Peruvian Agricultural Research
ISSNe 2706-9397
Homepage: http://revistas.unjfsc.edu.pe/index.php/PeruvianAgriculturalResearch

Received: Mar 3, 2025 / Accepted: May 5, 2025

Articulo Original

Measurement of colorimetric parameters in fruits using smartphones and comparison with a tristimulus colorimeter

Medición de parámetros colorimétricos en frutas empleando teléfonos inteligentes y su comparación con un colorímetro triestímulo

E. Macavilca-Ticlayauri[1*], E. Carmelo-Cabrera[2], M. Andrade-Oré[2], J. Garcia-Tafur[2]

https://doi.org/10.51431/par.v6i3.1010

Abstract

Objectives: Measure color using smartphones on fruits and compare it with the measurement of a tristimulus instrumental colorimeter. ***Methodology***: Fruits at different ripening stages were selected, and colour was measured in a three-dimensional CIEL*a*b* space for strawberries, lemons, tangerines, and chilli peppers. The colorimetric coordinates L*, a* and b* are compared by the color difference of (ΔE*). Seven colourimetric parameters were calculated using colour coordinates to compare the two measurement methods, and the statistical techniques of correlation and Bland-Altman Plot were used to evaluate their performance. ***Results:*** The colorimetric coordinates of both methods showed ΔE* values between 2.42 and 59.24 with a greater difference in mandarin fruits and less in peppers, while five colorimetric parameters showed a high correlation coefficient (r=0.943-0.999) for all the fruits evaluated. The Bland-Altman plots showed in detail that the whiteness and yellowness indices did not show similarity, lemon showed a high concordance in five colorimetric parameters, mandarin and strawberry had low similarity and are dependent on their ripening stage. ***Conclusion:*** the use of smartphones in the measurement of color in fruits may vary compared to a colorimeter, but their reliability is surpassed when calculating colorimetric parameters that relate the colorimetric coordinates L*, a* and b*, we suggest using these devices as a potential tool to evaluate and monitor the ripening stages of various fruits.

Keywords: Smartphone, color index, ripening indicator, Bland-Altman.

Resumen

Objetivo: Medir el color empleando teléfonos inteligentes en frutas y compararlo con la medición de un colorímetro instrumental triestímulo. **Metodología**: Se seleccionaron frutas con diferentes estadios de maduración, el color fue medido en el espacio tridimensional CIEL*a*b* en fresas, limones, mandarinas y ajíes. Las coordenadas colorimétricas L*, a* y b* se compararon mediante la diferencia de color del (ΔE*). Se calcularon siete parámetros colorimétricos empleando las coordenadas de color para comparar ambos métodos de medición, y para evaluar su performance se utilizó la técnica estadística de correlación y grafica de Bland-Altman. **Resultados:** Las coordenadas colorimétricas de ambos métodos mostraron valores de ΔE* entre 2.42 hasta 59.24 con mayor diferencia en frutos de mandarina y menor en ajíes, en cambio cinco parámetros colorimétricos mostraron un alto coeficiente de correlación (r=0.943-0.999) para todos los frutos evaluados. Las gráficas de Bland-Altman expusieron detalladamente que los índices de blancura y amarillez no presentaron similitud, el limón presento una alta concordancia en cinco parámetros colorimétricos, la mandarina y la fresa tuvieron baja similitud y son dependientes de su estadio de maduración. **Conclusión:** El uso de los smartphones en la medición del color en frutos puede variar frente a un colorímetro, pero su confiabilidad es superada cuando se calculan parámetros colorimétricos que relacionan las coordenadas colorimétricas L*, a* y b*. Se sugiere emplear estos dispositivos como una herramienta potencial para evaluar y monitorear los estadios de maduración de diversos frutos.

Palabras clave: celular inteligente, índice de color, indicador de madurez, Bland-Altman.

[1]Departamento de Académico de Ingeniería en Industrias Alimentarias, Universidad Nacional José Faustino Sánchez Carrión, Lima, Perú
*Autor de correspondencia: emacavilca@unjfsc.edu.pe
[2]Escuela Profesional de Ingeniería en Industrias Alimentarias, Universidad Nacional José Faustino Sánchez Carrión, Lima, Perú

Introduction

Colour is one of the first indicators we use to judge whether a food is of good quality; it generates an expectation about its flavour, texture, and freshness. In addition, color is an attribute that influences our attention to certain products, can stimulate or inhibit our appetite and, therefore, our purchasing and consumption decisions. According to Pathare et al. (2013), accurate measurement of food colour enables producers and quality controllers to assess the freshness, ripeness, and chemical composition of products, thereby ensuring their quality and safety.

There are two basic methods of color measurement: sensory and instrumental. The sensory method performs a visual evaluation of color by trained panellists or consumers. The instrumental method, also referred to as colorimetry, uses equipment such as colorimeters and spectrophotometers to evaluate the color of a sample using techniques that measure its transmittance or reflectance (Fan et al. 2021).

In instrumental measurement for the accurate description, interpretation and reproduction of color, use is made of numerical color space models, and CIELAB, also referred to as CIEL*a*b* space, is currently one of the most popular and uniform color spaces used to evaluate color in the food area, providing an objective and uniform color description that is closely aligned with human color perception. Its model is based on three colorimetric coordinates, where L∗ is lightness from black (0) to white (100), a∗ is green (-) to red (+) and b∗ is blue (-) to yellow (+), when a* and b* take the positive sign (+a*, +b*), they define red and yellow colors, respectively. On the other hand, parameters with a negative sign (-a* and -b*) represent green and blue color profiles (Pandiselvam et al. 2023; Pathare et al. 2013; Ponnal et al. 2021; Shange et al. 2025).

However, the use of instruments to measure color is not so practical, many of them are expensive and lack portability, which has promoted to look for other alternatives, and one of them is digital image colorimetry (DIC) or digital image photometry (DIP) which is currently a hot research topic, in this technique the colorimetric analysis is based on the digitization of images collected by some image acquisition tools such as: digital cameras, webcams, scanners, cell phones, etc. (Fan et al. 2021; Kalinowska et al. 2021; Soares et al., 2023).

The use of smartphones has wide applicability and scientific interest stemming from its advantages, which include portability, low energy demand, cost-effectiveness, ease of use and wide availability of instrumentation (Soares et al. 2023). According to Ali et al. (2024), the use of smartphones is a more practical technology than software, as it eliminates the need to send data and is easier to use because it is available on the same cell phones, capable of exposing measurements in different color spaces. The advantage of using smartphone-based analysis is that the results can be automatically saved on secure servers in the cloud or shared on various public social media platforms (Kanchi et al., 2018). The various applications have mainly focused on environmental studies, clinical analysis, food and beverage analysis, pharmaceutical/agronomic testing,; and fuel/biofuel samples (Soares et al. 2023).

Measuring color in fruits with a smartphone can be considered reliable, especially if specific apps and accessories designed to improve accuracy are used. Lighting conditions, camera quality, and specific algorithms or calibration methods used can influence the accuracy of color measurement with a smartphone (Cubero et al., 2018; de Oliveira et al., 2024). Accuracy rates of between 80% and 93% have been demonstrated for classifying fruit ripeness and color, depending on the type of fruit and the algorithm used(Das et al., 2016). Research indicates that smartphones, equipped with the right tools, can effectively measure color attributes comparable to traditional methods (Ciaccheri et al., 2023).

The above is supported by studies where the use of smartphones is evidenced in measuring color in agricultural products reliably, assessing the ripening index of oranges, mandarins and other citrus fruits (Cubero et al., 2018; Srivastava et al., 2021; Vidal et al., 2013), in tomatoes (Carpenter & Farnand, 2020; Sherafati et al., 2022), in bananas (Cho & Koseki, 2021; Tanut et al., 2023), strawberries (Yue et al., 2020), kiwifruit (Khosravi et al., 2025), avocados (Cho et al., 2021; Jaramillo-Acevedo et al., 2020), avocados (Cerutti et al., 2018), apples (Das et al., 2016), stone fruits (Scalisi et al., 2022), in sorting the ripening stage of carambola fruits (Saha et al., 2023) among other applications.

Although color measurement with smartphones is promising, it is essential to take into account the possible limitations, and ensure by comparison with an instrumental device to validate the reliability, so in this research it was proposed to compare the measurement of color in fruits, between two methods, using a smartphone and a tristimulus colorimeter, comparing the colorimetric coordinates L*, a* and b* and seven colorimetric parameters

Methodology

The research was carried out at the Laboratorio de Procesos de Ingeniería of the Faculty of Agricultural, Food Industries and Environmental Engineering, Universidad Nacional José Faustino Sánchez Carrión, Huacho, Lima, Peru.

Fruit samples

The samples were fruits of lemon (*Citrus Aurantifolia Swingle*), Satsuma mandarin (*Citrus Unshin*), strawberry (*Fragaria x ananassa Duch*), and chilli bell pepper cv. "limo" (*Capsicum baccatum*), in different stages of maturation (from immature to mature), acquired in the central markets of the city of Huacho and the Huaral market, Lima region.

Instrumental Color Mesurement

Referential color measurement was performed on the surface of the fruits with a tristimulus colorimeter (CR-400, Konica Minolta, Tokyo, Japan) calibrated using a standard white ceramic plate (calibration plate CRA43, Konica Minolta Inc., Japan). For each fruit, the colorimetric coordinate values of each sample were measured three times and averaged. The color values were in CIEL*a*b* space where they were expressed as L* value (lightness or brightness), a* value (redness or greenness) and b* value (yellowness or blueness), and ranged from 0 to 100 (L* value) and from -127 to 127 (a* and b* values).

Color measurement using a smartphone

The color measurement with the smartphone was using the free Color Grab application (Loomatix, version 3.9.2, 2021) available for Android systems installed on a Redmi Note 12S smartphone, color readings were uniformized in CIEL*a*b* space by placing the samples inside a photographic studio box (Coolbox, Peru) controlling the Led illumination intensity (5.36 Kilolux, Luxmeter HI 97500, Hanna Instrument, USA).

Calculation of colorimetric parameters

Calculations of the colorimetric parameters for the two measurement methods were performed according to the equations given in Table 1 based on the CIEL*a*b* color coordinates measured by both instruments. The total color difference was calculated by the formula

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$\Delta L^* = L^*_{colorimeter} - L^*_{Smartphone}$, $\Delta a^* = a^*_{colorímeter} - a^*_{Smartphone}$, and $\Delta b^* = b^*_{colorímeter} - b^*_{Smartphone}$.

Table 1

Calculated colorimetric parameters used in the comparison between a colorimeter and a smartphone

Colorimetric parameter	Equation	Reference
Citrus color index (CCI)	1000 x a*/(L*x b*)	Cubero et al. (2018), Machado Molina et al., (2019).
Whiteness index (IB).	100-((100-L*)^2+a*^2+b*^2)^0.5	Pathare et al. (2013), Supapvanich et al., (2016).
Yellowness Index (AI)	142.86 (b*/L*)	Cueva-Mena, (2016), Pathare & Al-Dairi, (2022)
Red/yellow indicator	a*/b*	Zaccari et al., (2017), Flores-López et al., (2024).
Maturity indicator (MI)	L*(a*/b*)	Manera et al., (2013), Fernandes et al., (2015).
Ripening color index (MCI)	200/(1-(a*/b*))	Santos-Gomes et al., (2013), Juncai et al., (2015).
Red fruit color index (RFCI)	2000 x a*/(L* (a*^2+b*^2)^0.5)	Goisser et al., (2020), Iswahyudi et al., (2024).

Data analysis

The colorimetric data obtained by both devices were processed using Microsoft Excel spreadsheet, and Pearson's correlation was used to evaluate the linear relationship of the colorimetric parameters of both measurements. To evaluate the performance in matching the colorimetric parameters with a better interpretation, the Bland-Altman plot was employed which is a visual and intuitive way to measure the degree of similarity between both measurements (Giavarina, 2015) with the help of the Medcal version 23.2.1 program (trial version www.medcal.org, MedCalc Software Ltd. Belgica). The Bland-Altman plot represents the differences between the two analytical methods (y-axis= Colorimeter-Smartphone) versus the average of the values of both methods (x-axis= (Colorimeter+Smartphone)/2) for each colorimetric parameter and performs a comparative analysis of the measurements, this analysis illustrates any systematic bias or discrepancy between the measurements of both methods, can be employed with a minimum sample size (n = 10) (Bahar et al., 2017).

Results and discussion

Comparison of colorimetric coordinates

The colorimetric coordinates in CIEL*a*b* space and in average of both measurements are shown in Table 2. The L*a*b* values in the fruits, estimated with both devices, show changes in the color of the shells according to the ripening stage, indicating that suitable fruits were selected to perform a comparison in color measurement.

The color differences (ΔE*) between both color measurement methods are exposed, this value represents the Euclidean distance between two colors in the color space L*a*b*, according to Pathare et al., (2013), the interpretation of ΔE* values may vary depending on the chromatic region and human perception, and considers that at values of ΔE* > 3.0 human eyesight can easily perceive a color difference. The highest values of color difference between both measuring devices were in mandarin fruits (28.75 to 59.24), becoming more accentuated when the stage is immature, in strawberry the differences were from 34.13 to 55.47; something more moderate is presented in lemon with differences ranging from 11.38 to 53.69; and low values were obtained in the chili bell pepper samples in which the immature stage was more favorable with values ranging from 2.42 to 21.04, with the b* coordinate being the most distant, given that the color changes from green to yellow. From these results it can be affirmed that the colorimetric coordinates of the fruits are different in both measuring devices, and it can be assumed that this is due to the lighting conditions, distance between the sample and the device, and the quality of the camera, among other factors (Ciaccheri et al., 2023).

Table 2

*Colorimetric coordinates of the samples in CIEL*a*b* space and color difference between the two methods of measurement*

Fruit	MS	CR-400 Colorimeter			Smartphone			ΔE*
		L*	a*	b*	L*	a*	b*	
STRAWBERRY	F1	31.2±1.4	16.1±1.1	5.8±1.2	49.0±2.1	39.9±2.4	22.5±1.2	34.13
	F2	32.3±1.6	19.5±2.3	7.2±2.6	52.8±2.0	50.6±6.2	20.8±7.3	39.69
	F3	35.4±3.2	19.2±2.3	12.5±2.9	61.1±5.5	54.6±2.3	32.5±11.9	47.98
	F4	38.3±2.9	18.6±1.6	14.6±3.6	69.6±5.0	41.1±9.9	38.5±5.1	45.44
	F5	45.7±4.9	9.9±3.8	20.7±4.7	73.8±4.7	29.9±11.4	52.5±12.2	46.92
	F6	44.6±2.4	6.0±1.2	17.4±0.7	78.2±7.1	16.6±17.8	60.2±6.0	55.47
	F7	49.5±1.8	3.9±0.4	22.4±1.2	92.1±3.5	-7.2±2.1	51.3±13.0	52.62
TANGERINE	M1	36.5±2.5	-9.3±1.2	11.1±2.2	63.5±3.3	-37.7±3.7	49.2±7.5	54.72
	M2	41.7±1.6	-9.3±0.6	15.5±1.3	66.8±5.7	-32.1±6.1	64.0±5.6	59.24
	M3	40.9±1.7	-9.3±1.4	16.2±2.2	63.3±2.5	-25.8±1.6	56.8±9.2	49.27
	M4	50.8±5.2	-0.4±5.5	24.2±4.2	70.5±7.9	-12.5±8.4	62.6±18.1	44.84
	M5	51.9±2.9	2.0±4.6	26.1±2.9	71.7±2.4	-4.2±6.8	71.1±2.2	49.54
	M6	48.9±2.3	5.2±2.6	23.3±2.2	66.2±2.9	2.5±10.5	66.5±2.7	46.67
	M7	59.8±5.0	14.5±7.5	32.8±3.4	59.0±4.5	17.8±14.2	61.3±3.3	28.75
LEMON	L1	73.6±1.5	-6.1±1.4	48.2±2.7	86.3±1.2	-8.9±0.8	53.7±3.5	13.99
	L2	66.7±0.5	-9.9±1.7	43.9±0.6	86.5±5.8	-18.9±3.6	74.7±3.5	37.76
	L3	50.3±6.8	-13.3±3.5	26.5±7.7	78.9±10.2	-37.8±3.7	64.8±10.4	53.69
	L4	49.1±8.0	-17.5±1.3	35.9±8.9	40.9±9.5	-22.2±4.4	42.1±12.7	11.38
	L5	57.8±5.7	-17.8±0.6	46.6±5.8	51.8±14.6	-25.4±3.7	52.9±15.4	11.63
	L6	52.8±6.5	-16.8±1.5	36.4±7.4	60.3±10.8	-26.9±4.0	62.9±8.9	29.45
	L7	58.1±2.2	-15.0±0.7	38.6±2.0	62.3±3.3	-24.7±3.0	52.0±15.2	17.11
	L8	62.8±5.2	-8.0±5.1	37.6±5.2	64.2±10.7	-11.7±6.1	56.5±9.6	19.26
	L9	63.5±1.7	-13±1.2	42.9±1.4	70.9±9.0	-15.6±2.5	63.7±4.2	23.00
	L10	72.3±6.0	-1.2±4.0	52.3±1.5	79.2±2.4	-1.8±3.3	76.8±6.9	25.59
	L11	76.9±1.2	-4.4±0.6	54.4±1.7	84.6±6.4	-6.8±4.5	82.5±14.1	29.35
	L12	75.8±1.2	-2.2±3.8	56.2±8.0	81.2±9.3	-8.2±3.8	75.9±8.3	21.35
CHILI PEPPER	A1	58.7±6.7	-8.6±2.5	25.9±5.6	60.6±8.2	-9.3±2.0	24.6±6.9	2.42
	A2	55.9±4.2	-3.0±0.5	28.0±1.9	61.3±3.7	3.0±2.8	34.4±3.7	10.28
	A3	54.9±8.8	4.1±1.0	38.1±0.6	55.2±9.4	6.0±0.6	44.0±9.1	6.22
	A4	52.0±4.0	20.0±2.1	33.7±4.5	47.3±5.7	19.6±12.7	29.2±13.3	6.47
	A5	52.4±6.8	11.8±2.2	47.8±10.1	44.4±10.1	28.3±2.5	37.4±19.5	21.04
	A6	39.1±5.2	25.4±3.8	24.2±8.9	34.0±11.5	35.8±3.6	28.1±11.0	12.21
	A7	40.3±2.7	36.6±4.9	27.1±4.9	37.4±7.0	45.0±7.6	32.2±3.3	10.27
	A8	35.2±0.7	38.0±1.6	19.6±1.0	34.0±4.5	54.3±0.4	32.8±2.2	20.97
	A9	30.5±3.6	18.7±9.4	7.4±6.5	15.4±8.4	27.5±10.9	12.1±10.3	18.15

MS: maturation stage.

Comparison of colorimetric coordinates

The color measurement of fruits with different ripening stages allowed to calculate the colorimetric parameters and to make a comparison between both meaurements and in each group of fruits, in the first instance a simple linear regression was used taking the value of the slope and the correlation coefficient (r), the correlation coefficients evaluate the association (as opposed to agreement) between the two methods and the closer to 1 or -1 the stronger the linear relationship between both measurements (smartphone and colorimeter), since the measurements should be similar a value of r close to unity is expected, similarly the slope (or regression coefficient) indicates the magnitude of the change between the two variables, in this specific case between the colorimetric parameter values calculated from both measurements, a value of 1 and -1 would indicate a perfect regression coefficient, the line formed overlaps the line of identity (slope =1) and the further away from this value the reference linearity is lost. Linear regression and correlation play an important role in the interpretation of quantitative method comparison studies (Roustaei, 2024).

The linear dependence between the two methods was evaluated and summarized in Table 3, the results of the correlation coefficient and the slope of the simple linear regression of the colorimetric parameters calculated for each fruit are presented, it can be seen that in strawberries except for the AI the other correlation coefficients are greater than 0.943 which is perceived as a strong linear relationship with good association between both measurements, the CIRF presents a slope of 0.59 which would indicate that the data are dispersed and therefore a low linearity between both measurements. The standard error reflects the effect between agreement and linearity of the data; a large standard error indicates that the estimation is less accurate and more variable (Weisburd et al. 2020). YI and CIRF are the colorimetric parameters of strawberry that do not show consistency between the data of both measurements. Yue et al. (2020) state that strawberries have different colorations from immature to ripe, defined by pigments ranging from green due to chlorophyll to red due to anthocyanins, and that more samples are required to obtain data to improve accuracy.

In the case of mandarin, the colorimetric parameters that presented low correlation and linearity were WI and YI, in addition that CIRF and CCI would indicate good agreement, but low linearity, in this regard Cubero et al. (2018) in the measurement of CCI states that it is a standard used to determine the color of citrus fruits, it is a property that describes the coloration of the epidermis of the fruit, allowing to follow the evolution of ripening, its values range from -24 for green fruits and 22 for orange fruits.

Table 3

Pearson correlation values and regression slope of the colorimetric parameters of both measurement methods

Fruit	Colorimetric parameter	Regression		
		r	Slope	Standard error
Strawberry	CCI	0.993	1.00	3.08
	WB	0.952	0.98	2.13
	YI	0.424	0.68	22.58
	Indicator a*/b*	0.974	0.95	0.24
	MI	0.979	1.03	9.69
	RCI	0.988	1.07	64.83
	CIRF	0.943	0.59	5.05
Tangerine	CCI	0.986	0.72	1.34
	WB	0.152	0.31	7.96
	YI	0.469	0.88	20.29
	Indicator a*/b*	0.995	0.93	0.05
	MI	0.986	1.15	4.45
	RCI	0.999	1.04	4.45
	CIRF	0.981	0.62	2.47
Lemon	CCI	0.997	1.01	0.28
	WB	0.643	1.40	6.47
	YI	0.708	1.10	11.94
	Indicator a*/b*	0.999	0.99	0.01
	MI	0.965	1.13	2.87
	RCI	0.994	0.99	2.49
	CIFR	0.995	1.02	0.64
Chili Pepper	CCI	0.999	0.99	1.77
	WB	0.980	1.15	2.66
	YI	0.995	1.02	2.63
	Indicator a*/b*	0.993	0.92	0.14
	MI	0.979	0.91	6.48
	RCI	0.999	1.01	19.57
	CIRF	0.985	1.06	5.28

CCI: Citrus color index. WI: Whiteness Index. YI: Yellowness Index. MI: maturity indicator. RCI: Ripening color index. CIRF: Color index in red fruits.

The sampling of very green mandarins could be a reason for the ICC of both measurements not agreeing, according to the **r**-value and the slope being far from the line of identity (slope =1). For citrus lemon fruits, the ICC was more concordant between both measurements, as well as a*/b*, MI, RCI and CIRF, but not in WIB and YI, according to Supapvanich et al. (2016). YW can be applied to evaluate the anti-browning effect in apples. Pathare et al. (2013) add that WI is used to monitor the quality of flours, bakery and dairy products. YI is used to quantify yellowness in objects, textiles, and foods; it has been reported in the case of rice (Pathare et al., 2013) and in the storage process of carambola slices (Cueva-Mena, 2016).

The chili "limo" presented a strong correlation between the colorimetric parameters coming from both measuring devices; likewise, the regression coefficient does not move too far from the identity line (Slope=1), the use of WI and YI were reported by Baississe et al., (2022) in the evaluation of chili bell pepper drying.

Graphical comparison of colorimetric parameters

Comparison of test values is often performed using simple linear regression with the coefficient of determination (R^2) or Pearson's correlation coefficient (r) using the primary metric of assay agreement. However, these approaches alone do not adequately quantify the constant or proportional errors needed for optimal test evaluation, also the range of experimental data and the number of experimental points inflate the correlation coefficient (Kandi & Charles, 2019), also, correlation studies the relationship between one variable and another, not the differences, and is not highly recommended for assessing comparability between methods, so broader statistical approaches, such as the Bland-Altman (Figure 1) or concordance limits method, can be used (Giavarina, 2015).

The results shown in Figure 1-A, by Bland-Altman analysis showed that the measured difference between the CCI values for lemon and chili are within the 95% agreement limit and are concentrated in the mean difference line 0.2 (average bias), in the case of strawberry and mandarin it is observed that a measurement protrudes from the limit line of -3.1 and 3.5 (mean ± 1.96 standard deviation), this possibly due to the extremes of immaturity or over-ripeness, the p-value=0.492 confirms that the mean value of the CCI calculated from the data obtained by the Smartphone does not differ significantly from that obtained by the CR-400 colorimeter. In the case of WI shown in Figure 1-B it is observed that there are no data or points that are outside the confidence limit, but a look at the mean bias line shows that there is only one data (strawberry) that indicates minimal difference between both measurements, most of them are far from the zero difference line, this indicates that WI is a colorimetric parameter not suitable to evaluate the fruits under study, supported by the fact that the differences of their means are very far from zero and highly significant ($p < 0.0001$).

Figure 1-C shows the comparison in the YI where it is possible to appreciate values outside the lower confidence limit (-16.7- 1.96*SD) corresponding to mandarin fruits, but in the line of zero difference there are only some values corresponding to lemon, this indicates that the differences of the means of both measurements are different to zero, a high significance ($p < 0.0001$) since most of the data are far from the line of minimum difference.

Figure 1-D shows results of the color indicator a*/b*, where the a* value corresponds to the degree of redness and the b* value represents yellowness. Flores-López et al. (2024) reported that, with this relationship evaluated the degree of maturity in the postharvest quality of tomato fruits was evaluated. It was also employed by Zaccari et al. (2017) in the comparison of five guava fruit peel colors, and Goisser et al. (2020) employed it to predict lycopene in tomatoes. In this research it was observed that only chili fruits obtained two comparative values that were outside the 95% agreement limit, therefore, this colorimetric parameter presented a low difference between the two measurement methods, the *p*-value=0.559 confirms that the data obtained from the Smartphone did not differ significantly from that obtained by the CR-400 colorimeter.

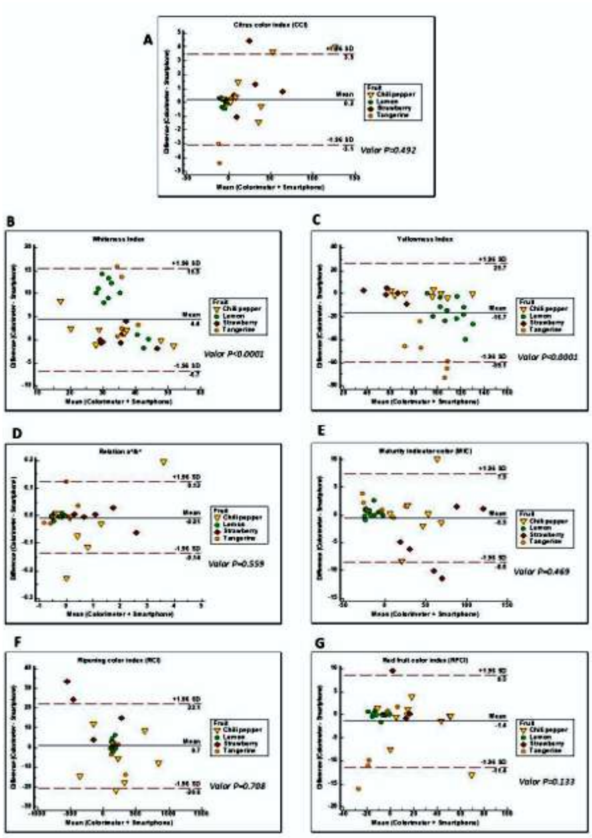

Figure 1: Bland-Altman Graphs in the comparison of colorimetric parameters measured by a colorimeter and a smartphone. A) Citrus Color Index (CCI), B) Whiteness Index (WI). C) Yellowness Index (YI). D) Indicator a*/b*. E) Maturity Indicator (MI). F) Ripening Color Index (RCI). G) Red Fruit Color Index (RFCI)

Figure 1-E, exposes the colorimetric parameter MI, where Manera et al., (2013) and Fernandes et al. (2015) reported it as a colorimetric index of maturity used to determine how the external and internal color of the pomegranate fruit evolves, the Bland-Altman plot for the MI exposed that strawberry and chili fruits present few data that exceed the confidence limits, but a value of p=0.469 indicate that the differences between the means of MI tend to be equal to zero, so that, both devices agree in their measurement.

Figure 1-F corresponding to the RCI which is a colorimetric parameter reported by Santos-Gomes et al. (2013) and Juncai et al. (2015) used as a ripening color index for colorimetric classification of banana fruits, the Bland-Altman plot show that the MI obtained from the Smartphone does not differ significantly with that obtained by the CR-400 colorimeter (p=0.708) although two data corresponding to strawberry can be observed that stand out from the upper confidence limit, which would indicate us that the maturity stage influences both color measurements.

Figure 1-G shows the result of the CIRF comparison; this parameter was used by Goisser et al. (2020) in tomatoes and by Iswahyudi et al. (2024) in apple fruits. In this research this parameter is influenced by the extremes of the fruit ripening stage, strawberry, chili and mandarin present at least one data that go out of the confidence limit region, but the agreement between the calculated from the data of both color measurement devices do not differ significantly (p-value=0.133), the statistical test of the Bland-Altman plot gives validity and reliability to the use of the smartphone to measure color and calculate the colorimetric parameters.

Conclusion

The study evaluated the reliability of measuring color in fruits with smartphones versus a colorimeter. While L, a, b* coordinates differed, it highlighted the need for pre-calibration (distance, illumination, device). Seven derived colorimetric parameters (used for ripening) showed correlation, but not perfect linearity. Bland-Altman analysis confirmed good agreement for Citrus Color Index, a*/b*, Maturity Indicator, Ripening Color Index and Red Fruit Color Index. In contrast, the Whiteness Index and Yellowness Index showed significant differences. Lemon had the best performance and it is recommended to evaluate more fruits and their extreme ripening stage.

Acknowlegments

The authors would like to thank Miriam Villafuerte Ramírez of the Faculty of Education for her support in the grammatical revision of this article.

References

Ali, D. S., Hassan, R. O., Othman, H. O., Taha, H. T., Mousavi Khaneghah, A., & Smaoui, S. (2024). Revolutionizing detection: Smartphone-powered colorimetry for the drugs and food analysis. *Microchemical Journal*, *205*, 111228. https://doi.org/10.1016/j.microc.2024.111228

Bahar, B., Tuncel, A. F., Holmes, E. W., & Holmes, D. T. (2017). An interactive website for analytical method comparison and bias estimation. *Clinical Biochemistry*, *50*(18), 1025-1029. https://doi.org/10.1016/j.clinbiochem.2017.08.008

Baississe, S., Boulelouah, N., Bedjaoui, H., Mehaoua, M. S., & Reguieg, L. (2022). Convection Drying Influence on Thermo-Physical Properties, Bioactive Substances, Color and Texture Profile of Red Pepper (Capsicum Spp). *Acta Universitatis Cibiniensis. Series E: Food Technology*, *26*(1), 83-98. https://doi.org/10.2478/aucft-2022-0007

Carpenter, K., & Farnand, S. (2020). Assessing the Use of Smartphones to Determine Crop Ripeness. *Electronic Imaging*, *32*, 1-6. https://doi.org/10.2352/ISSN.2470-1173.2020.12.FAIS-173

Cerutti, P., Wille, C. L., Melo, R. C. de, Santos, M. dos, Adams, C. R., & Barichello, E. C. (2018). Uso de smartphones como ferramenta de baixo custo na avaliação de cor em frutos. *Revista da Jornada de Pós-Graduação e Pesquisa - Congrega Urcamp*, *0*, Article 0.

Cho, B.-H., & Koseki, S. (2021). Determination of banana quality indices during the ripening process at different temperatures using smartphone images and an artificial neural network. *Scientia Horticulturae*, 288, 110382. https://doi.org/10.1016/j.scienta.2021.110382

Cho, B.-H., Koyama, K., & Koseki, S. (2021). Determination of 'Hass' avocado ripeness during storage by a smartphone camera using artificial neural network and support vector regression. *Journal of Food Measurement and Characterization*, *15*(2), 2021-2030. https://doi.org/10.1007/s11694-020-00793-7

Ciaccheri, L., Adinolfi, B., Mencaglia, A. A., & Mignani, A. G. (2023). Smartphone-Enabled Colorimetry. *Sensors*, *23*(12), Article 12. https://doi.org/10.3390/s23125559

Cubero, S., Albert, F., Prats-Moltalbán, J. M., Fernández-Pacheco, D. G., Blasco, J., & Aleixos, N. (2018). Application for the estimation of the standard citrus colour index (CCI) using image processing in mobile devices. *Biosystems Engineering*, *167*, 63-74. https://doi.org/10.1016/j.biosystemseng.2017.12.012

Cueva-Mena, J. F. (2016). Cambios fisicoquimicos durante el almacenamiento de carambola (Averrhoa carambola L.) mínimamente procesado. *Vitae*, *23 (Supl. 1)* (S806). https://doi.org/10.17533/udea.vitae.26177

Das, A. J., Wahi, A., Kothari, I., & Raskar, R. (2016). Ultra-portable, wireless smartphone spectrometer for rapid, non-destructive testing of fruit ripeness. *Scientific Reports*, *6*(1), 32504. https://doi.org/10.1038/srep32504

de Oliveira, M. A., Ribeiro, M. N., Valente, H. M., da Silva Mutz, Y., Pinheiro, A. C. M., & Nunes, C. A. (2024). Feasibility of Using Reflectance Spectra from Smartphone Digital Images to Predict Quality Parameters of Bananas and Papayas. *Food Analytical Methods*, *17*(1), 145-153. https://doi.org/10.1007/s12161-023-02556-8

Fan, Y., Li, J., Guo, Y., Xie, L., & Zhang, G. (2021). Digital image colorimetry on smartphone for chemical analysis: A review. *Measurement*, *171*, 108829. https://doi.org/10.1016/j.measurement.2020.108829

Fernandes, L., Pereira, J. A. C., Lopéz-Cortés, I., Salazar, D. M., & Ramalhosa, E. C. D. (2015). Physicochemical Changes and Antioxidant Activity of Juice, Skin, Pellicle and Seed of Pomegranate (cv. Mollar de Elche) at Different Stages of Ripening. *Food Technology and Biotechnology*, *53*(4), 397-406. https://doi.org/10.17113/ftb.53.04.15.3884

Flores-López, M. L., Vieira, J. M., Rocha, C. M. R., Lagarón, J. M., Cerqueira, M. A., Jasso de Rodríguez, D., & Vicente, A. A. (2024). Postharvest Quality Improvement of Tomato (Solanum lycopersicum L.) Fruit Using a Nanomultilayer Coating Containing Aloe vera. *Foods*, *13*(1), Article 1. https://doi.org/10.3390/foods13010083

Giavarina, D. (2015). Understanding Bland-Altman analysis. *Biochemia Medica*, *25*(2), 141-151. https://doi.org/10.11613/BM.2015.015

Goisser, S., Wittmann, S., Fernandes, M., Mempel, H., & Ulrichs, C. (2020). Comparison of colorimeter and different portable food-scanners for non-destructive prediction of lycopene content in tomato fruit. *Postharvest Biology and Technology*, *167*, 111232. https://doi.org/10.1016/j.postharvbio.2020.111232

Iswahyudi, I., Darmawati, E., Mardjan, S., & Garfansa, M. P. (2024). Color and Firmness Quality Changes of Java Apple During Postharvest Transportation and Storage. *Current Applied Science and Technology*, e0257493-e0257493. https://doi.org/10.55003/cast.2024.257493

Jaramillo-Acevedo, C. A., Choque-Valderrama, W. E., Guerrero-Álvarez, G. E., & Meneses-Escobar, C. A. (2020). Hass avocado ripeness classification by mobile devices using digital image processing and ANN methods. *International Journal of Food Engineering*, *16*(12). https://doi.org/10.1515/ijfe-2019-0161

Juncai, H., Yaohua, H., Lixia, H., Kangquan, G., & Satake, T. (2015). Classification of ripening stages of bananas based on support vector machine. *International Journal of*

Agricultural and Biological Engineering, *8*(6), Article 6. https://doi.org/10.25165/ijabe.v8i6.1275

Kalinowska, K., Wojnowski, W., & Tobiszewski, M. (2021). Smartphones as tools for equitable food quality assessment. *Trends in Food Science & Technology*, *111*, 271-279. https://doi.org/10.1016/j.tifs.2021.02.068

Kanchi, S., Sabela, M. I., Mdluli, P. S., Inamuddin, & Bisetty, K. (2018). Smartphone based bioanalytical and diagnosis applications: A review. *Biosensors and Bioelectronics*, *102*, 136-149. https://doi.org/10.1016/j.bios.2017.11.021

Kandi, S., & Charles, A. L. (2019). Statistical comparative study between the conventional DPPH spectrophotometric and dropping DPPH analytical method without spectrophotometer: Evaluation for the advancement of antioxidant activity analysis. *Food Chemistry*, *287*, 338-345. https://doi.org/10.1016/j.foodchem.2019.02.110

Khosravi, A., Kompany-Zareh, M., & Ghaffari, M. (2025). Food quality assessment and quantification using multispectral images from screen and smartphone for kiwifruit ripeness and rice discrimination. *Journal of Food Composition and Analysis*, *144*, 107630. https://doi.org/10.1016/j.jfca.2025.107630

Machado Molina, M., García Pereira, A., Machado García, N., Machado Molina, M., García Pereira, A., & Machado García, N. (2019). Propuesta de rangos de Índice de Color según estados de maduración en frutas. *Revista Ciencias Técnicas Agropecuarias*, *28*(4). http://scielo.sld.cu/scielo.php?script=sci_abstract&pid=S2071-00542019000400002&lng=es&nrm=iso&tlng=es

Manera, F. J., Legua, P., Melgarejo, P., Brotons, J. M., Hernández, Fca., & Martínez, J. J. (2013). Determination of a colour index for fruit of pomegranate varietal group "Mollar de Elche". *Scientia Horticulturae*, *150*, 360-364. https://doi.org/10.1016/j.scienta.2012.11.036

Pandiselvam, R., Mitharwal, S., Rani, P., Shanker, M. A., Kumar, A., Aslam, R., Barut, Y. T., Kothakota, A., Rustagi, S., Bhati, D., Siddiqui, S. A., Siddiqui, M. W., Ramniwas, S., Aliyeva, A., & Mousavi Khaneghah, A. (2023). The influence of non-thermal technologies on color pigments of food materials: An updated review. *Current Research in Food Science*, *6*, 100529. https://doi.org/10.1016/j.crfs.2023.100529

Pathare, P. B., & Al-Dairi, M. (2022). Effect of mechanical damage on the quality characteristics of banana fruits during short-term storage. *Discover Food*, *2*(1), 4. https://doi.org/10.1007/s44187-022-00007-7

Pathare, P. B., Opara, U. L., & Al-Said, F. A.-J. (2013). Colour Measurement and Analysis in Fresh and Processed Foods: A Review. *Food and Bioprocess Technology*, *6*(1), 36-60. https://doi.org/10.1007/s11947-012-0867-9

Ponnal, R. P., Wood, J. E., Gill, B. D., Bergonia, C. A., Longstaff, W. M., Slabbert, V., Bainbridge-Smith, L. C., & Crawford, R. A. (2021). Colorimetry of dairy products. *International Dairy Journal*, *113*, 104886. https://doi.org/10.1016/j.idairyj.2020.104886

Roustaei, N. (2024). Application and interpretation of linear-regression analysis. *Medical Hypothesis, Discovery and Innovation in Ophthalmology*, *13*(3), 151-159. https://doi.org/10.51329/mehdiophthal1506

Saha, K. K., Rahman, A., Moniruzzaman, M., Syduzzaman, M., Uddin, M. Z., Rahman, M. M., Ali, M. A., al Riza, D. firmanda, & Oliver, M. M. H. (2023). Classification of starfruit maturity using smartphone-image and multivariate analysis. *Journal of Agriculture and Food Research*, *11*, 100473. https://doi.org/10.1016/j.jafr.2022.100473

Santos-Gomes, J. F. S.-G., Vieira, R. R., & Leta, F. R. (2013). Colorimetric indicator for classification of bananas during ripening. *Scientia Horticulturae*, *150*, 201-205. https://doi.org/10.1016/j.scienta.2012.11.014

Scalisi, A., O'Connell, M. G., Islam, M. S., & Goodwin, I. (2022). A Fruit Colour Development Index (CDI) to Support Harvest Time Decisions in Peach and Nectarine Orchards. *Horticulturae*, *8*(5), Article 5. https://doi.org/10.3390/horticulturae8050459

Shange, S. F., Mdluli, P. S., & Deenadayalu, N. (2025). A review of the application of CIELAB colour systems for the development of gold and silver nano-enabled colorimetric assays for the detection of chromium. *Results in Chemistry*, *13*, 102048. https://doi.org/10.1016/j.rechem.2025.102048

Sherafati, A., Mollazade, K., Koushesh Saba, M., & Vesali, F. (2022). *TomatoScan*: An Android-based application for quality evaluation and ripening determination of tomato fruit. *Computers and Electronics in Agriculture*, *200*, 107214. https://doi.org/10.1016/j.compag.2022.107214

Soares, S., Fernandes, G. M., & Rocha, F. R. P. (2023). Smartphone-based digital images in analytical chemistry: Why, when, and how to use. *TrAC Trends in Analytical Chemistry*, *168*, 117284. https://doi.org/10.1016/j.trac.2023.117284

Srivastava, S., Vani, B., & Sadistap, S. (2021). Handheld, smartphone based spectrometer for rapid and nondestructive testing of citrus cultivars. *Journal of Food Measurement and Characterization*, *15*(1), 892-904. https://doi.org/10.1007/s11694-020-00693-w

Supapvanich, S., Mitrsang, P., Srinorkham, P., Boonyaritthongchai, P., & Wongs-Aree, C. (2016). Effects of fresh Aloe vera gel coating on browning alleviation of fresh cut wax apple (Syzygium samarangenese) fruit cv. Taaptimjaan. *Journal of Food Science and Technology*, *53*(6), 2844-2850. https://doi.org/10.1007/s13197-016-2262-4

Tanut, B., Tatomwong, W., & Buachard, S. (2023). Developing a Colorimetric Equation and a Colorimetric Model to Create a Smartphone Application That Identifies the Ripening Stage of Lady Finger Bananas in Thailand. *Sensors*, *23*(14), Article 14. https://doi.org/10.3390/s23146387

Vidal, A., Talens, P., Prats-Montalbán, J. M., Cubero, S., Albert, F., & Blasco, J. (2013). In-Line Estimation of the Standard Colour Index of Citrus Fruits Using a Computer Vision System Developed For a Mobile Platform. *Food and Bioprocess Technology*, *6*(12), 3412-3419. https://doi.org/10.1007/s11947-012-1015-2

Weisburd, D., Britt, C., Wilson, D. B., & Wooditch, A. (2020). Measuring Association for Scaled Data: Pearson's Correlation Coefficient. En D. Weisburd, C. Britt, D. B. Wilson, & A. Wooditch (Eds.), *Basic Statistics in Criminology and Criminal Justice* (pp. 479-530). Springer International Publishing. https://doi.org/10.1007/978-3-030-47967-1_14

Yue, X.-Q., Shang, Z.-Y., Yang, J.-Y., Huang, L., & Wang, Y.-Q. (2020). A smart data-driven rapid method to recognize the strawberry maturity. *Information Processing in Agriculture*, *7*(4), 575-584. https://doi.org/10.1016/j.inpa.2019.10.005

Zaccari, F., Puerto, M. D., Vignale, B., Pritsch, C., Zaccari, F., Puerto, M. D., Vignale, B., & Pritsch, C. (2017). Parámetros colorimétricos y contenido de pigmentos en cinco colores de cáscara de fruto de guayabo [*Acca sellowiana* (Berg) Burret]. *Agrociencia (Uruguay)*, *21*(2), 23-30.