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ORIGINAL ARTICLE

Comparative Evaluation of Colorimetric and Computer Vision Systems for Red Meat Color Analysis During Refrigerated Storage

Alper GÜNGÖREN[1,*] Gülşah GÜNGÖREN[2]

[1]Kastamonu University Faculty of Veterinary Medicine, Department of Food Hygiene and Technology, Kastamonu, Türkiye.

[2]Kastamonu University Faculty of Veterinary Medicine, Department of Animal Science, Kastamonu, Türkiye.

Alper GÜNGÖREN, Kastamonu University Faculty of Veterinary Medicine, Department of Animal Science, Kastamonu, Türkiye.

E-mail: agungoren@kastamonu.edu.tr

ORCID ID: 0000-0001-7818-1372

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ABSTRACT

This study compared a traditional colorimeter device and a computer vision system (CVS) for monitoring color changes in beef tenderloin during refrigerated storage. Beef samples were obtained from 2-3-year-old male Simmental cattle, portioned into uniform slices, and stored at 4±2 °C for four days. Color was measured at 24-hour intervals by both methods, while aerobic plate counts (APC) and pH were also recorded. Over the 4-day storage period, both methods detected significant changes in *Lab**, Chroma, Hue, and the redness index (RI), with microbiological and pH analyses confirming spoilage progression. CVS consistently yielded higher *L**, *b**, Chroma, and Hue values, whereas the colorimeter produced higher RI values due to lower *b** measurements. A significant method and day interaction indicated that these differences persisted under dynamic storage conditions. The results suggest that due to its surface-focused measurement principle, CVS offers a reliable, practical, and non-destructive approach for both point-in-time assessments and continuous monitoring of red meat color.

Keywords: *Colorimeter, Computer Vision System, Meat Quality Monitoring, Redness Index, Shelf Life.*

Introduction

One of the key quality traits guiding consumer choices is meat color, which is influenced by numerous factors acting at pre-slaughter, slaughter, and post-slaughter stages. Factors that may affect meat color include the animal's race, breed, gender, nutrition, slaughter method, and muscle metabolism during the pre-, during, and post-rigor phases (King et al., 2023; Tomasevic et al., 2019; Tomasevic et al., 2021).

Hedonic color panels may be used to assess a meat's or a meat product's visual attractiveness. Consumer panels or qualified descriptive panelists may conduct these panels. However, since they are costly, time-consuming, and need volunteers and ethical approvals, sensory panels are often challenging to create. The sample size must be determined statistically if volunteer consumers are included in a sensory color panel. When statistical data is unavailable, at least 100 consumers' views should be gathered. Panelist training (Farnsworth-Munsell 100-Hue tests, scoring scales, and visual aids), orientation, and preliminary trials are included if trained panelists are available. These inverses comprise several elements, including panelist performance monitoring, viewing conditions, and sample identification. Actually, spectrophotometric and colorimetric-based instrumental color assessments have surpassed sensory panels as the preferred option (King et al., 2023; Ruedt et al., 2023; Taheri-Garavand et al., 2019; Tomasevic et al., 2021). Commission Internationale de l'Eclairage (CIE) developed the *Lab** color space in 1976. In this system, the color differences one perceives correspond to distances when measured calorimetrically.

In summary, the central point of the color space corresponds to neutrality. The *a** axis expresses the red-green dimension, where positive readings reflect red and negative readings green, typically between +60 and -60. The *b** axis describes the yellow–blue dimension, with positive scores indicating yellow and negative scores indicating blue on the same scale. The third dimension, *L**, is mathematically represented with 100 corresponding to white and 0 to black (King et al., 2023; Sáenz et al., 2005; Taheri-Garavand et al., 2019).

Instrumental color equipment mostly works according to the *Lab** color space principle. To avoid bias in measurements, the surface being measured must be uniform and relatively small. This is a requirement for all colorimeters. In addition, researchers have found that, throughout the process of instrumental color determination, the accuracy of color assessment improves with increasing the number of readings taken from each sample. An additional problem is that the light beam emitted by the colorimeter is refracted, reflected, diffused, and absorbed by an optically non-homogeneous matrix such as meat. Consequently, it is not unprecedented for there to be small variations in color measurements (*L**, *a**, and *b**) when using the same colorimeter on the same patch of meat during repetitions (Girolami et al., 2013; Tomasevic et al., 2019).

On the flip side, in computer vision systems (CVS) for meat color analysis, a single digital image suffices for effective color assessment; digital photographs elucidate surface color variation, and the data obtained from these photographs can be converted into other color-measuring methods. The main negative aspect of CVS, relative to the used instrumental color equipment, is that it has a more complex and time-consuming calibration process that demands special software (Barbut, 2001; Girolami et al., 2013; Güngören & Güngören, 2025; Taheri-Garavand et al., 2019; Tomasevic et al., 2019).

There are investigations in the publications on the evaluation of red meat color using CVS and instrumental color devices. However, the number of studies evaluating the color of red meat during its shelf life using both CVS and instrumental color devices is limited. This research intends to examine the progression of red meat color under cold storage by employing two different measurement techniques: a colorimeter and a computer vision method. The study also aims to reveal significant contrasts between the two techniques in terms of precision and efficiency. Findings from this study could provide insights into optimizing color measurement systems for better quality control in the meat industry.

Material and Method

Ethical Statement

This study did not involve the use of any live animals or experimental animal materials. The meat used was food-grade and obtained from a local slaughterhouse. Therefore, this study is not subject to HADYEK permission in accordance with Article 8 (k) of the Regulation on Working Procedures and Principles of Animal Experiments Ethics Committees (official gazette no: 28914).

Experimental design

The whole meat was obtained from a 2- to 3-year-old male Simmental cattle. After rigor mortis and carcass aging occurred, beef tenderloin (M. psoas major) samples were purchased from a local slaughterhouse. The sample was brought to the laboratory under cold chain conditions and quickly divided into 10 pieces with similar thicknesses and dimensions (2-2.5 cm). Each piece was numbered and placed on aseptically prepared plates. The central temperature of all samples was brought to 4±2 °C.

Additionally, for microbiological and pH analyses, 10 g sub-samples were aseptically collected and stored in sterile sampling bags. Then, for the computer vision system, color measurements were taken every 24 hours until spoilage was observed in the samples. This procedure was performed in three independent repetitions. Thirty beef tenderloin samples from three cattle, divided into ten portions each, were examined over their shelf life.

Computer Vision System (CVS)

As illustrated in Figure 1, the CVS setup included a camera, a lighting module, and a computer. A light-isolated dark box (30×30×30 cm) was used to minimize external light interference. A camera and LED light source were fixed inside the box, and a lux meter was placed to monitor lighting conditions before each photograph was taken. Images were captured using a smartphone camera (Xiaomi 23049PCD8G, Beijing, China) equipped with a 64-megapixel CMOS sensor (9248 × 6944 pixels, 1/2.0'', 0.7 µm pixel size, f/1.8 aperture, optical image stabilization). The device operated in manual mode and was calibrated using a Color Checker (Calibrite®). Illumination was provided by a ULANZI VL49RGB LED lamp (Hong Kong, China) with a >95 Color Rendering Index, set at a color temperature of 6500 K (D65 daylight standard). The camera was mounted vertically at a distance of 30 cm from the sample and connected to a monitor (LG-29UM68-P) for real-time visualization (Güngören & Güngören, 2025).

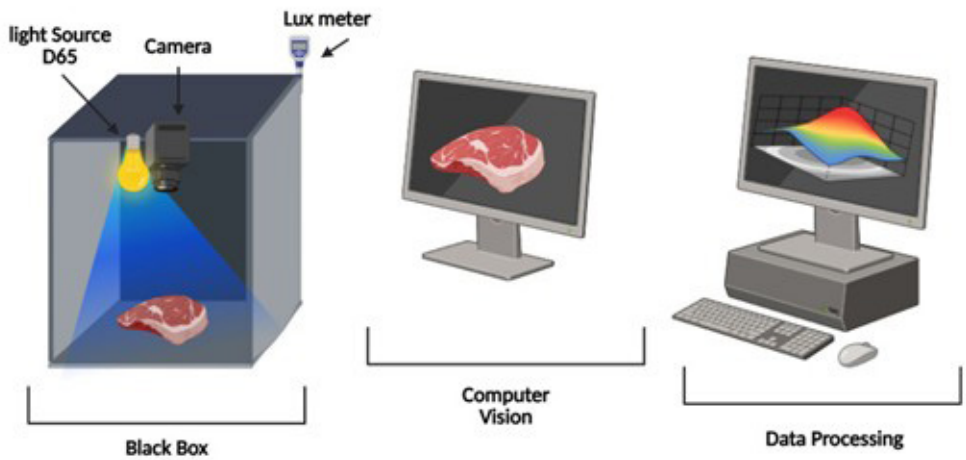

Figure 1. Installation of the computer vision system (CVS)

Images were analyzed using the ImageJ® freeware program (http://imagej.nih.gov). Each image was split into *L**, *a**, and *b** stacks, and the meat region was manually selected from each stack. Whole images were converted to TIFF format, and color analysis was performed to obtain the photos' *L**, *a**, and *b** values for calculating the color difference (Figure 2).

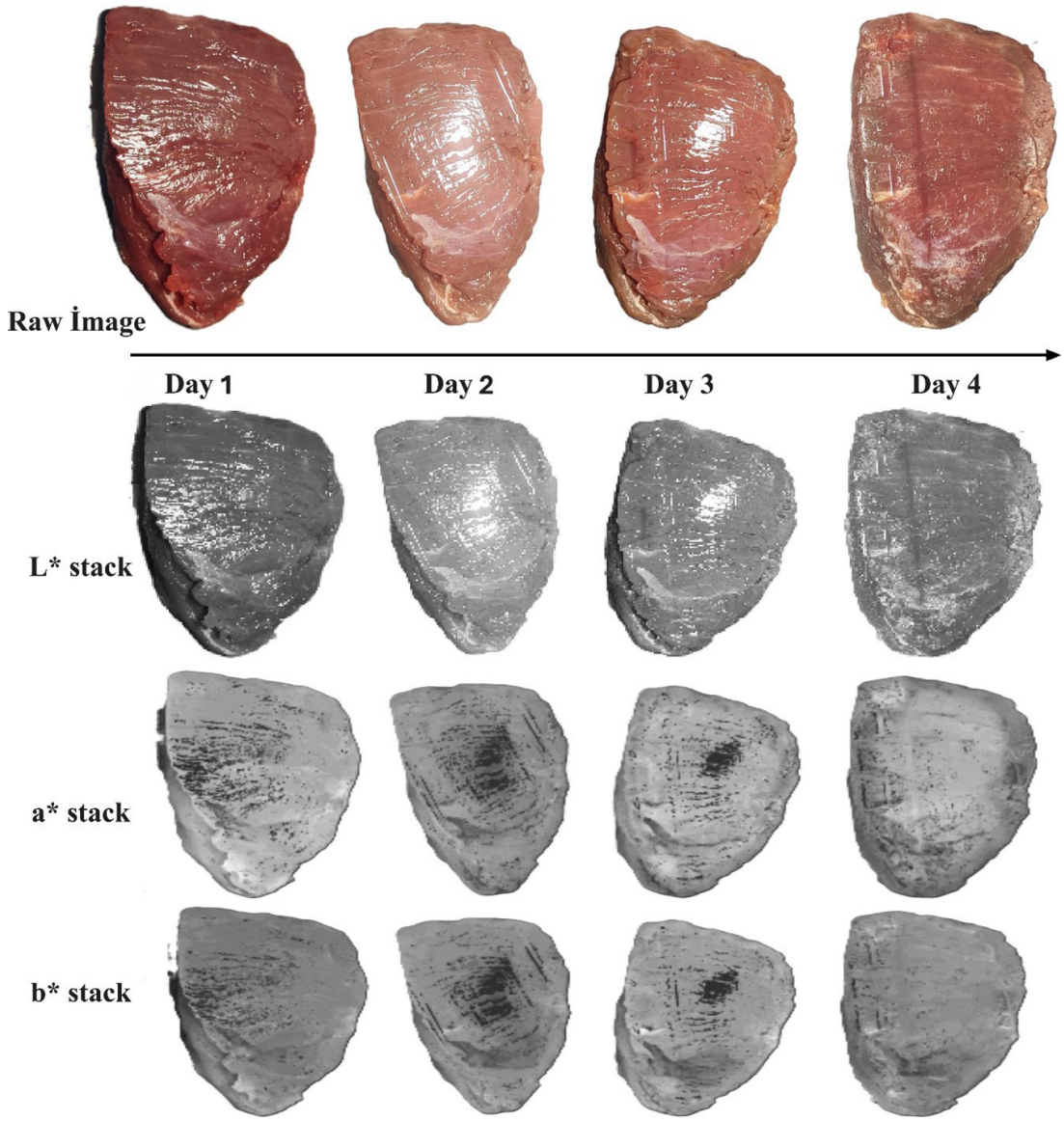

Figure 2. Appearance of the red meat sample during its 4-day shelf life at 24-hour intervals in the CVS method, and the raw image along with the *L**, *a**, and *b** stacks generated using a freeware computer program
CVS: Computer vision system

Then, the Chroma, Hue angle, and Redness index (RI) were determined using the following equations, respectively (King et al., 2023).

$$Chroma = \sqrt{(a^*)^2+(b^*)^2}$$

$$Hue\ angle\ = tan^{-1}\left(\frac{b^*}{a^*}\right)$$

$$Redness\ index\ (\mathrm{RI})\ = \frac{a^*}{b^*}$$

Instrumental Color Analysis

In the analysis of the color properties of raw meat samples, a colorimeter was used with Illuminant D65 (noon daylight, 6.500 K). CS-10 was used (CHNSpec, Hangzhou, China) (Güngören et al., 2025). The results were given in terms of the factors *L**, *a**, and *b**. At least 5 color spots were measured for each sample at room temperature. Then, the Chroma, Hue angle, and Redness index (RI) were determined, as described before.

Microbiological Load Analysis

On each analysis day, 10 g of meat samples were removed from cold storage and homogenized with 90 mL of 0.1% sterile peptone water using a stomacher for 120 seconds. Aerobic plate counts (APC) were determined using Plate Count Agar (PCA; Merck, Darmstadt, Germany). Petri dishes were incubated at 35±1 °C for 24-48 hours, and microbial counts were expressed as log CFU/g.

Determination of pH

Once the microbiological analyses were completed, the pH values of the samples were determined. A digital pH meter (HI 11310, Hanna Instruments, USA) was employed for this analysis, and the readings were taken directly from the stomacher bags in which the meat samples had been homogenized. This approach enabled precise measurements under sterile conditions, minimizing the risk of external contamination or altered results.

Statistical Analysis

The statistical evaluation of the experimental results was conducted with IBM SPSS Statistics (v27.0, IBM Corp., Armonk, NY, USA). A two-way multivariate analysis of variance (Multivariate General Linear Model - GLM) was performed to evaluate the effects of measurement method (group) and storage day on color parameters (*L**, *a**, *b**, Chroma, Hue, and RI). The measurement method was included as a fixed factor, and the color data recorded over four days were treated as dependent variables. In addition, one-way ANOVA was applied to analyze the microbiological load (APC) and pH values across storage days, and also to compare the differences between storage days within each group. The data were presented as mean ± standard deviation. Tukey's post-hoc test was used to identify significant differences between means ($P<0.05$).

Results

The samples have been stored at refrigerated conditions (4±2 °C) for 4 days. The initial microbial load of the red meat samples was 4.03 log CFU/g. This value increased logarithmically, reaching 7.19 log CFU/g by the 4th day of storage. The pH values of the samples were also determined, with an initial average of 5.95. As the meat spoiled, this value increased to 7.02 (Figure 3).

Color measurements obtained by both methods from red meat samples stored under refrigeration are presented in Table 1. Also, in the colorimetric method, *L** values were similar on days 1 and 2, but decreased on days 3 and 4, indicating a loss of brightness ($P<0.05$). In contrast, CVS measurements yielded substantially higher *L** values, which remained relatively stable except on day 1. The *a** value in the colorimeter method declined consistently over time, reflecting a gradual loss of redness ($P<0.05$). However, in the CVS method, the decline in *a** fluctuated more. Regarding the *b** value, the colorimeter method showed a significant increase from day 1 to days 2-4, while in CVS, *b** was initially low but increased on days 3 and 4. Chroma values measured by the colorimeter decreased over time, whereas CVS values fluctuated. Hue angle increased progressively during storage, with both methods following a parallel trend. The Redness Index decreased steadily with the colorimeter ($P<0.05$), whereas the decline was less pronounced with the CVS method.

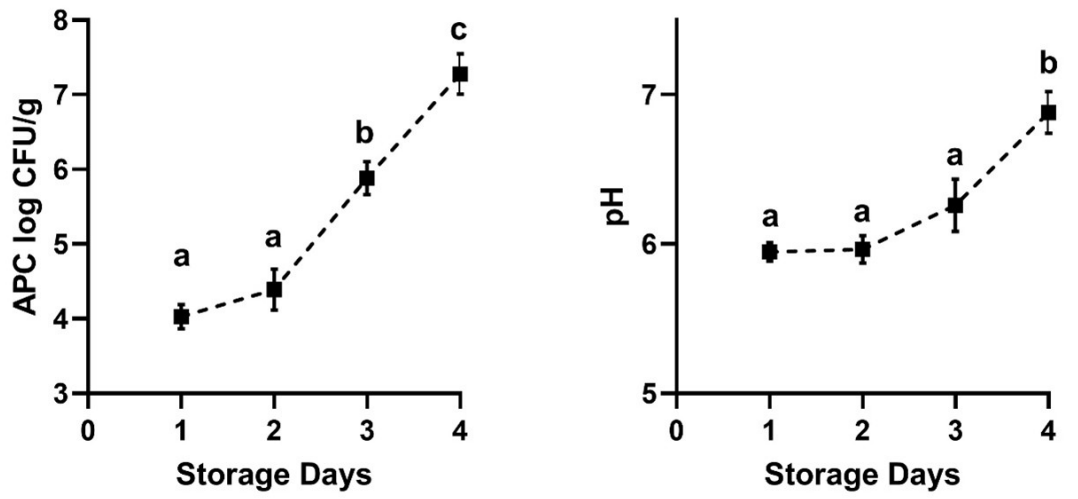

Figure 3. Changes in aerobic plate count (APC, log CFU/g) and pH values of red meat samples during refrigerated storage.

The data were presented as mean ± standard deviation.

Different letters (a-c) above the error bars indicate statistically significant differences between storage days (P<0.05).

Table 1. Changes in color parameters of red meat samples during refrigerated storage, as measured by a colorimeter and a computer vision system (CVS)

Color parameters		Storage days			
		1	2	3	4
Colorimeter	L*	34.95±2.07^{b}	35.31±1.79^{b}	34.41±3.06^{ab}	32.72±4.92^{a}
	a*	26.06±3.36^{c}	23.24±4.25^{c}	19.64±6.28^{b}	15.01±6.71^{a}
	b*	3.17±0.83^{a}	4.60±1.14^{b}	5.14±1.73^{b}	4.89±1.68^{b}
	Chroma	26.26±3.39^{c}	23.75±4.06^{bc}	20.50±5.82^{b}	16.05±6.24^{a}
	Hue angle	6.90±1.55^{a}	11.72±4.38^{ab}	16.62±8.92^{bc}	21.46±12.65^{c}
	Redness index	8.80±2.82^{c}	5.49±1.69^{b}	4.41±2.31^{ab}	3.49±2.11^{a}
CVS	*L**	49.98±7.24^{a}	64.26±3.92^{c}	58.04±4.73^{b}	59.79±5.31^{b}
	*a**	29.57±3.20^{c}	20.25±3.61^{a}	23.23±3.66^{b}	20.99±4.31^{ab}
	*b**	21.28±3.72^{b}	18.79±3.03^{a}	21.28±2.74^{b}	21.01±3.25^{b}
	Chroma	36.48±4.53^{c}	27.67±4.39^{a}	31.59±3.39^{b}	29.80±4.81^{ab}
	Hue angle	35.55±2.98^{a}	42.93±3.50^{b}	42.62±4.49^{b}	45.27±4.74^{b}
	Redness index	1.41±0.16^{b}	1.08±0.13^{a}	1.10±0.16^{a}	1.00±0.17^{a}

Values are expressed as mean ± standard deviation (n=3). Different superscript letters (a-c) within the same row indicate significant differences between storage days (P<0.05).

Results from the GLM analysis indicated that *L**, *b**, Chroma, hue, and Redness Index values were significantly influenced by storage duration and by the interaction between storage time and measurement technique. Furthermore, a clear difference was observed between the two measurement approaches (P<0.001). Across all storage days, the CVS yielded consistently higher values for *L**, *b**, Chroma, and

hue than the colorimeter. However, although the measurement methods yielded different results for the *a** value, neither method demonstrated absolute superiority over the other. In contrast, the colorimeter produced higher Redness Index values than the CVS method (Table 2). The higher redness index measured by the colorimeter can be attributed to its considerably lower *b** values. Since the redness index, expressed as the *a*/b** ratio, depends on accurate, precise measurement of the *b** value, using a colorimeter may yield misleading results for the redness index.

Table 2. Multivariate analysis of the effects of storage time and instrument type on meat color attributes

Color attributes	Storage days effect	Methods	Storage and methods interaction	Difference between methods
*L**	F(3,56) = 29.99 *P*<0.001	F(1,58) = 1800.63 *P*<0.001	F(3,56) = 26.20 *P*<0.001	CVS > Colorimeter
*a**	F(3,56) = 45.21 *P*<0.001	F(1,58) = 10.63 *P*=0.002	F(3,56) = 19.08 *P*<0.001	CVS ≠ Colorimeter*
*b**	F(3,56) = 9.36 *P*<0 .001	F(1,58) = 1385.56 *P*<0.001	F(3,56) = 10.66 *P*<0.001	CVS > Colorimeter
Chroma	F(3,56) = 33.98 *P*<0.001	F(1,58) = 151.41 *P*<0.001	F(3,56) = 18.20 *P*<0.001	CVS > Colorimeter
Hue angle	F(3,56) = 47.04 *P*<0.001	F(1,58) = 540.93 *P*<0.001	F(3,56) = 10.07 *P*<0.001	CVS > Colorimeter
Redness index	F(3,56) = 69.64 *P*<0.001	F(1,58) = 191.61 *P*<0.001	F(3,56) = 52.83 *P*<0.001	Colorimeter > CVS

*No absolute superiority was observed. F-values with corresponding degrees of freedom and *P*-values are provided.
Significant differences between methods are also summarized.
CVS: Computer vision system

Discussion

The research focused on contrasting a standard colorimeter with a computer vision system (CVS) to assess their effectiveness in monitoring the color development of red meat throughout refrigerated storage. Color is a key quality attribute in fresh meat, as it directly influences consumer perception of freshness and acceptability. Throughout the four-day storage period, both measurement systems consistently detected significant changes in standard color parameters (*Lab**, Chroma, hue, and redness index). These optical changes corresponded well with microbiological and pH measurements, which both confirmed the progression of spoilage. The observed agreement between microbiological, physicochemical, and instrumental color data reinforces the well-established understanding that initial microbial load and muscle pH are critical determinants of a meat products potential shelf life and susceptibility to discoloration (Altun et al., 2024; Aydemir et al., 2024; Lemos Junior et al., 2024; Liu et al., 2023; Ramanathan et al., 2022; Rani et al., 2023). In this context, the four-day refrigerated display period used in the current experiment represents a realistic approximation of the typical retail shelf life for beef under cold conditions (Gonzalez et al., 2024).

Although both systems were internally consistent in their measurements over time, the CVS consistently yielded higher *L**, *b**, Chroma, and hue values than the colorimeter. This discrepancy is most plausibly explained by the fundamentally different measurement principles of the two instruments. Whereas the colorimeter uses a focused light source and a small aperture to penetrate relatively deeply into the translucent meat matrix, the CVS relies on surface-reflected light captured under controlled illumination and geometric conditions. The deeper optical penetration of the colorimeter increases the likelihood of subsurface chromophore mixing,

particularly in heterogeneous tissues. It may reduce the measured intensity of specific color components, especially *a** and *b** values (Tomasevic et al., 2019). The results of this study are in close agreement with previously reported inter-device variations in meat color measurement (Girolami et al., 2013; Ramanathan et al., 2020; Tomasevic et al., 2019; Tomasevic et al., 2021).

Girolami et al. (2013) reported that a calibrated CVS produced *b** values nearly three times those obtained with a colorimeter and *a** values approximately 0.5 times those obtained with a colorimeter. This research data supports the observation that CVS measurements in the current study showed similar magnitude differences, particularly in *b** values, across multiple storage days (Table 1).

Chroma (*C**), often called the saturation index, quantifies the purity or vividness of a color (King et al., 2023; Zhang et al., 2023). Higher Chroma values indicate more vivid, saturated colors, whereas lower values approach a duller, more neutral or gray appearance. The consistently lower Chroma readings from the colorimeter in the current study can be explained by its lower b* values, again supporting the link between subsurface light integration and reduced saturation readings in translucent products.

The hue angle (h°) is used to numerically express the dominant wavelength of a color, with about 0° corresponding to red, 90° to yellow, 180° to green, and 270° to blue. In the current study, the two methods yielded distinct hue angle values, yet both showed a general increase over time. This trend likely reflects a shift in meat surface color from vivid red to more brownish or yellowish tones during storage, a change consistent with the oxidation of myoglobin pigments and the accumulation of metmyoglobin on the surface (Ruedt et al., 2023; Suman & Joseph, 2013). The higher redness index and stronger red tones recorded by the colorimeter may appear contradictory to its lower *b** values, but this can be reconciled by recognizing that the redness index is more sensitive to changes in *a** than to corresponding shifts in *b**, and the low *b** values themselves suppress the calculated hue angle.

A review of the publications announces that CVS instruments frequently report higher *L** values than colorimeters, although the direction and magnitude of differences in *a** and *b** values vary with meat type, storage duration, and surface properties (Girolami et al., 2013; Tomasevic et al., 2019; Tomasevic et al., 2021). Girolami et al. (2013) validated CVS accuracy by comparing it with trained sensory panels and found significant device-dependent shifts in *L*, a*, b**, hue, and Chroma values. They attributed the colorimeters bias to its greater optical penetration depth, approximately 15-20 mm compared with about 5 mm for the CVS, leading to averaging of surface and subsurface signals and a consequent underestimation of chromatic intensity. The current study corroborates these findings, with the CVS generally providing higher *L*, b**, Chroma, and hue values throughout storage. The significant method-day interaction observed in this dataset further demonstrates that these differences persist and may even amplify under conditions of progressive surface change during refrigerated storage. Such results underline the importance of matching the measurement method to the intended application. The CVS appears particularly well suited for surface color monitoring over time, whereas spot colorimeter readings may be less representative when evaluating translucent or heterogeneous products (Hosseinpour et al., 2019; Taheri-Garavand et al., 2019).

Previously, Chmiel et al. (2012) demonstrated that computer vision systems, by analyzing color lightness and specific color model components, can effectively distinguish dark, firm, and dry (DFD) beef from regular beef, with specific parameters showing strong correlations with meat pH. Current results also find indirect support from the work of Hosseinpour et al. (2019), who developed a smartphone-based CVS and evaluated its performance under variable shooting conditions, including differences in lighting, camera angle, distance, and rotation. The image processing algorithms were specifically designed to minimize the impact of these variations, enabling the system to deliver high accuracy (R^2 =0.97-0.99) even under uncontrolled field conditions. These findings suggest that CVS-based color evaluation is not only viable in

laboratory environments with controlled lighting and geometry but also adaptable to real-world scenarios, such as retail display monitoring or on farm quality control.

Conclusions

Taken together, the present study strengthens the case for CVS as a primary tool in meat color assessment. Its capacity to deliver consistent, surface-focused color metrics that align with quality indicators such as pH and microbial counts makes it a valuable complement to, and in some cases a replacement for, traditional colorimeters. However, when interpreting CVS and colorimeter data, it is essential to account for the underlying physical and optical principles that govern their readings. Future work could extend these findings by applying CVS in predictive shelf-life modeling or integrating it with other non-destructive quality assessment technologies, thereby offering a more comprehensive, real-time approach to meat quality monitoring.

Conflict of Interest

The authors stated that they did not have anyreal, potential or perceived conflict of interest.

Ethical Approval

This study did not involve the use of any live animals or experimental animal materials. The meat used was food-grade and obtained from a local slaughterhouse. Therefore, this study is not subject to HADYEK permission in accordance with Article 8 (k) of the Regulation on Working Procedures and Principles of Animal Experiments Ethics Committees (official gazette no: 28914).

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