Evaluation of the influence of digital camera acquisition parameters for the accuracy of colorimetric measurements

A E Moura[1], **G S Barcelos**[1], **J M Napolitano**[1], **L C Dias**[1], **I L R Amorim**[1], **P B Costa**[1]

[1]Centro de Estudos Metrológicos (CEMETRO), Universidade Federal de Minas Gerais, Belo Horizonte-MG, 31.270-901, Brasil

pedro@demec.ufmg.br

Abstract: Law 9,972 of 2000 instituted the classification of vegetable products, by-products, and waste of economic value, making their classification mandatory when intended for human consumption, in purchase and sale operations, and at ports and airports when destined for export. The classification of these vegetables consists of separating the product into different categories of quality according to their peculiarities, forming homogeneous batches, as well as determining the quality based on official standards. Among the quality standards to be observed in this classification process are shape, size, weight, defects in the skin, and color, which will be the focus of this work. Currently, much of this classification process is carried out manually, based on the knowledge and experience of operators. With a focus on automating this type of process, studies in the field of computer vision are being developed with the aim of autonomously reproducing the classification of fruits and vegetables usually carried out by trained operators. However, in various applications in the current literature, digital cameras are used to extract quantitative measurements. These pieces of information require metrological analyses like any other conventional measurement system. In this sense, the present paper proposes a study to evaluate the errors in the application of a digital camera for color measurement. Results will be shown from tests comparing numerical aperture, exposure time, and ISO parameters with the results of a colorimeter using a color chart as a measurand. The goal is to evaluate the accuracy and estimate the error curves of a conventional sensor when applied to color metrology. This study is an important step in ensuring the reliability of color measurements using digital cameras for automatic fruit and vegetable classification systems.

1. Introduction
The evaluation of visual aspects of food holds paramount importance as it exerts a substantial impact on consumer perception, satisfaction, and purchasing decisions. Moreover, visual assessments serve the purpose of identifying and rectifying any deviations or flaws that might compromise the overall quality of food items. In this regard, metrology assumes a vital role in the evaluation of food, as it provides precise and accurate measurements that uphold quality, safety, and consistency within the food industry. Particularly, image metrology specializes in visual analysis and measurement techniques that are indispensable for appraising diverse facets of food quality and desirability. Through the implementation

of image metrology, the field enables the assessment of attributes such as color, texture, shape, and size, which significantly contribute to the visual appeal and freshness of food.

The utilization of metrology for ensuring food quality has received significant attention in academic research. A noteworthy investigation focused on employing color measurement techniques to assess the quality of potato samples [1]. Similarly, Mohammad et al. (2017) [2] employed color measurement methods to improve the drying processes of kiwifruits. Although both studies acknowledge the calibration procedures implemented in their respective systems, they overlook the potential impact of camera acquisition parameters on the measurement outcomes. This oversight is also evident in other relevant studies, such as Gökmen and Sügüt (2007) [3], León et al. (2006) [4], and Masawat et al. (2015) [5]. While the studies mentioned above have not explicitly addressed the parameters of image acquisition, it is crucial to emphasize the significance of metrology in assessing the quality of food, particularly with respect to its color. This serves to highlight the necessity of thoroughly considering all influencing factors to ensure the precision and reliability of measurements.

This article presents a study that aims to evaluate the impact of camera acquisition parameters, specifically ISO, aperture, and exposure time, on color measurements. The primary objective of this research is to determine the extent to which these parameters influence color measurements by calculating the measurement error in relation to the measurements obtained from a standardized colorimeter. By gaining insights into the influence of these parameters on color measurement, it becomes possible to confirm their significance in color measuring systems. Such understanding is crucial for enhancing the accuracy and reliability of color measurement techniques and their practical application within the food industry.

2. Color Measuring System

The study required the establishment of a robust and controlled measurement system. The setup involved assembling a workstation comprising a Canon T3 digital camera, a 24-ColorChecker color plate, and a D65 lamp with a color temperature of 6500K. Careful positioning of these components on a Newport I-2000 Series anti-vibration table was undertaken to ensure stability and accuracy. To minimize any potential interference from external lighting, the entire system was securely enclosed within a black box. The versatility of the setup allowed for the precise adjustment of the color checker's position, achieving the desired 45°/0° geometry where the lamp was positioned at 45 degrees and the camera at 0 degrees, as illustrated in Figure 1.

To establish a reliable reference for measurements, a ColorFlex colorimeter of the HunterLab model was employed. This device served as a standardized measurement source, enhancing the accuracy and consistency of the results obtained. Figure 2 visually depicts the 24-ColorChecker color plate utilized in the study, which featured numbered colored squares, including gradations of black and white.

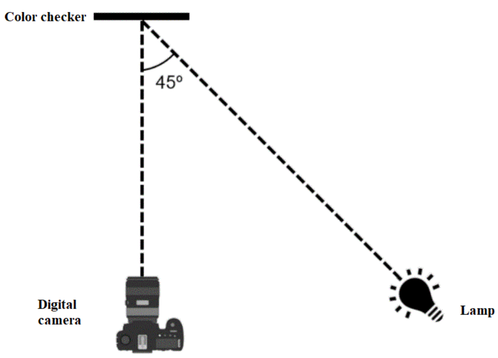

Figure 1. Setup Schematics.

Figure 2. 24-ColorChecker color plate

The camera control was facilitated through two MATLAB routines. The first routine enabled the systematic capture of a predetermined number of photos, incorporating varying parameters to capture the desired range of data. The second script accessed the generated photo folder, allowing for the selection of 24 points within the image that corresponded to the central regions of the color chart squares. These points were subsequently expanded into 50 by 50 pixel squares, enabling precise color calculations and the derivation of average values in terms of L*a*b* color space for each selected point in every image. The functioning of the program is illustrated in Figure 3.

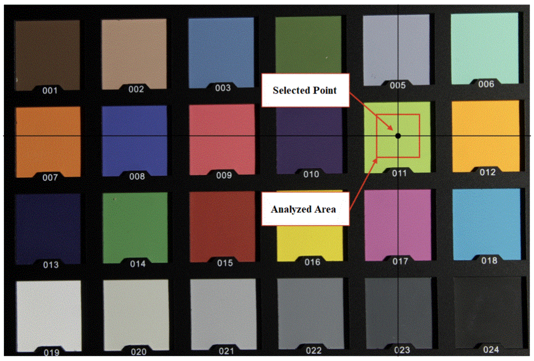

Figure 3. Representation of point selection in the images

3. Evaluation of acquisition parameters

In order to evaluate the impact of camera acquisition parameters on color measurements a total of three tests were conducted, with each test featuring a distinct aperture value (1.8f , 5.6f and 36f). During each test, data collection involved measuring seven specific points while systematically adjusting the ISO settings. The ISO range covered values from 100 to 6400, with intermediate increments of 200, 400, 800, 1600, and 3200. Furthermore, configuring the camera with a specific combination of aperture and ISO and manually adjusting the exposure time in the camera allowed for the achievement of optimal image exposure. The exposure time for each combination of aperture and ISO is shown in Table 1:

Table 1. Exposure time in seconds for each combination of aperture and ISO

Aperture/ISO	1.8f	5.6f	36f
100	1/15	2/5	15
200	1/30	1/5	8
400	1/60	1/10	4
800	1/125	1/20	2
1600	1/250	1/40	1
3200	1/500	1/80	1/2
6400	1/1000	1/160	1/4

For the analysis, the DE and DH parameters were chosen over the individual errors of the L*a*b* color space. This decision aimed to condense the values of the coordinates (L*, a*, b*) into a single error value, in the case of DE, and to condense the values of the coordinates (a*, b*) into a single DH value. These errors are relative to the measurements obtained from the ColorFlex colorimeter. This approach simplifies the interpretation of results by significantly reducing the total amount of data to be analyzed. Furthermore, to further narrow the scope of the analysis, a single color was selected from the 24-ColorChecker color plate. Color 9, positioned centrally within the palette, was selected for analysis. Considering all 24 colors would substantially increase the data volume to be analyzed, compromising the efficiency and conciseness of the analysis.

The ColorFlex colorimeter, a calibrated instrument with a calibration certificate, was utilized in this study as the reference for color measurements. The measurements obtained from the ColorFlex colorimeter were used to calculate the Delta E and Delta H errors, which quantify the color differences between the measured colors and the reference colors. These errors provide a valuable metric for assessing the accuracy of colorimetric measurements. Each color was individually measured using the ColorFlex colorimeter, guaranteeing meticulous data acquisition and minimizing any potential variation. This standardized approach, using the ColorFlex colorimeter and the calculated errors, allowed for consistent and reliable color comparisons throughout the experiment.

4. Results

As mentioned before, the main focus of this study is to evaluate the behavior of the digital camera in color capture according to its acquisition parameters. For this purpose, 10 measurements (10 images) were taken for each configuration shown in Table 1. This allows us to investigate how the camera captures color when the lens aperture allows for lower and higher light inputs. The variation in ISO allows us to assess whether the sensitivity adjustments made by the camera affect the color after the digitized image. Thus, with all the possible variations, a total of 210 images were evaluated.

Table 2 shows the average results for different ISO values at an aperture of 1.8f. The results for an aperture of 5.6f are presented in Table 3, and Table 4 for an aperture of 36f. The tables also display the ΔE and ΔH values when comparing the results with the reference value for the new color number of the standard obtained with the colorimeter, which was *L = 50.48 a* = 43.89 e b* = 11.89*

Table 2. L*a*b*, ΔE and ΔH for the Color 9 with 1.8f aperture

ISO	L*	a*	b*	ΔE	ΔH
100	65.72	49.29	14.57	16.39	6.03
200	66.18	49.40	14.57	16.85	6.12
400	66.40	49.56	14.58	17.11	6.28
800	66.20	49.55	14.42	16.89	6.20
1600	65.31	47.70	13.73	15.42	4.77
3200	59.60	49.35	15.40	11.19	7.72
6400	61.87	47.81	13.94	12.22	5.93

Table 3. L*a*b*, ΔE and ΔH for the Color 9 with 5.6f aperture

ISO	L*	a*	b*	ΔE	ΔH
100	60.40	50.58	16.24	12.73	7.98
200	60.63	50.76	16.36	13.04	8.19
400	60.67	51.04	16.23	13.18	8.36
800	60.45	50.87	16.17	12.89	8.18
1600	60.41	51.01	16.16	12.94	8.30
3200	59.16	53.07	17.46	13.80	10.74
6400	58.41	52.68	17.18	12.97	10.29

Table 4. L*a*b*, ΔE and ΔH for the Color 9 with 36f aperture

ISO	L*	a*	b*	ΔE	ΔH
100	65.64	50.75	15.01	16.92	7.54
200	65.80	51.08	15.16	17.23	7.90
400	65.86	51.33	15.18	17.40	8.14
800	65.61	51.32	14.95	17.13	8.03
1600	65.63	51.40	15.03	17.20	8.14
3200	65.22	53.71	15.93	18.16	10.62
6400	64.91	53.57	16.15	17.89	10.58

As a way to make the obtained results visible, Table 5 exemplifies in colors the variations in aperture according to the changes in ISO. For the visual evaluation of errors, Figure 4 displays the color representation of the values obtained as references in the colorimeter.

L = 50.48
a = 43.89*
b = 11.89*

Figure 4. Example of reference value.

Table 5. Example of color variation for the different measurement parameters.

	ISO 100	ISO 400	ISO 1600	ISO 6400
f1.8				
f5.6				
f36				

4.1 Analysis

As a way to identify possible variations in color measurements based on parameter changes, Table 5 can be observed in two different ways. By looking at the colors vertically, the influences of the lens aperture can be evaluated. On the other hand, by observing the colors horizontally, the influences of ISO can be assessed.

To obtain numerical descriptions of these two evaluations simultaneously, the factorial experiment analysis technique was employed, where the factors are Aperture (represented by f-stops: f1.8, f5.6, and f36) and ISO, with each factor divided into several levels. For the Aperture factor, three levels were used, and for the ISO factor, seven levels were considered (100, 200, 400, 800, 1600, 3200, 6400).

The technique consists of describing the measurements following the model represented by Equation 1, where Yijk represents each of the 210 measured values considering each aperture-i and each ISO-j for all k-th repetitions. The model assumes that each of these measured values is composed of an average value (μ) and the influences of the Aperture and ISO factors, along with a random error (ε), represented respectively by α, β, and ε.

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk} \quad (1)$$

Considering the model from Equation 1, an Analysis of Variance (ANOVA) test is then applied to test the hypothesis of whether the values of α and β are equal to zero or different from zero. For example, if there is statistical evidence to consider α equal to zero, it means that the aperture does not influence the Yijk results. The same analysis is performed for ISO using the parameter β.

The same procedure was carried out for the evaluation of ΔE and ΔH, with the aim of assessing whether the configurations also affect the brightness of the images. The results are presented in Table 6.

Table 6. ANOVA results.

	ΔE		
	F-value	P-value	Conclusion
Apperture	47.67	9.99×10^{-11}	$\alpha \neq 0$
ISO	0.15	0.70	$\beta = 0$
	ΔH		
	F-value	P-value	Conclusion
Apperture	38.50	2.96×10^{-9}	$\alpha \neq 0$
ISO	40.65	1.17×10^{-9}	$\beta \neq 0$

The results obtained from the ANOVA allow us to observe different important behaviors to understand how the camera's acquisition parameters influence the color values of the images.

One key point is that regardless of whether we consider the behavior of L, a, and b or just a and b, the aperture significantly influences the color values. A second consideration based on the results is the influence of ISO sensitivity in the images. When considering the L values for calculating ΔE, ISO variation does not show significant variations in the color results, which is not the case when the L values are excluded for calculating ΔH.

In practical terms, imagining each color as a position in a three-dimensional space, the values being considered close to each other means that the Euclidean distance between the points is statistically insignificant, indicating that the sensitivity correction based on light is accurately performed by the system.

5. Conclusion

This research is a continuation of studies related to evaluating the applicability of digital cameras for colorimetric measurements. In this stage, the influences of the acquisition parameters, such as lens aperture and ISO sensitivity control, were assessed. These parameters have been neglected in recent literature that uses digital cameras for color measurement.

For the evaluation, a color was used as a reference standard, previously measured with a colorimeter. Measurements were conducted by varying the parameter conditions on a setup with consistent illumination throughout the process.

The results were analyzed using analysis of variance (ANOVA), and it was confirmed, with a statistical significance level of 0.05, that the numerical aperture values and ISO sensitivity are significant for representing colors. Another important conclusion is that different literature uses various parameters to compare color values in quality control or product classification. The main parameters used are ΔE and ΔH. The difference between these parameters lies in the use of the L value in ΔE, which is not the case in ΔH.

The results of this experiment indicate that for applications using ΔE as an analysis parameter, ISO values can be used to correct lighting deficiencies in experiments or production lines without compromising the results. However, for experiments where ΔH parameters are used, a precise evaluation of errors according to the camera settings during measurements is necessary.

6. References

[1] Saldaña, E., Siche, R Huamán, R. Luján, M. Castro, W., Quevedo, R.berto. Computer vision system in real-time for color determination on flat surface food. Scientia Agropecuaria, vol. 4, no. 1, 2013, pp.55-63.

[2] Mohammad H. N., Mohammad H. A., Hassan S., Mahmood R. G., Mohammad T., Alex M. 2017, Improvement of kiwifruit drying using computer vision system (CVS) and ALM clustering method, Drying Technology, 35:6, 709-723, DOI: 10.1080/07373937.2016.1208665

[3] Gökmen, V. Sügüt, I., 2017, A Non-Contact Computer Vision Based Analysis of Color in Foods, International Journal of Food Engineering: Vol. 3: Iss. 5, Article 5. DOI: 10.2202/1556-3758.1129

[4] Katherine L., Domingo M., Franco P., Jorge L., 2006, Color measurement in L∗a∗b∗ units from RGB digital images, Food Research International, Volume 39, Issue 10, Pages 1084-1091, DOI:10.1016/j.foodres.2006.03.006.

[5] Prinya M., Antony H., Anan N., An iPhone-based digital image colorimeter for detecting tetracycline in milk, Food Chemistry, Volume 184, 2015, Pages 23-29, ISSN 0308-8146, DOI: 10.1016/j.foodchem.2015.03.089