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Effects of rice polishing duration and tomato maturity on their colorimetric characteristics

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Optical sensing techniques have emerged as vital tools for assessing the quality of agricultural products. In this study, an optical sensing analysis of the effects of rice polishing duration and tomato maturity on colorimetric characteristics was conducted at the Physical Properties and Quality Evaluation of Agricultural Products Laboratory, located at the National Storage Training Center (CENTREINAR), at the Federal University of Viçosa. The effects of five polishing durations of 0, 20, 40, 60, and 80 seconds, as well as three maturity stages of tomato, including green, moderately red, and very red, on the physical appearance of the two products were analyzed. The colorimetric properties of the products were determined using a Miniscan XE Plus machine, and the relationship between these properties was analyzed using regression analysis to assess the effects of rice polishing time and the maturity stage of tomatoes on their colorimetric properties. The results of the analysis revealed a strong linear relationship between the products and their colorimetric properties, with R^2 values of 0.9955, 0.9912, 0.9983, and 0.9758, respectively, for Total Color Difference (ΔE), Darkness Index (IE), Yellowing Index (YI), and Whitening Index (WI) for tomatoes, and 0.8976 (ΔE), 0.9563 (IE), 0.9348 (YI), and 0.9268 (WI) for rice. This research provides valuable insights for the agricultural sector, specifically in the quality assessment and processing optimization of rice and tomatoes, which ultimately helps enhance product standards and consumer satisfaction.

Keywords: Optical sensing, quality assessment, polished rice, tomatoes, non-destructive testing.

INTRODUCTION

Agricultural products are vital for human nutrition and essential for sustaining life. The quality of these products is a key characteristic and a major concern for agricultural scientists. To identify high-quality agricultural products, accurate quality assessments are necessary. Currently, quality inspection is categorized into two types: external and internal. External assessment focuses on attributes such as aroma, shape, surface gloss, color, and size. In contrast, internal evaluation examines factors like physiological changes, the presence of pests, water loss, and mechanical damage (Wang *et al.,* 2024).

The quality of agricultural products can be evaluated based on their shape and color. Generally, visual appearance is a crucial indicator of quality, as it reflects the light characteristics of fruits and vegetables (Angerosa and Campestre, 2013; Natarajan and Ponnusamy, 2022). The visual evaluation of these products depends on how they absorb electromagnetic radiation within the optical wavelength range. This includes aspects such as visible light and color, as well as the transmission, reflection, and refraction of light (Liu and Luo, 2022; Nishimura and Kurimoto, 2021).

Electromagnetic waves are produced by variations in electric and magnetic fields, traveling through a vacuum at

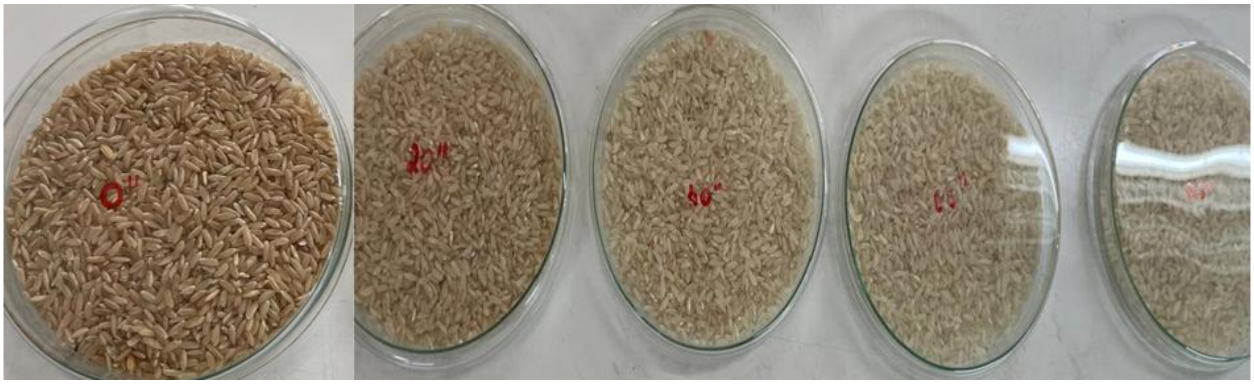

Figure 1. Rice samples used for the study.

the speed of light, which is approximately 3 × 10^8 m/s (Lu, 2024). These waves have dual characteristics; they can behave both as wave phenomena and as discrete packets of energy called photons. The fundamental relationships among the speed of radiation (c), wavelength (λ), frequency (v), and photon energy (E) are described by Equations 1 and 2.

$$C = \lambda V \quad (1)$$

$$E = hV = \frac{hC}{\lambda} \quad (2)$$

The interaction between electromagnetic radiation and solid materials depends on the wavelength of the light. When light strikes a material, it can undergo one of three outcomes: transmission, absorption, or reflection. These interactions are quantitatively characterized by three key parameters: transmittance (T), absorbance (A), and reflectance (R). These parameters are described by Equations 3 to 7.

$$T = \frac{T_T}{I_O} \quad (3)$$

$$A = \frac{T_A}{I_O} \quad (4)$$

$$R = \frac{T_R}{I_O} \quad (5)$$

$$T + A + R = 1 \quad (6)$$

$$I_0 = I_T + I_A + I_R \quad (7)$$

Where; I_0 is the intensity of the incident beam.

Rice *(Oryza sativa*) is a staple Brazilian food with a significant portion of the population relying on rice as a primary source of carbohydrates; its production not only supports domestic consumption but also stimulates rural employment opportunities (Fageria et al., 2014). Rice farming engages thousands of farmers and workers across Brazil, particularly in regions with suitable climatic conditions for cultivation. On the other hand, tomatoes (*Solanum lycopersicum*) hold considerable economic weight within Brazil's agribusiness sector, ranking as the second most important vegetable crop. With Goiás leading the production, tomatoes are not just crucial for local diets but also serve as a primary ingredient in numerous processed foods, from sauces to canned vegetables (Furquim *et al.*, 2020; Evangelista *et al.,* 2022).

Optical sensing of rice and tomatoes is essential for standardizing their quality and maturity (Shao *et al*., 2024; Bello *et al.,* 2020). This can be achieved through color measurement, which considers the characteristics of light and the perceptions of the observer. Human vision relies on three types of cone cells that are sensitive to red, green, and blue light, with their sensitivity varying based on the angle of observation (Dai *et al.,* 2023). Also, the International Commission on Illumination (CIE) has developed frameworks to define light, illumination, color, and color spaces. The CIE Lab* color space is a widely used model that classifies colors based on three coordinates: L* for lightness, a* for the red/green axis, and b* for the yellow/blue axis (Buitrago and Vargas, 2024).

MATERIALS AND METHODS

This study was conducted at the Physical Properties and Quality Evaluation of Agricultural Products Laboratory, located at the National Storage Training Center (Centro Nacional de Treinamento em Armazenagem - CENTREINAR), at the Federal University of Viçosa campus (UFV) in Viçosa, Minas Gerais, Brazil. Polished rice was obtained from raw rice that underwent five different polishing durations: 0, 20, 40, 60, and 80 seconds, as illustrated in Figure 1. Additionally, tomato samples were randomly selected to represent various maturity stages, including green, moderately red, and very red (Figure 2).

During the color scanning analysis of the samples, the Miniscan XE Plus machine (Appendix 1) at the CENTREINAR laboratory was powered on and allowed to boot up in preparation for the experiment. A green, mature tomato was placed in the scanning area, and the scan button was pressed to measure the fruit's color at various points around its circumference. For each scan, the values of lightness (L*),

Figure 2. Tomatoes samples used for the study.

the red/green color coordinate, and the yellow/blue color coordinate were recorded on the machine's monitor. This same procedure was then repeated for the rice samples and data obtained was analyzed using regression analysis to assess the effects of rice polishing time and the maturity stage of tomatoes on their colorimetric properties.

For the rice samples, the sample with zero polishing duration was placed in a specially designed cup and covered with a black, opaque item to prevent interference from ambient light. The scan button was then pressed, and the values for lightness (L*), the red/green color coordinate, and the yellow/blue color coordinate were recorded on the monitor of the machine. This procedure was repeated for the other rice samples, with five replicates conducted for each sample. The data obtained were then used to calculate the color evaluation parameters.

$$C^* = \sqrt[2]{a^{*2} + b^{*2}} \quad (8)$$

$$h^* = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (9)$$

$$\Delta E^* = \sqrt[2]{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (10)$$

$$IE = \frac{100(X - 0.31)}{0.172} \quad (11)$$

$$X = \frac{a^* + 1.75L^*}{5.64L^* + a^* - 3.01b^*} \quad (12)$$

$$YI = \frac{100(0.72a^* + 1.79b^*)}{L^*} \quad (13)$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (14)$$

Where;

- Chroma (C*) expresses color intensity or saturation, with values close to zero representing neutral colors and values close to 60 representing vivid colors.
- Hue (°h*) sets the tonality angle of the color, with specific angles representing red, yellow, green, and blue.
- Total color difference (ΔE*) considers differences in lightness (ΔL*), red/green (Δa*), and yellow/blue (Δb*).
- Darkness Index (IE) and Yellowing Index (YI) are specific metrics for evaluating color changes.
- Whitening Index (WI) measures the degree of whiteness.

RESULTS AND DISCUSSION

Tables 1 and 2 showed the results of the colorimetric properties of tomatoes and rice respectively. The colorimetric properties of tomatoes, as outlined in Table 1, show significant variations in color characteristics among green, average red, and fully ripe red tomatoes, reflecting their stages of maturity.

Green tomatoes exhibit the highest lightness (L* = 73.242), which indicates a brighter appearance. They also have low red intensity (a* = 9.164) and high yellow intensity (b* = 35.336), suggesting that they are less attractive due to the lack of the red color typically associated with ripeness. In contrast, average red tomatoes display a balanced lightness (L* = 60.1) and increased red intensity (a* = 25.062). This indicates a transition towards maturity, accompanied by a slightly elevated Chroma (C* = 43.48445). Fully ripe red tomatoes demonstrate the lowest lightness (L* = 48.096) along with the highest red intensity (a* = 36.852) and Chroma (C* = 47.46659), showcasing their deep red hue. The hue angle (h*) shifts from 75.528 in green tomatoes to 39.08 in fully ripe red tomatoes, emphasizing the transition from green to a vibrant red.

The total color difference (ΔE) quantifies the noticeable changes between these stages, highlighting the visual impact of ripening on tomato appearance. Furthermore, the increases in the Darkening Index (IE) and decreases in the Whiteness Index (WI) among the varieties indicate a more appealing and rich coloration as tomatoes ripen. This is accordance with the submission reported in Ayuso-Yuste *et al.* (2022) and Bhandari and Lee (2016).

The colorimetric results of rice at varying polishing times, as shown in Table 2, reveal significant changes in color parameters that reflect the impact of polishing on rice quality. Initially, at 0 seconds of polishing, the rice exhibits a lightness (L*) value of 71.802 and a relatively high yellow component (b* = 27.258), indicating a darker and more yellowish appearance. As polishing time increases to 20 seconds, the lightness improves to 78.168, while the red component (a*) decreases, suggesting a shift towards a lighter and less red hue.

By 40 seconds, the lightness further increases to 83.208, with the Chroma (C*) reaching its peak at 24.16829, indicating enhanced brightness and color saturation. At 60 seconds, lightness continues to rise to 86.49, while the a* and b* values stabilize, leading to a higher hue angle (h* = 87.92) that reflects a more neutral color.

Finally, at 80 seconds, the rice maintains a high lightness (L* = 86.646), but exhibits a slight decrease in Chroma and an increase in hue angle, indicating a more polished and visually appealing appearance. The total color difference (ΔE) values demonstrate perceptible changes in color with increased polishing time, and both the Index of Excitement (IE) and Whiteness Index (WI) suggest that polishing enhances the visual appeal of the rice, making it more attractive to consumers.

Table 1. Colorimetric properties of tomatoes.

Product	Parameter									
	L*	a*	b*	C*	h*	ΔE	IE	YI	WI	X
Green	73.242	9.164	35.336	36.50854	75.528	81.96437[a]	73.89372	96.1518	63.42074	0.437097
Avg. Red	60.1	25.062	35.33	43.48435	54.96	74.25367[b]	113.7581	135.4433	56.44279	0.505664
Red	48.096	36.852	29.906	47.46659	39.08	67.57806[c]	142.4511	166.5138	52.45748	0.555016

Table 2. Colorimetric properties of rice.

Polishing Duration (sec)	Parameter									
	L*	a*	b*	C*	h*	ΔE	IE	YI	WI	X
0	71.802	6.644	27.258	28.05698	76.29	77.08934[a]	53.15746	74.61023	71.84849	0.401431
20	78.168	4.278	26.7	27.04082	80.90	82.71351[b]	44.61633	65.08493	72.87292	0.38674
40	83.208	1.864	24.096	24.16829	85.58	86.64768[c]	34.8649	53.44941	75.74706	0.369968
60	86.49	0.768	22.92	22.93329	87.92	89.47916[d]	30.56241	48.07619	76.98672	0.362567
80	86.646	0.534	22.142	22.14896	88.62	89.43228[d]	29.12654	46.18931	77.76872	0.360098

Correlation between maturity stage of the fruits and colorimetric parameters

The regression results presented in Figure 3 illustrate the relationship between the maturity stage of tomatoes and their colorimetric properties, specifically ΔE, IE, YI, and WI. Each colorimetric parameter demonstrates a distinct linear trend as maturity increases, with corresponding equations and R-squared values that indicate the strength of these relationships. For example, the R-squared values for ΔE, IE, YI, and WI are 0.9955, 0.9912, 0.9983, and 0.9758, respectively, suggesting a strong correlation between these parameters and tomato maturity. Overall, the consistent upward trends in the colorimetric parameters highlight the changes in color characteristics as tomatoes mature, which can be quantitatively, assessed using the regression models.

Correlation between polishing time of rice and colorimetric parameters

Figure 4 illustrates the relationship between the polishing time of rice and its colorimetric properties, specifically ΔE, IE, YI, and WI. As the polishing time increases, both ΔE and IE show a slight upward trend, indicating that these colorimetric properties improve with longer polishing durations. This is supported by their respective R-squared values of 0.8976 for ΔE and 0.9563 for IE, reflecting a strong correlation. In contrast, YI and WI demonstrate a downward trend, with R-squared values of 0.9348 and 0.9268, respectively, indicating a moderate negative correlation with polishing time. This suggests that as rice is polished for longer periods, the yellow index (YI) and whiteness index (WI) decrease, likely due to the removal of the outer layers that contribute to these properties. Overall, the distinct trends highlight how polishing time significantly influences the appearance and quality of rice, with specific colorimetric parameters responding differently to the polishing process.

Conclusion

In conclusion, this study highlights the significant impact of rice polishing duration and tomato maturity stages on the physical appearance of these agricultural products. By employing optical sensing techniques, we were able to establish a clear relationship between the processing parameters and the colorimetric properties of both rice and tomatoes. The colorimetric analysis of tomatoes illustrates how maturity stages influence color characteristics, with measurable changes that correlate with consumer appeal and perceived

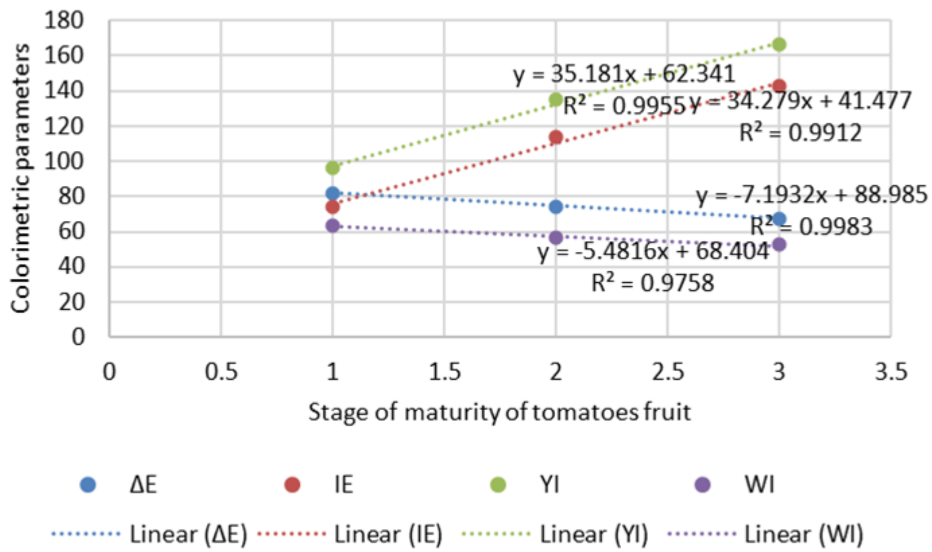

Figure 3. Regression analysis of the effects of maturity stage of the fruits and colorimetric parameters.

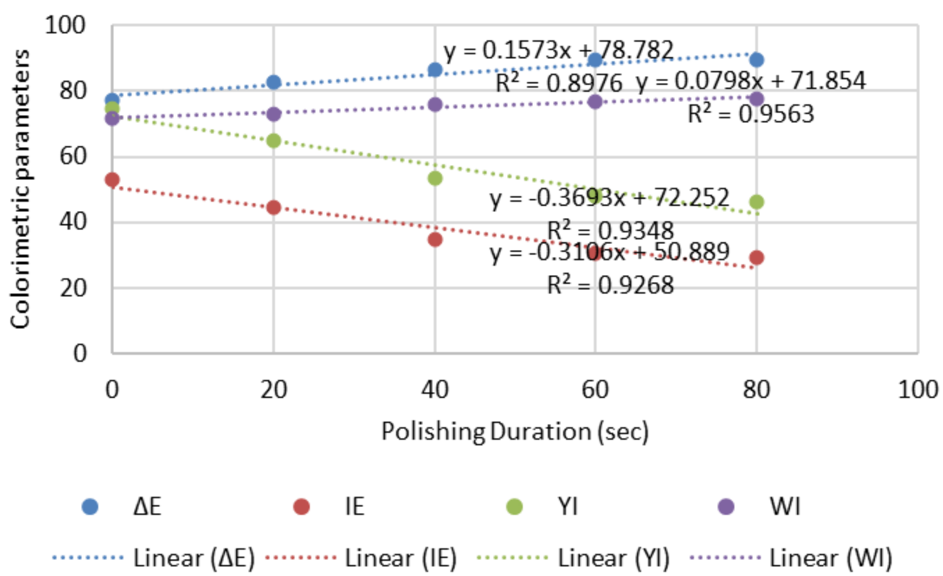

Figure 4. Regression analysis of the effects of polishing duration of rice and colorimetric parameters.

ripeness. The rice polishing study further emphasizes the impact of processing time on color properties, enhancing visual attractiveness and quality. These findings suggest that optimizing rice polishing duration and monitoring tomato maturity could be crucial for improving product quality. The use of precise optical sensing methods not only enhances quality assessment but also offers valuable insights for the agricultural industry, enabling producers to make informed decisions that ultimately enhance the marketability of their products.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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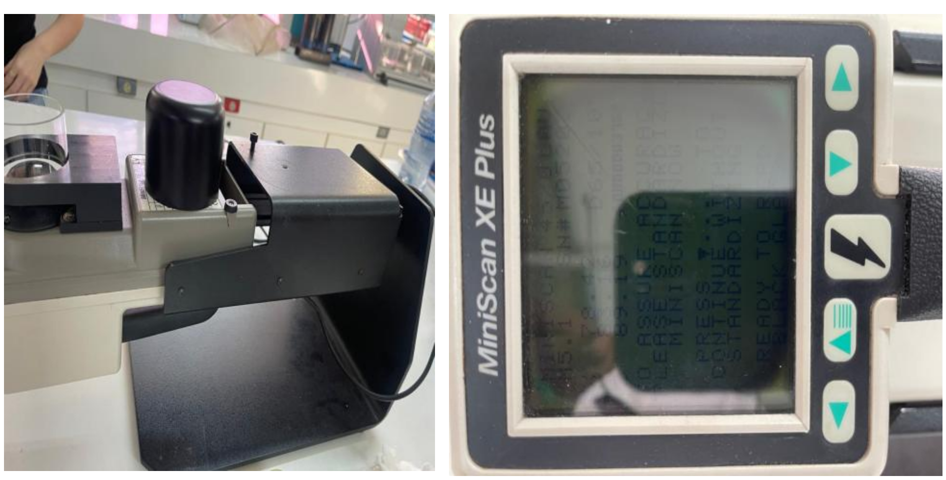
Appendix



Appendix 1. Miniscan XE Plus machine.