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ORIGINAL

Classification of tomato ripeness in the agricultural industry using a computer vision system

Clasificación de la madurez de tomates en la industria agrícola mediante un sistema de visión artificial

Mateo Valencia Buitrago[1], Olga Lucía Torres Vargas[2]

[1]Universidad del Quindío, Ingeniería Electrónica, Facultad de Ingeniería. Colombia.
[2]Universidad del Quindío, Ingeniería de Alimentos, Instituto Interdisciplinario de las Ciencias. Colombia.

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ABSTRACT

Machine vision systems (SVA) occupy an important place in the field of food and agriculture, these techniques are performed in situ, are efficient, non-invasive, time-saving and more economical than traditional techniques. Tomatoes (Solanum lycopersicum) are extensively cultivated throughout the world, are essential in the agricultural and culinary fields and are recognized for their beneficial contributions to health. Lack of knowledge about fruit maturity, proper harvesting and postharvest handling are factors responsible for large postharvest losses. Therefore, the objective of this research was the construction of a VAS that allows establishing relationships between color and maturity stage of the Chonto Roble F1 tomato. The VAS built is composed of hardware and software duly synchronized through the application of computer vision algorithms in Python 3.9 software that allow it to perform the acquisition and segmentation of the image and present the user with the color coordinates in the CIEL*a*b* system. Finally, color measurements were performed on tomato samples at different stages of ripening in the VAS and a HunterLab ColorQuest XE (EHL) spectrophotometer. The results obtained indicated that there are no significant differences in both measurement systems for L* values, the changes produced in b* and a* were statistically significant for tomato samples. The results obtained indicated the potential use of the constructed VAS for the determination of the degree of maturity of tomatoes in real time, in a non-invasive and low-cost way.

Keywords: Image Analysis; CIEL*a*b*; Spectrophotometer; Machine Vision System; Tomato.

RESUMEN

Los sistemas de visión artificial (SVA) ocupan un lugar importante en el campo de la alimentación y la agricultura, estas técnicas se realizan en sitú, son eficientes, no invasivas, ahorran tiempo y son más económicas que las técnicas tradicionales. Los tomates (*Solanum lycopersicum*), son cultivados extensivamente en todo el mundo, son esenciales en el ámbito agrícola y culinario y son reconocidos por sus aportes benéficos a la salud. La falta de conocimiento sobre la madurez del fruto, una cosecha adecuada y el manejo postcosecha son factores responsables de grandes pérdidas postcosecha. Por lo tanto, el objetivo de esta investigación fue la construcción de un SVA que permite establecer relaciones entre el color y el estado de madurez del tomate Chonto Roble F1. El SVA construido está compuesto por un hardware y un software debidamente sincronizados mediante la aplicación de algoritmos de visión computacional en el software Python 3.9 que le permiten realizar la adquisición y segmentación de la imagen y presentar al usuario las coordenadas de color en el sistema CIEL*a*b*. Finalmente fueron realizadas medidas de color en muestras de tomate con diferentes estados de maduración en el SVA y un espectrofotómetro HunterLab ColorQuest XE (EHL). Los resultados obtenidos indicaron que no hay diferencias significativas en ambos sistemas de medida para los valores de L*, los cambios producidos en b* y a* fueron estadísticamente significativos para las muestras de tomate. Los resultados obtenidos indicaron el potencial uso del SVA construido, para la determinación el grado de madurez de tomates en tiempo real, de una forma no invasiva y a bajo costo.

Palabras clave: Análisis de Imagen; CIEL*a*b*; Espectrofotómetro; Sistema de Visión Artificial; Tomate.

INTRODUCTION

Tomatoes, grown extensively throughout the world, are valuable not only for the livelihood they provide to farmers and consumers but also for their health benefits, containing vitamin C and lycopene (Ciptaningtyas et al., 2022), the latter of which can reduce the risk of breast and prostate cancer, osteoporosis, cardiovascular disease and reduce high blood pressure (Przybylska &Tokarczyk, 2022). However, a lack of knowledge about maturity and postharvest handling contributes to growers' huge losses today. The assessment of tomato maturity and quality depends largely on the external characteristics of the fruit; its assessment can be done using non-invasive methods (Ninja & Manuj-Kumar, 2022). Assessing maturity and harvesting a product at the right stage is an art that differs from crop to crop; maturity is an irreversible process that directly affects the internal and external quality of the fruit (Prasad et al., 2018). During tomato cultivation, it is common to consider six stages for tomato color ripening (Maturity and ripening stages): green, brittle, turning, pink, light red, and red; in addition to the development of flavor, texture, and aroma, these ripening stages in tomatoes occur from greenhouse or growing plot, transportation, purchase, shelf, refrigeration to consumption (Hongli et al., 2023).

Electronic machine vision systems (EVS) represent an emerging technique in food and agriculture; they play an important role in solving practical problems of automatic sorting and recognition. These techniques have surpassed manual labor and are non-invasive, time-saving, economical, rigorous, and accurate. Research using VAS for color assessment in food has focused on the conversion of images obtained using the RGB color measurement system to the CIEL*a*b* system (Larraín et al., 2008); several approaches have been explored in this field, including the examination of color indices about tomato ripeness and the use of image processing. Khan et al. 2011 conducted studies for tomato maturity recognition with convolutional transformers, Konagaya et al. 2020 monitored the quality of ripe tomato (red stage) during storage using image processing images red) during storage using ultraviolet light-induced visible fluorescence imaging, Changxia et al. (2021) formulated a tomato ripeness recognition algorithm based on a multilevel deep residual network, Nassiri et al. (2022) used fuzzy logic classification on ripe tomatoes based on physical property fusion. Sharma et al. (2020) implemented a ripening index for color-based evaluation of the ripening behavior of tomato fruits. Color assessment should be performed consistently and objectively to obtain reliable and reproducible results that reflect human perception and can be performed in a non-invasive manner (Wu et al., 2013). Therefore, this research's objective was to construct a VAS that establishes relationships between color images in CIEL*a*b* coordinates and the maturity stage of the Chonto Roble F1 tomato.

METHOD

For the development of the research presented below, a machine vision system (SVA) was built and implemented to classify tomatoes by their maturity stage based on the CIEL*a*b* color spaces (1986).

Raw material

Tomatoes (Solanum lycopersicum) of Roble F1 variety, harvested from farms in the Quindío region, representing an important part of the department's economy, were used as raw material. The color of the pericarp visually classified the tomatoes, applying the ripening stage criteria established by the Colombian Technical Standards ICONTEC for tomatoes (NTC 1103-1). Once selected, these were analyzed in the SVA and EHL.

Machine Vision System (SVA)

To carry out the process of taking color images of the tomato samples, a VAS was built using a low-cost Logitech PRO C920 Full HD digital camera, graphic processing units (GPU), data storage devices, and an illumination device (series of LEDs)—the programming of the hardware.

The hardware measurement system was programmed using Python 3.9. Both systems, properly synchronized, are responsible for presenting to the user the CIEL*a*b* coordinates of tomato samples with different days of ripening.

For the implementation of the VAS, we proposed the design of software that allows the calibration of the camera and the detection of the color of tomatoes with different degrees of ripeness, following the steps shown in figure 2.

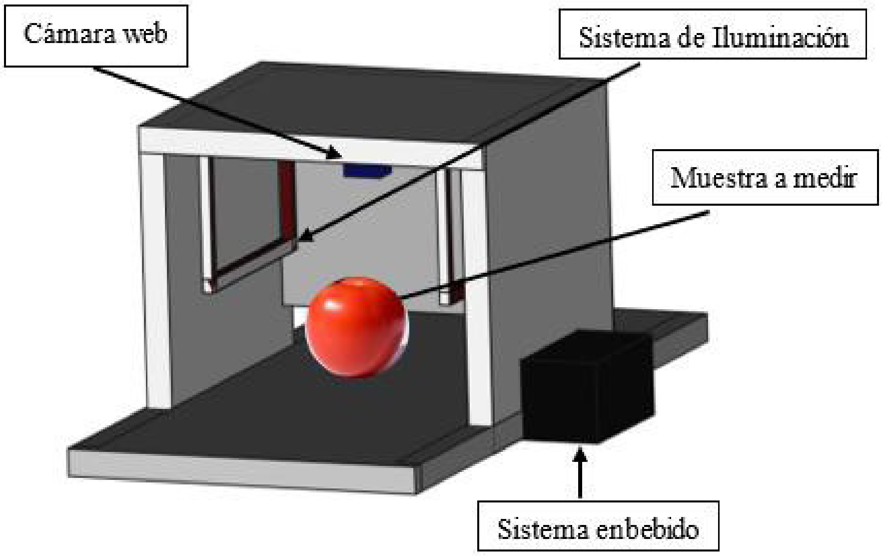


Figure 1. Machine Vision System (SVA) for the measurement and analysis of color in tomato samples

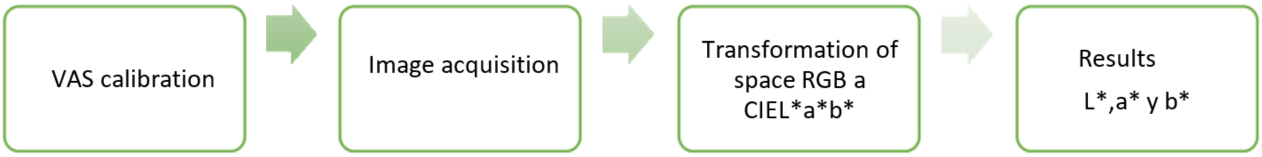


Figure 2. Stages established in the design and construction of the software for the Machine Vision System (SVA)

The backbone of the VAS consists of an embedded system, implemented in a Raspberry Pi 4, running the Raspberry Pi OS operating system, which is in charge of capturing the image, segmenting it, resizing it, storing it, and delivering a response in terms of CIEL*a*b* coordinates to the user (Valencia, 2023).

Prior to image capture, a calibration stage was performed. The color was determined using a Logitech PRO C920 camera, which offers advantages such as the capture of a large amount of spatial information, the ability to measure surfaces of various sizes, the availability of a wide range of models at more affordable prices, and not require direct contact with the surface to be measured. However, using theoretical models, the information obtained in color space Red, Green, and Blue (RGB) must be transformed to CIEL*a*b* color space (Castellanos et al., 2022). The parameters and equations used at this stage are presented in table 1.

Table 1. Color characterization in tomato: equations and specialized equipment

Parameters	Equations	Color measurement equipment
Brightness: L*	$L^* = 116\ (Y^{1/3}/Yn) - 16$ Ec.(1)	
Coordinate coordinate: a*	$a^* = 500\ [(X^{1/3}/Xn) - (Y^{1/3}/Ym)]$ Ec. (2)	
Coordinate coordinate: b*	$b^* = 200\ [(Y^{1/3}/Yn) - (Z^{1/3}/Zn)]$ Ec. (3)	HunterLab Spectrophotometer ColorQuest XE (EHL).

In order to establish a comparison parameter, color measurements were made in the VAS and EHL on tomatoes with different degrees of ripening (table 3). The coordinates L*, a*, b* in the EHL system were taken using a D65 lamp, 1 cm diameter aperture, and a 2° standard observer at five points on the pericarp of each tomato sample and the values reported were calculated as the average of these measurements. The determination and expression of color were carried out based on CIEL*a*b* coordinates (table 1) and reflectance values (CIE, 1986), obtaining the parameters of Luminosity (L), red-green (a*), yellow-blue (b*) directly from the equipment.

Statistical analysis

To establish if there are differences between the color measurements made by the SVA and the EHL, an analysis of variance (ANOVA- Multifactorial) by least significant difference (LSD) with p-value ≤ 0.05 was performed, with three interaction factors, taking as response variables the coordinates L*, a*, b*, and as a factor: the degree of maturation. This analysis was performed using the statistical package Stratigraphic ® Plus, Centurion.15.2.12 XV (Numagistics Ltda).

RESULTS AND DISCUSSION

Once the construction of the electronic system and the programming of the VAS hardware measurement system in its structural form were completed, a compartment was built for image acquisition, which functions as the main structure of the equipment, supports the tomato sample to be analyzed and the other components, as can be seen in figure 1.

The image is captured by the Logitech PRO C920 camera and subjected to an analysis process to reduce noise and improve its quality; contrast and color correction adjustments were also made to optimize its usefulness in subsequent analyses. After the previous stage, the image was segmented to identify the region of interest (ROI) within the obtained tomato image. This segmentation involved advanced image processing techniques, such as thresholding and threshold detection.

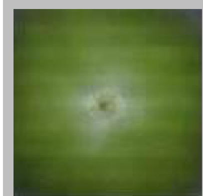
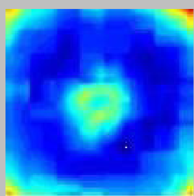
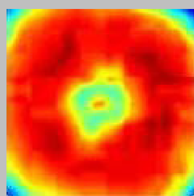
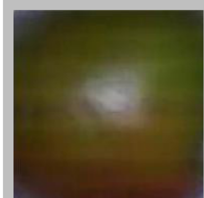
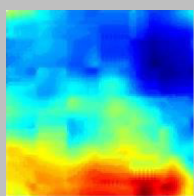
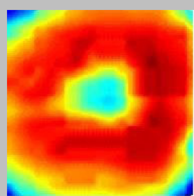
This segmentation involved using advanced image processing techniques such as thresholding and feature detection to distinguish the ROI from the background and other irrelevant elements. The identified region of interest becomes the main focus of further analysis and applications, allowing feature detection, pattern recognition, and decision-making based on accurate and relevant visual information.

The acquired image is processed by Python 3.9 software and converted from RGB space to CIEL*a*b* space using equations (1), (2), and (3) presented in table 1. The system computes the mean of the Luminance (L*), red-green (a*), and yellow-blue (b*) coordinates. Finally, the user will be able to visualize both components facing the original tomato image in the interface, and this information will be stored on the computer.

Table 2 shows the L*, a*, and b* coordinates obtained in the epicarps of the six tomato samples analyzed with different degrees of ripening in the SVA and EHL. The tomato ripening process is characterized by a high synthesis of carotenoids that generates changes in the L*, a*, and b* coordinates (Artés-Calero & Artés-Hernández, 2004). The* coordinate presented significant changes; samples 1 and 2 presented negative values (green color) that progressively became positive (red color). López-Camelo et al. (2003) point out that during tomato ripening, phytoene (colorless) is initially synthesized, to later give rise to ζ-carotene (pale yellow), lycopene (red), ß-carotene (orange) and xanthophylls and hydroxylated carotenoids (yellow); as we can observe in samples 3 and 4.

The synthesis of yellowish pigments precedes reddish pigments, but the massive accumulation of the latter masks the former. When the red pigments began to be synthesized, a decrease in the values of the L* coordinate occurred, indicating a darkening or decrease in brightness, as seen in samples 5 and 6 (table 3). The changes in the b* coordinate were not significant.

Table 2. Images obtained by the VAS for the different ripening stages of the cherry tomato variety Roble F1

Samples	Coordinates CIEL*a*b*	
		
1	a*-10,06	b* 70,73
		
2	a* -5.68	b* 71,25

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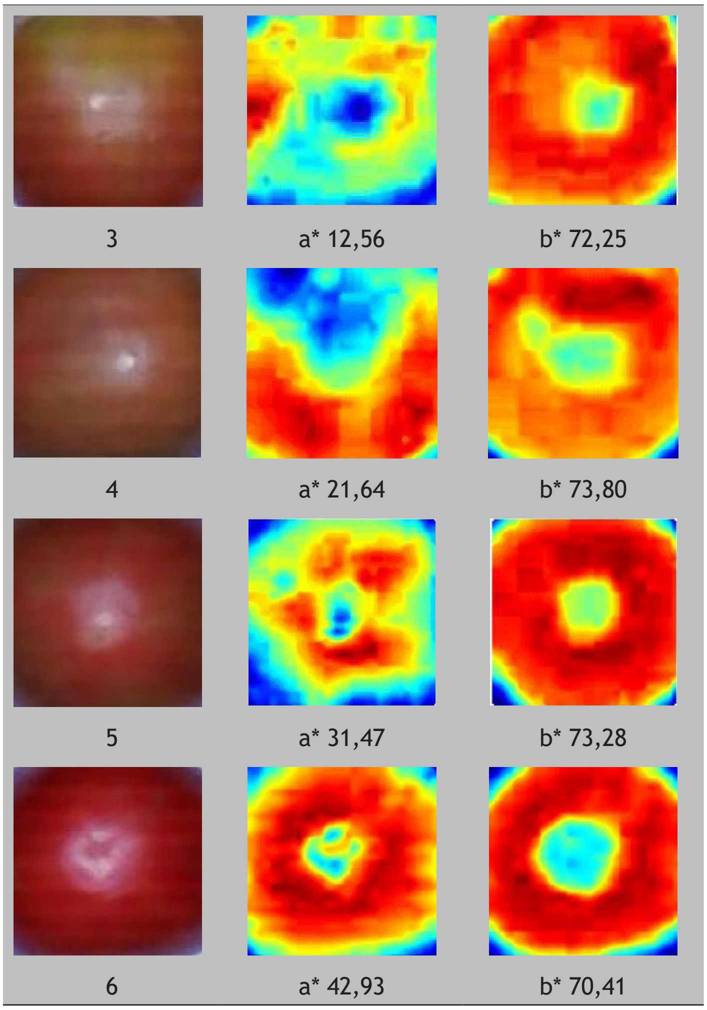

Table 3 shows the values for L*, a*, and b* coordinates obtained in the VAS and EHL for tomatoes at different maturity levels. The values obtained do not show significant differences, indicating the potential use of the VAS in the selection of tomatoes by maturity level.

Table 3. Results for L*, a* and b* coordinates obtained in the VAS and EHL for tomatoes at different maturity levels

Sistema de Visión Artificial				**HunterLab Spectrophotometer**		
Samples	**L***	**a***	**b***	**L***	**a***	**b***
1	85,42±0,35	-10,06±0,16	70,73±0,68	82,19±0,44	-9,06±0,09	68,21±0,08
2	81,58±0,19	-5,68±0,13	71,25±1,05	80,71±0,70	-6,25±0,72	67,17±1,20
3	78,99±0,59	12,56±0,98	72,25±0,74	76,14±0,04	8,56±0,95	69,54±0,91
4	70,23±0,52	21,68±0,53	73,80±0,60	69,4±0,06	20,15±0,90	68,70±0,08
5	66,05±0,27	31,47±0,31	73,28±0,94	65,97±0,19	33,62±1,06	69,12±0,02
6	62,28±0,03	43,93±0,07	70,41±0,70	60,57±1,05	44,08±1,53	68,32±0,21

The results obtained made it possible to evaluate the use of the VAS constructed to determine color as a parameter for classifying the ripening stage of tomatoes in a non-invasive, economical, and real-time manner. Farmers can use this technological tool to inspect, classify, and estimate the maturity of fruit and vegetable products and determine the optimum time to harvest them, increasing their productivity and strengthening the Colombian fruit and vegetable chain.

CONCLUSIONS

The methodology used by the developed VAS allows for analyzing the global color of the sample and its heterogeneity, captures, processes, analyzes the images, and evaluates the color non-invasively, using the CIEL*a*b* coordinates. This system offers the possibility of analyzing the entire surface of the product, its characteristics, and defects, allowing you to estimate the state of maturity quickly and at a low cost, factors that differentiate it from a commercial spectrophotometer. The images obtained allow the farmer to classify unripe, ripe, and overripe fruit for subsequent marketing or agro-industrial processing.

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CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

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Investigation: Mateo Valencia Buitrago, Olga Lucía Torres Vargas.
Methodology: Mateo Valencia Buitrago, Olga Lucía Torres Vargas.
Drafting - original draft: Mateo Valencia Buitrago, Olga Lucía Torres Vargas.
Writing - proofreading and editing: Mateo Valencia Buitrago, Olga Lucía Torres Vargas.