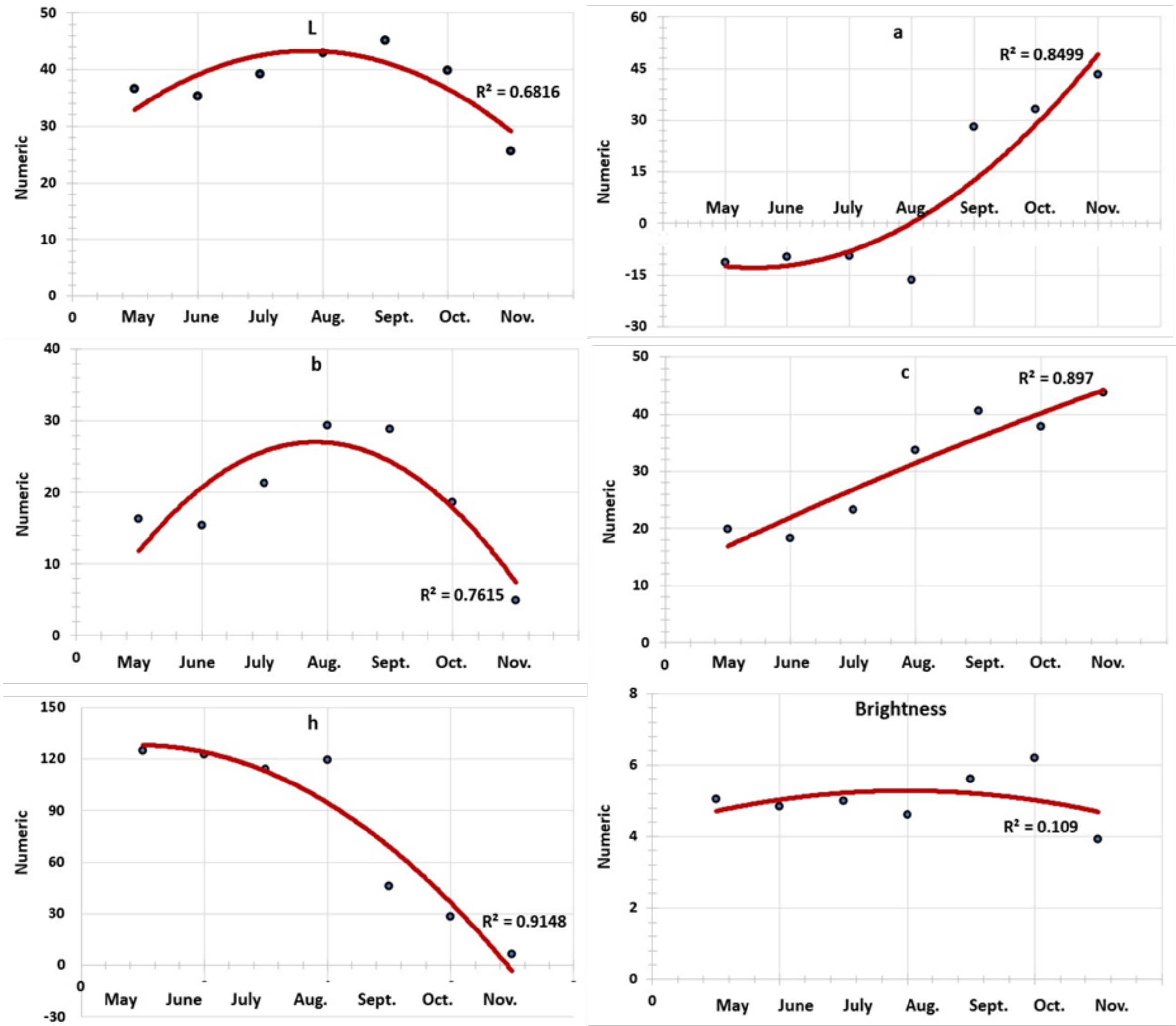

Figure 5. The relationship between color values over time for *Torminalis glaberrima* leaves.

leaves is an important criterion of acceptance in landscape design practices, the measured mathematical results may also be taken into consideration when planting species in open public spaces where aesthetic appearance is important.

Lastly, to find the combined effects of the color space regarding lightness and hue angle on *Torminalis glaberrima* leaves, the obtained values were plotted against one another and shown in Figure 6. The senescence of the leaves being clearly realizable is very apparent. Their lightness (L) was found to be 36.56 in the initial month of May and to continuously lower to 25.67 in November. A similar trend was also very visible with hue angle (hº). It measured 124.91º initially in May, which means a* had a negative (greenish) value and b* a positive (yellowish) value in the color chart (Figure 7); it then continuously lowered to 3.91º, which means a* gained a positive (reddish) and b* a positive (yellowish) value in the color chart in November (Figure 7).

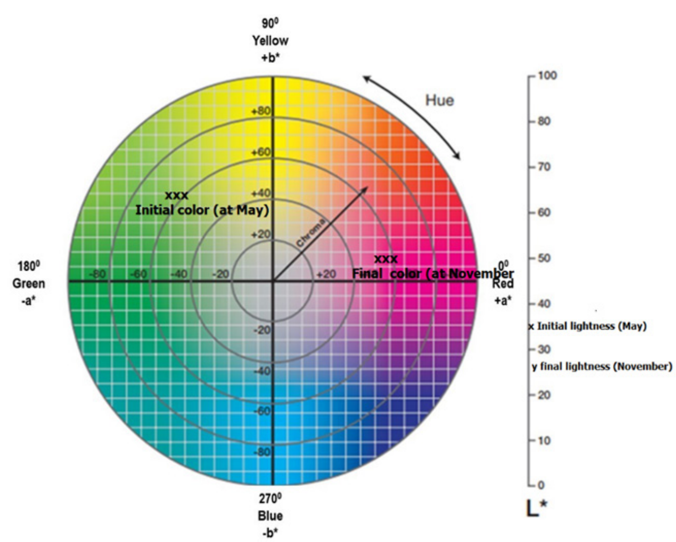

Figure 7: The initial and final color properties of *Torminalis glaberrima* leaves.

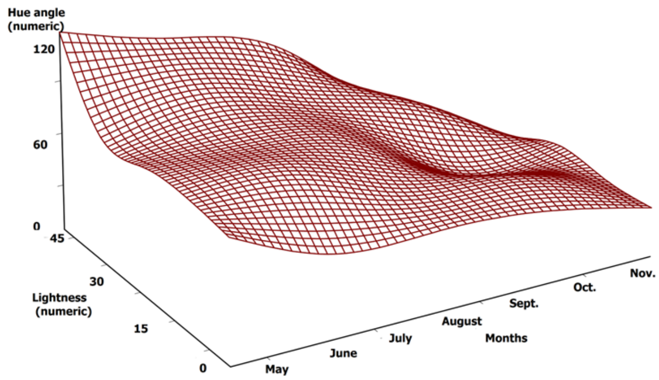

Figure 6: The relationship between lightness (L) and hue angle (hº) over time for *Torminalis glaberrima* leaves.

The plot shape in Figure 6 and color properties in Figure 7 clearly suggest that all sample monitoring times apparently affected a change in the lightness and hue angle values. This was expectable, considering the vast amount of information that has been reported in the literature on how weather conditions impact leaf senescence.

CONCLUSION

Some plants have become an important source for landscaping with cost effective ways in design practices. However, many deciduous plants have been used in combination with other elements to provide an aesthetic appearance in public spaces. The *Sorbus* species has been generally described as a very durable tree whose growth habits vary from low growing to upright and from a spreading shrub to a small tree. However, *Torminalis glaberrima* can be found over a wide range of shapes and sizes, with its leaf color varying from green to orange and reds in fall. Therefore, *Torminalis glaberrima* may be suggested for use in urban settings due to its high tolerance to heat and poor dry soils. Due to the wide variations in physical appearance, this species may be given preference in landscape plantings when used as screens, windbreaks, foundation plants, hedges, and other diverse landscape designs due to their formal appearance. The experimental results found in this study clearly suggest the fall coloration of *Torminalis glaberrima* to be measurable using spectral densitometric values. However, many phenomenological properties have been reported in detail for plant substrates, and quantifying all of these is very complicated and requires further investigation.

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