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NIX quality control colorimeter can evaluate color of yerba mate

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Abstract

Color is a crucial attribute in the herbal market. One of the primary parameters consumers deem essential when selecting a product is the green color intensity, which is directly associated with the freshness of *Ilex paraguariensis* yerba mate. During the yerba mate production process, there is a need for instrumental tools to evaluate color, which aim to minimize the empirical method of assessment in the production process. This study aimed to compare the color of yerba mate samples using the Nix Quality Control and the Konica Minolta CR-410 colorimeter and to evaluate the Nix Quality Control's potential for scientific research and application within the yerba mate production sector. The CIELAB color space of 219 yerba mate batches from various storage periods was analyzed using Konica Minolta and Nix Quality Control colorimeters. The highest correlation observed between the equipment was for the parameter a*, with r = .931 Control charts, which indicated a good agreement between Nix Quality Control and Minolta for a* and b* parameters. Since a* and b* are the most significant color parameters for yerba mate, it is possible to say that the Nix Quality Control colorimeter can serve as a suitable substitute for the Minolta.

Keywords: yerba mate, color, colorimeter, minolta CR-410, nix quality control, control charts.

Practical Application: The Nix Quality Control was compared to the Minolta CR-400 in evaluating the color of the yerba mate. All instruments were capable of detecting changes in color across the yerba mate. The Nix Quality Control proves to be a successful tool for measuring the color of yerba mate. The Nix Quality Control is a reliable alternative to the Minolta for assessing yerba mate color at a lower cost.

1 INTRODUCTION

Ilex paraguariensis, commonly known as yerba mate, is a native species from the South American subtropical region and holds economic and cultural significance. The sector involved in yerba mate processing, known as the yerba mate industry, has undergone significant transformations over the years, which particularly concerns the development of new products to meet the rising consumer demand (Croge et al., 2021; Gerber et al., 2023; Sarreal, 2024). This dynamic resulted in increased competitiveness within this sector.

The variety of product profiles is a relevant aspect that varies according to the consumer market. In Brazil, for instance, the predominant characteristic of consumed yerba mate is its fresh appearance and intense green coloration (Rząsa-Duran et al., 2022; Sarreal, 2024). However, in other countries, the consumed product is aged (with a minimum storage time of 6 months), resulting in a color range from olive to yellow due to chlorophyll degradation (Cabral-Malheiros et al., 2010; Holowaty et al., 2014). The chlorophyll presence mainly influences this color range. This pigment concentration directly relates to green coloring intensity in yerba mate (Lewinski et al., 2015).

Many factors can lead to chlorophyll degradation, such as pH, enzymes, oxygen, temperature, and light. Pheophytinization (when two hydrogen ions replace the magnesium ion in the center of the chlorophyll's porphyrin ring, the result is a change in color from bright green to olive-brown) and oxidation are the most probable chlorophyll degradation reactions that happen during the aging phase in dehydrated vegetables like yerba mate. Instrumental color analysis, such as the CIELAB system, has been used to measure quality characteristics. Reduction on the –a* values (green indicator) has been assigned to chlorophyll and/or shiny green color loss (Lewinski et al., 2015; Valduga et al., 2016).

Considering the importance of product color to yerba mate consumers, the industry must develop reliable measurement methods. One of them is the CIELAB color space measurement, a well-established method that allows for the specification

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creation and identification of quality deviations in the product (Lewinski et al., 2015).

Several devices are available for color measurement; one of the most utilized for yerba mate color measurements is manufactured by Konica Minolta (Holowaty et al., 2014; Schelkopf et al., 2021). This device is employed in the yerba mate industry primarily for evaluating changes in green coloration during storage (Lewinski et al., 2015). However, its acquisition and maintenance entail high costs, making it financially prohibitive for many industries (Croge et al., 2021).

The Nix Quality Control (Nix QC) colorimeter is a portable device capable of capturing CIE L^*, a^*, b^* values, with readings accessible through a smartphone application (Holman et al., 2018; Schelkopf et al., 2021; Swetha et al., 2022). The equipment has shown positive results in beef, pork, poultry, vegetable evaluations, and soil analyses in these studies.

Yerba mate is known for its green color intensity, caused by the amount of undegraded chlorophyll in the product (Lewinski et al., 2015). L^*, a^*, and b^* values can objectively measure yerba mate color. The instrument for analysis has to be carefully selected as various instruments are available for color measurement (Dang et al., 2021). Other than the CIE L^*, a^*, and b^* basic parameters, it is important to estimate chroma (C^*), de-greening (D^*), and yellowing (YI) indexes during aged yerba mate color analysis; all three are deeply related to maturing stages.

In this context, this study's goal was to investigate Nix Color Sensor Quality Control and Konica Minolta traditional CR-410 colorimeter's precision and performance in color measurement. It compared the data obtained from each piece of equipment to verify which one presented the best standardization potential in objective aged yerba mate color measurement.

1.1 Relevance of the work

This manuscript presents groundbreaking insights into using the Nix Quality Control colorimeter as a cost-effective and efficient tool for assessing yerba mate color. To our knowledge, this is the first study to demonstrate Nix QC's capability in evaluating this critical attribute of *Ilex paraguariensis*, a product of significant cultural and economic importance. The findings show that Nix QC not only correlates strongly with the industry-standard Konica Minolta CR-410 but also offers better accessibility without compromising accuracy. Furthermore, it captures the true olive-green color of yerba mate more effectively than the traditional approach, enhancing consumer perception and market competitiveness.

2 MATERIAL AND METHODS

2.1 Sample material and reagents

A total of 219 samples of yerba mate from Guayaki's company, located in the state of Paraná – Brazil, were used in this study. To guarantee maximum success in evaluating the tested devices, researchers used different yerba mate samples from distinct postprocessing aging stages. Yerba mate comes from native plants in Paraná, a central-western region. All samples showed standard granulometry levels, measured through stick removal sieving using a 20-mesh sieve and subsequent knife mill grind. The samples were packaged in vacuum-sealed polyvinyl chloride (PVC) cases to maintain quality characteristics until analysis.

Minolta Chroma Meter CR400 (Konica Minolta, Osaka, Japan) colorimeter was adjusted with a standard whiteboard and a D65 illuminant was used for color analysis, whose results were exhibited on the device's screen. NIX QC – Nix Quality Control (D65 illuminant, 10 mm aperture, 10° observer angle, and 45/0 measuring geometry) was the second piece of equipment used. Its adjustment also required a standard whiteboard, and the results were exhibited through a smartphone app.

2.2 Color analysis

Homogenized samples were placed and compacted on an acrylic plate with 20.33 mm × 27.58 mm dimensions for color measurement. All readings were performed in triplicate. All CIE color coordinates (L^*, a^*, and b^* colorimetric) were collated and then used to calculate chroma (C^*), de-greening (D^*), and yellowing index (YI) using Equations 1, 2, and 3, respectively. These parameters are critical as they provide insights into the product's visual and potential nutritional quality, essential for consumer acceptance and market value.

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

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

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 \ (\Delta b*)^2} \quad (3)$$

2.3 Statistical analysis

Color measurement variation and dispersion on Konica Minolta CR-410 and Nix Color Sensor devices were analyzed through statistical methods, including creating Control Charts. Pearson's correlation coefficient was used to evaluate the linear relation between the device readings. Coefficient values close to 1 or −1 indicated a strong correlation, while values close to 0 indicated little or no correlation. Regression equations that allowed the estimation of the Minolta colorimeter parameter results were created based on the experimental data, which help evaluate the precision and linearity of the devices' reading. The software R (R Core, 2016) analyzed correlation and regression. To assess the "good fit" between Minolta's real values and the values estimated by the regression equation, the average of the differences between these values was used so that the lower the average value, the better the equation fit.

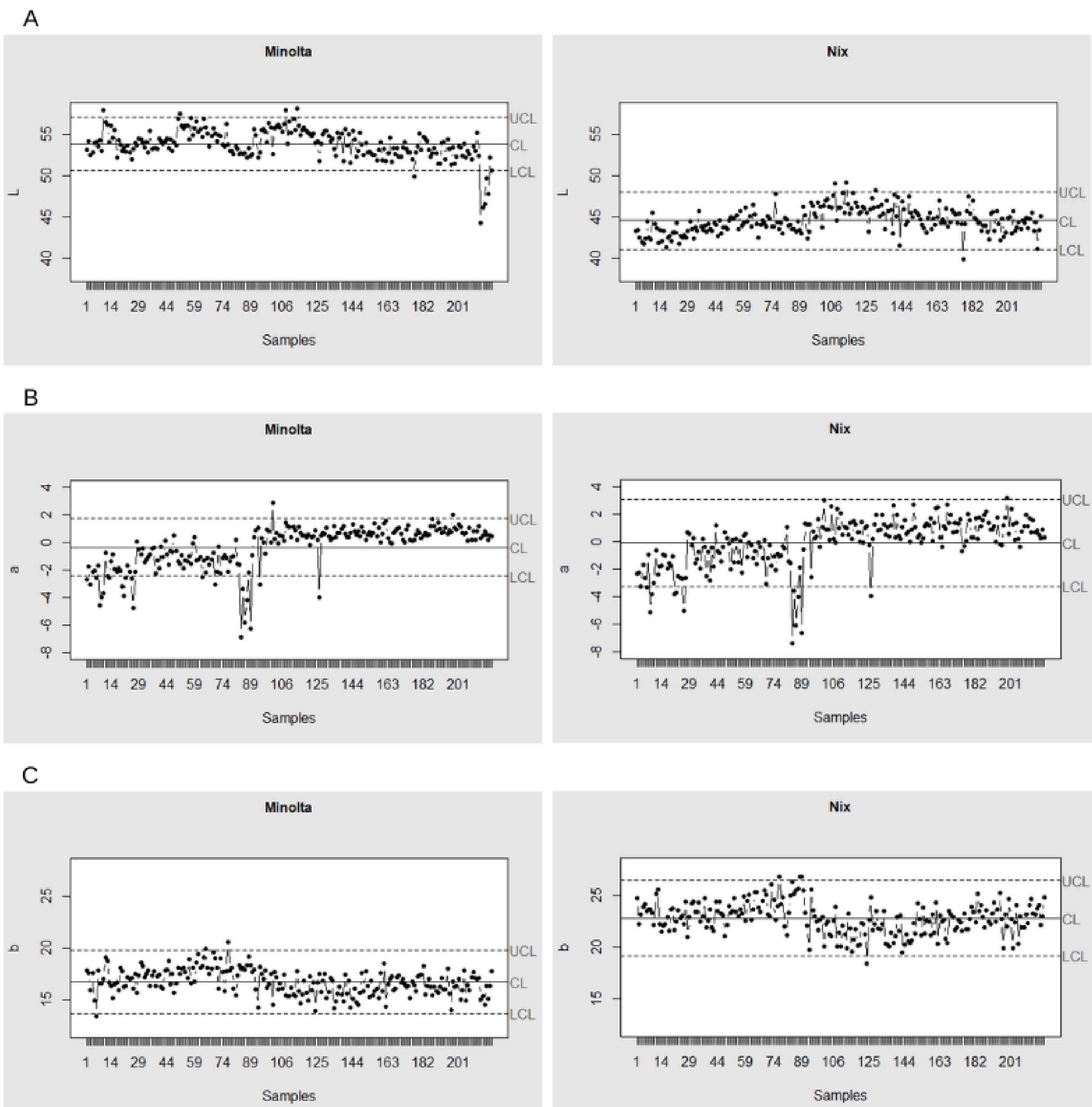
3 RESULTS AND DISCUSSION

A total of 438 yerba mate samples' colorimetric results (L^*, a^*, and b^*) obtained from Minolta and Nix QC colorimeters are presented in the supplementary material (Supplement 1).

Comparative analysis between Minolta and Nix colorimeters based on different yerba mate samples' color parameters reveals differences between the equipment (Figure 1). The results indicate that Nix has a higher variance in results than Minolta's, especially for L^* (luminosity) and b^* (yellow-blue) values.

Minolta has presented less standard deviation on the analyzed samples, reflecting greater robustness to possible sampling variability. On the other hand, Nix tended to have more significant fluctuations, especially in less uniform color samples, which can be attributed to sensor sensibility and the analysis software characteristics.

Colorimeter precision and reproducibility are crucial for scientific and industrial acceptance (Dang et al., 2021; Holman et al., 2018; Schelkopf et al., 2021). Choosing between Nix and Minolta requires considering the specific context used. Nix is lighter, smaller, and easier to transport and measure small sample volumes. Regarding cost–benefit analysis, it can be an excellent option for field measurements and prelaminar



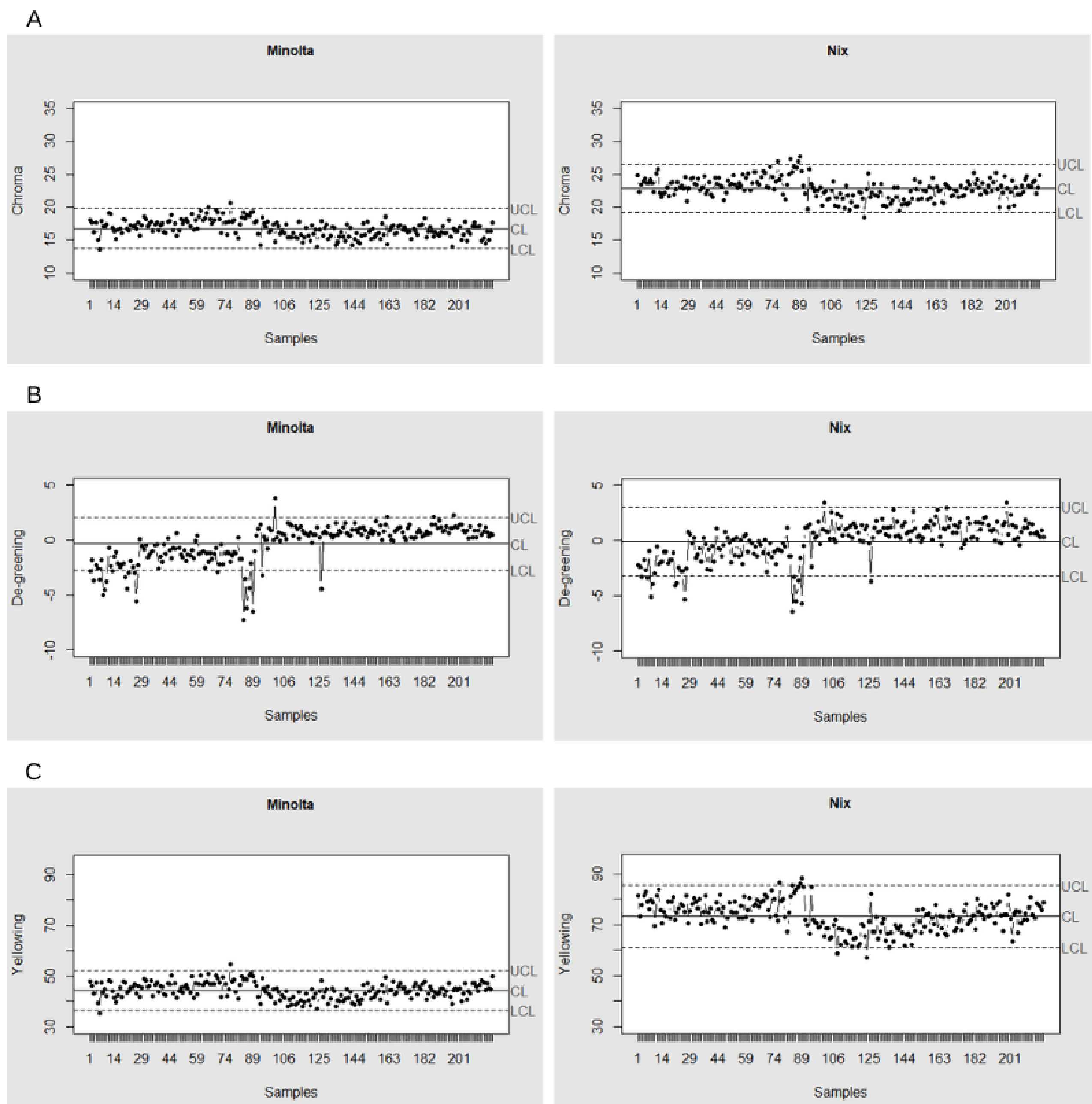
CL: central line/mean of the samples; LCL: lower control limit; UCL: upper control limit; LCL and UCL are established as the mean of the samples ± three times the standard deviation of the samples and are also called control limits.

Figure 1. Control charts: L^* (A), a^* (B), and b^* (C) Minolta and Nix Quality Control colorimeters.

analysis. Alternatively, Minolta has high precision and stability, which can be indicated by detailed studies and rigorous quality control in situations that require data consistency.

Yerba mate coloring is crucial for quality and product acceptance by consumers, influencing its sensorial and marketing characteristics. Yerba mate samples' color measurement results (L^*, a^*, and b^*) using Konica Minolta and Nix QC colorimeters were highly similar to those reported in studies by Lewinski et al. (2015), Nabechima et al. (2014), and Thewes et al. (2021); all debated the impacts of changes in packaging, storage environment, storage time, and processing methods. Luminosity (L^*) indicates the product clarity or darkness, while a^* (red/green) and b^* (yellow/blue) characterize color intensity, influenced by factors like oxidation and chlorophyll degradation. The similarity between the results obtained through colorimeters and previous studies highlights the robustness and reliability of these two yerba mate color-measuring devices.

During the aging phase, color varies from dark green to light olive green, which is why color parameters are generally used to control the aging degree (Holowaty et al., 2016). This study used chrome, de-greening, and yellowing colorimetric parameters for yerba mate (*llex paraguariensis*) quality rating. Control charts generated with yerba mate samples' colorimetric results from Minolta and Nix QC colorimeters are displayed in Figure 2.



CL: central line/mean of the samples; LCL: lower control limit; UCL: upper control limit; LCL and UCL are established as the mean of the samples ± three times the standard deviation of the samples and are also called control limits.

Figure 2. Control charts: chroma (A), de-greening (B), and yellowing (C) in Minolta and Nix Quality Control colorimeters.

In general, Nix equipment showed more variability in results, with a wider control range and a greater number of off--limit points in all parameters. Minolta kept a narrower control range, specifically for chrome and yellowing but had a greater number of beyond-limit points on de-greening.

Chrome, which represents color saturation or its intensity, plays a significant role in the esthetic appeal of yerba mate. Higher chrome values indicate more vibrant and intense coloration, generally perceived as a freshness and high-quality indicator. In the context of yerba mate, a higher chrome might be associated with better chlorophyll and other pigment preservation, which suggests minimal degradation during processing and storage (Schmalko et al., 2005).

De-greening refers to green coloration reduction, often caused by chlorophyll breakage. This parameter is vital as it can signal the yerba mate degradation extent (Schmalko et al., 2005). Factors such as light, oxygen, and heat exposure during processing and storage can accelerate de-greening (Akan, 2022; Lewinski et al., 2015; Thewes et al., 2021). A lower de-greening rate is desirable as it implies better green color retention, often associated with higher quality. Understanding factors influencing the de-greening process can help develop strategies to minimize chlorophyll degradation, thus preserving visual and nutritional yerba mate qualities (Morawicki et al., 1999).

Yellowing is also a critical parameter that affects yerba mate's visual quality. The process is usually a result of carotenoids and other pigment accumulation that become more visible as chlorophyll breaks down (Rodriguez-Amaya, 2001). While some extent of yellowing degree might be acceptable or desirable under specific contexts, consumers can perceive excessive yellowing negatively because it indicates overmaturity or poor storage conditions (Akan, 2022; Milovanovic et al., 2021). Having control over the yellowing process is essential for the product's appeal and its nutritional value, as excessive yellowing might also imply the loss of essential nutrients (Francis, 1995; Lee & Coates, 2003).

These parameters affect more than just the visual appeal; they also provide indirect insights into the product's nutritional status and processing history (Frizon et al., 2015; Frizon & Nisgoski, 2020). Producers can ensure a higher quality product that meets customer expectations and stands out by closely monitoring and controlling these parameters.

This research proposed regression equations that made obtaining results from Minolta with NIX color measurements possible. Regression equations and correlation coefficients between parameters are displayed in Table 1.

a^* and b^* parameters' correlation was moderate (b^*, $r = .788$, $p < .05$) to high (a^*, $r = .926$, $p < .05$), indicating that Nix measurement can predict Minolta values with great precision. A good match was found in a^* and b^* parameters' equation, demonstrating that it is possible to estimate Minolta results through equations. L^* parameter correlation was moderate ($r = .541$, $p > .05$) but not significant, suggesting that although there is a linear relation between the two equipment-measuring systems, data suggest that the linear correlation coefficient is not significantly different from zero.

As for other calculated parameters, the data were promising; they demonstrated that it is possible to estimate Minolta results with precision through equations. Chrome correlation was moderate ($r = .804$, $p < .05$), indicating a linear relation with moderate variability, but the predicted values are reasonably precise. Nevertheless, the values of de-greening ($r = .923$, $p < .05$) and yellowing ($r = .776$, $p < .05$) parameters were high, suggesting a strong match between the two pieces of equipment, which had a very great precision over the predicted values. These last parameters are highlighted because they are important indexes that keep up the yerba mate storage and aging process (Cabral-Malheiros et al., 2010; Holowaty et al., 2014; Nabechima et al., 2014).

All analyzed parameters had a close-to-zero-difference average (Table 1). This indicates a "good fit" equation between real Minolta and regression-estimated values.

Figure 3 represents dispersion charts that enable comparison of real values obtained from colorimeters with equation--estimated results regarding L^*, a^*, b^*, chrome, yellowing, and de-greening parameters.

Gray spots represent Minolta values estimated through regression, and black-painted values are the real ones obtained through colorimeter reading. The equations expressed promising a^*, b^*, chroma (C*), de-greening (D*), and YI Minolta values; this demonstrates that Nix readings and regression equations can be used by the way of comparison to estimate other colorimeters.

All evaluated color parameters revealed an excellent agreement between Nix QC and Konica Minolta colorimeters. These results are consistent with Hodgen's findings, who evaluated these devices similarly for deoxymyoglobin and

Table 1. Pearson's correlation coefficient, regression equations, and mean of differences between the CIE L^*, a^*, b^*, chroma (C*), de-greening (D*), and yellowing index (YI) values obtained from yerba mate samples ($n = 219$) using the Konica Minolta CR-410 and Nix Color Sensor colorimeters.

	a^* Nix × a^* Minolta	b^* Nix × b^* Minolta	L^* Nix × L^* Minolta	C* Nix × chroma Minolta	D* Nix × Minolta	YI Nix × Minolta
Pearson's correlation	0.926**	0.788**	0.541	0.804**	0.923**	0.776**
Regression equation	Minolta = 0.8198 Nix + 0.2993	Minolta = 0.628 Nix + 2.3946	Minolta = 0.639 Nix + 25.329	Minolta = 0.6462 Nix + 2.0099	Minolta = 0.9235 Nix + 0.3062	Minolta = 0.4199 Nix + 13.652
Mean difference*	−0.599	−0.00071	0.00086	3.7×10^{-5}	6.1×10^{-6}	0.0018

*Mean difference (Minolta color value – values' estimate). Correlation coefficient values range from −1 to +1. The closer to −1, the stronger the negative correlation between the variables. The closer to +1, the stronger the positive correlation between the variables. Correlation values close to zero indicate that there is no correlation between the variables. **Significant correlation ($p < 0.05$).

oxymyoglobin samples. Hodgen's (Hodgen, 2016) noteworthy study included not only a Minolta colorimeter comparison but also used the well-recognized Hunter Miniscan equipment, which yielded similar consistent results. Besides, a survey conducted by Schelkopf [9] using the HunterLab Miniscan colorimeter on fresh beef samples showed that the results indicated Nix QC as a possible viable alternative to the equipment traditionally employed for this purpose. Other studies have also highlighted Nix's reliability and versatility in various applications, which supports its effectiveness in color analysis (Dang et al., 2021; Holman et al., 2018; Swetha et al., 2022).

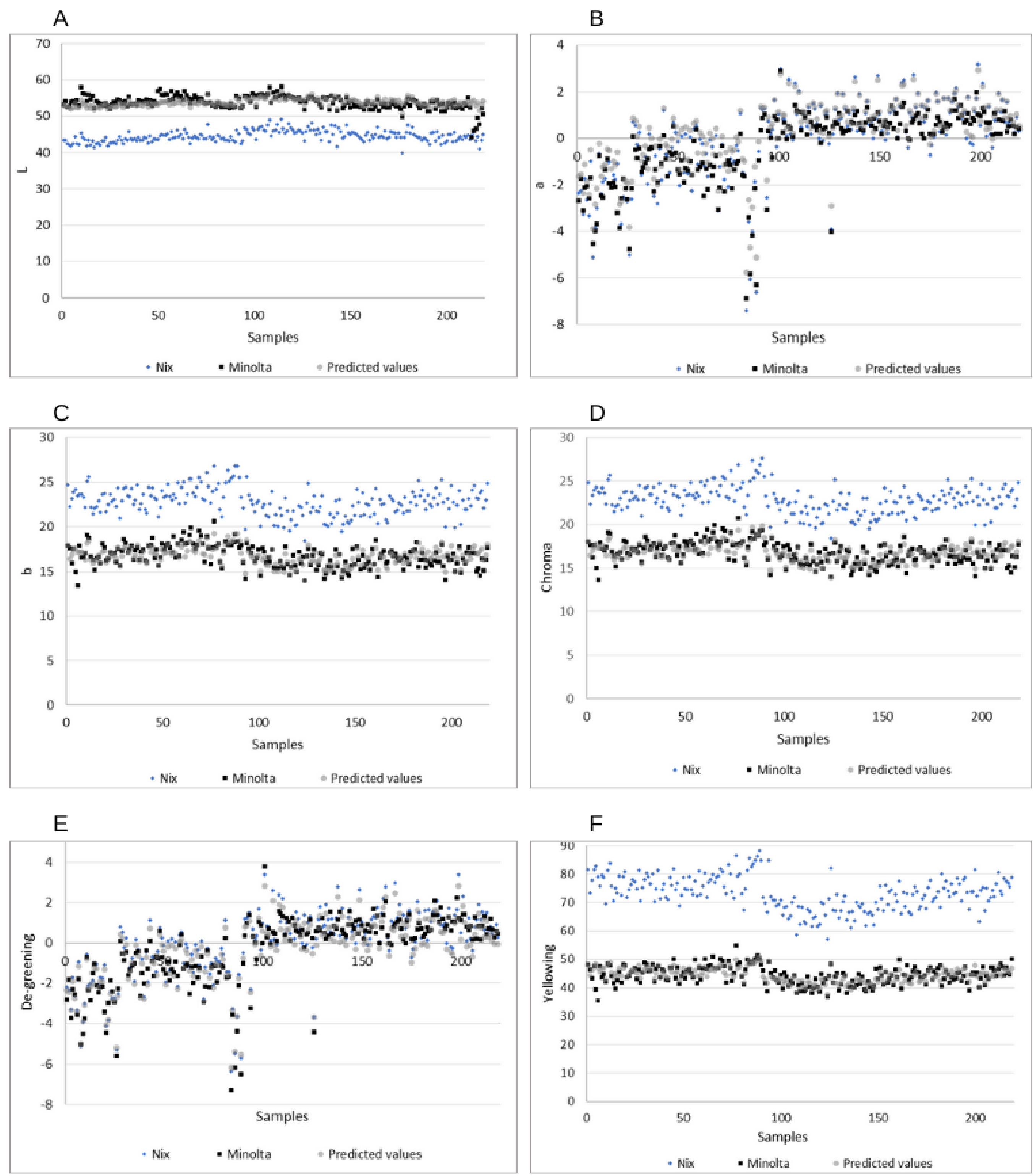


Figure 3. Linear regression: L^* (A), a^* (B), b^* (C), chroma (D), de-greening (E), and yellowing (F) in Minolta and Nix Quality Control colorimeters.

Our findings generally showed consistency and correlation in the data behavior between equipment. Variations observed can be explained by the fact that Minolta employs a xenon flash, while Nix uses high Color Rendering Index (CRI) light-emitting diodes (LEDs) (Dang et al., 2021). Lighting technology influences color measurements significantly. Minolta xenon flash provides more intense and consistent lighting, which may result in more precise color readings over non-uniform and reflective surfaces. Still, it can also be less efficient under less controlled lighting conditions (Yagiz et al., 2009). High CRI Nix LEDs offer a closer portrayal of natural light (Schelkopf et al., 2021).

Concerning this, it explains Nix readings' greater variance due to its sensibility to texture and sample surface composition. Beyond that, Nix can also demonstrate precision and stability under natural light conditions, which may be an advantage in practical applications where lighting conditions are variable (Dang et al., 2021).

Nix QC not only simplifies the measuring process but also offers consistent and reliable results, which is essential to guarantee the quality and uniformity of the final product. Choosing this device represents a significant advance in standardization and quality control, providing a solid base for process optimization. The equations proposed allow for verifying Minolta results by comparison (Table 1). Nix also has software (Nix Print Pro) that makes it possible to measure color that does not depend on the human eye. Through this software, combined with the sample reading data obtained in this research, the following images in Figure 4 were obtained.

Figure 4 presents an exhibition comparing yerba mate samples at different aging stages; the exhibit was made with Nix QC and Konica Minolta colorimeter readings converted from Lab* to RGB color values. Nix represents an interesting alternative, and it is better at replicating natural light, capturing a more faithful color portrayal.

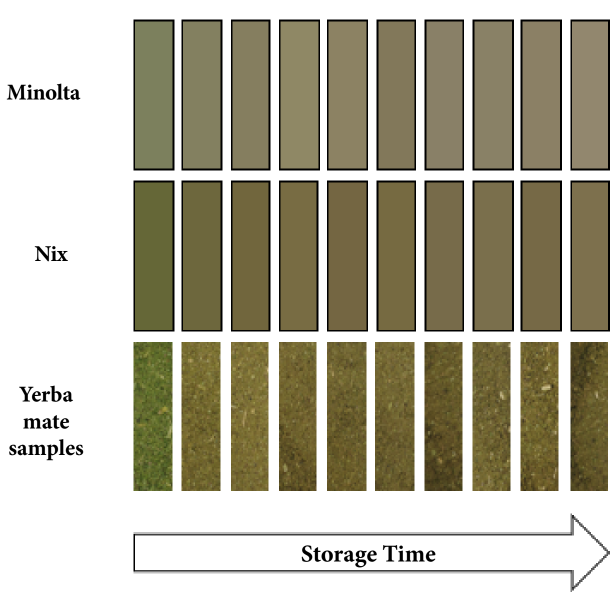


Figure 4. Comparison of the color of yerba mate samples obtained through photography and via readings from Minolta and Nix Quality Control colorimeters.

The samples' surface state, the measurement instrument geometry, and many other factors can affect color readings (Yagiz et al., 2009). Both Nix and Konica Minolta Color Sensor proved effective in this aspect, allowing precise color change analysis over time. In addition, although colors recorded by both devices are slightly different, they exhibit variation that correlates with sample aging. This highlights the colorimeter's consistency and reliability in measuring the yerba mate color.

4 CONCLUSION

Statistical analysis demonstrated a significant correlation between a^*, b^*, de-greening (D^*), and YI color parameters, emphasizing the importance of considering all these elements in yerba mate color evaluation.

Control Chart application between Konica Minolta and Nix Color Sensor devices revealed a satisfactory match for all evaluated color parameters, indicating that the Nix Color Sensor is a viable and more affordable alternative to Konica Minolta. This offers an affordable solution that does not compromise the color measurement accuracy, which contributes to the yerba mate industry's efficiency and competitiveness.

Based on this study results, the Nix Color Sensor is a recommended choice as a practical and efficient option for color evaluation in yerba mate production. Choosing this device may result in a significant cost saving that does not compromise quality and reliability on color measurement, contributing to more effectiveness and competitiveness in the yerba mate industry. Besides that, Nix equipment offers a closer portrayal of natural light.

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REFERENCES

Akan, S. (2022). Effects of storage temperature and packaging on physiological and nutritional quality preservation of minimally processed spinach. *Journal of Agricultural Science and Technology*, *24*(3), 679–691. https://jast.modares.ac.ir/article--23-53103-en.html

Cabral-Malheiros, G., Hecktheuer, L. H. R., Canto, M. W., & Balsamo, G. M. (2010). O tempo e o tipo de embalagem sobre a erva-mate tipo chimarrão durante armazenagem em condições ambientais. *Ciência Rural*, *40*(3), 654–660. https://doi.org/10.1590/s0103-84782010005000028

Croge, C. P., Cuquel, F. L., & Pintro, P. T. M. (2021). Yerba mate: cultivation systems, processing and chemical composition. A review. *Scientia Agricola*, *78*(5), Article e20190259. https://doi.org/10.1590/1678-992x-2019-0259

Dang, D. S., Buhler, J. F., Stafford, C. D., Taylor, M. J., Shippen, J. E., Dai, X., England, E. M., & Matarneh, S. K. (2021). Nix Pro 2 and color muse as potential colorimeters for evaluating color in foods. *LWT*, *147*, Article 111648. https://doi.org/10.1016/j.lwt.2021.111648

Francis, F. J. (1995). Quality as influenced by color. *Food Quality and Preference*, *6*(3), 149–155. https://doi.org/10.1016/0950-3293(94)00026-R

Frizon, C. N. T., & Nisgoski, S. (2020). Color parameters to predict moisture and tannin content in yerba mate process. *Floresta e Ambiente*, *27*(2), Article e20180098. https://doi.org/10.1590/2179-8087.009818

Frizon, C. N. T., Oliveira, G. A., Perussello, C. A., Peralta-Zamora, P. G., Camlofski, A. M. O., Rossa, Ü. B., & Hoffmann-Ribani, R. (2015). Determination of total phenolic compounds in yerba mate (Ilex paraguariensis) combining near infrared spectroscopy (NIR) and multivariate analysis. *LWT*, *60*(2), 795–801. https://doi.org/10.1016/j.lwt.2014.10.030

Gerber, T., Nunes, A., Moreira, B. R., & Maraschin, M. (2023). Yerba mate (Ilex paraguariensis A. St.-Hil.) for new therapeutic and nutraceutical interventions: A review of patents issued in the last 20 years (2000–2020). *Phytotherapy Research*, *37*(2), 527–548. https://doi.org/10.1002/ptr.7632

Hodgen, J. (2016). Comparison of nix color sensor and nix color sensor pro to standard meat science research colorimeters. *Meat Science*, *112*, Article 159. https://doi.org/10.1016/j.meatsci.2015.08.129

Holman, B. W. B., Collins, D., Kilgannon, A. K., & Hopkins, D. L. (2018). The effect of technical replicate (repeats) on Nix Pro Color Sensor™ measurement precision for meat: A case-study on aged beef colour stability. *Meat Science*, *135*, 42–45. https://doi.org/10.1016/j.meatsci.2017.09.001

Holowaty, S. A., Surkan, S. A., Trela, V. D., Byczko, G. D., & Schmalko, M. E. (2014). Variation of physicochemical and sensory properties during the aging of yerba mate. *International Journal of Food Studies*, *3*(2), 228–238. https://doi.org/10.7455/ijfs/3.2.2014.a8

Holowaty, S. A., Trela, V., Thea, A. E., Scipioni, G. P., & Schmalko, M. E. (2016). Yerba Maté (Ilex paraguariensis St. Hil.): Chemical and Physical Changes under Different Aging Conditions. *Journal of Food Process Engineering*, *39*(1), 19–30. https://doi.org/10.1111/jfpe.12195

Lee, H. S., & Coates, G. A. (2003). Effect of thermal pasteurization on Valencia orange juice color and pigments. *LWT - Food Science and Technology*, *36*(1), 153–156. https://doi.org/10.1016/S0023-6438(02)00087-7

Lewinski, C. S., Gonçalves, I. L., Borges, A. C. P., Dartora, N., Souza, L. M., & Valduga, A. T. (2015). Effects of UV light on the physic--chemical properties of yerba-mate. *Nutrition and Food Science*, *45*(2), 221–228. https://doi.org/10.1108/NFS-07-2014-0065

Milovanovic, B., Tomovic, V., Djekic, I., Solowiej, B. G., Lorenzo, J. M., Barba, F. J., & Tomasevic, I. (2021). Color assessment of the eggs using computer vision system and Minolta colorimeter. *Journal of Food Measurement and Characterization*, *15*(6), 5097–5112. https://doi.org/10.1007/s11694-021-01085-4

Morawicki, R. O., Schmalko, M. E., & Känzig, R. G. (1999). Chlorophyll stability in yerba maté leaves in controlled atmospheres. *Brazilian Archives of Biology and Technology*, *42*(1), 740–745. https://doi.org/10.1590/s1516-89131999000100012

Nabechima, G. H., Provesi, J. G., Mantelli, M. B. H., Vieira, M. A., Amboni, R. D. M. C., & Amante, E. R. (2014). Effect of the Mild Temperature and Traditional Treatments on Residual Peroxidase Activity, Color, and Chlorophyll Content on Storage of Mate (Ilex paraguariensis) Tea. *Journal of Food Science*, *79*(2), C163–C168. https://doi.org/10.1111/1750-3841.12329

R Core. (2016). *The R Project for Statistical Computing*. R Core Team. Retrieved May 21, 2025, from https://www.r-project.org

Rodriguez-Amaya, D. B. (2001). *A Guide to Carotenoid Analysis in Foods*. International Life Sciences Institute.

Rząsa-Duran, E., Kryczyk-Poprawa, A., Drabicki, D., Podkowa, A., Sułkowska-Ziaja, K., Szewczyk, A., Kała, K., Opoka, W., Zięba, P., Fidurski, M., & Muszyńska, B. (2022). Yerba Mate as a Source of Elements and Bioactive Compounds with Antioxidant Activity. *Antioxidants*, *11*(2), Article 371. https://doi.org/10.3390/antiox11020371

Sarreal, J. (2024). From South America to the United States: Guayakí and the Transformation of Yerba Mate. *Enterprise & Society*, *25*(4), 1295–1320. https://doi.org/10.1017/ESO.2023.43

Schelkopf, C. S., Rice, E. A., Swenson, J. K., Hess, A. M., Geornaras, I., Belk, K. E., & Nair, M. N. (2021). Nix Pro Color Sensor provides comparable color measurements to HunterLab colorimeter for fresh beef. *Journal of Food Science and Technology*, *58*(9), 3661–3665. https://doi.org/10.1007/s13197-021-05077-6

Schmalko, M. E., Scipioni, P. G., & Ferreyra, D. J. (2005). Effect of water activity and temperature in color and chlorophylls changes in yerba mate leaves. *International Journal of Food Properties*, *8*(2), 313–322. https://doi.org/10.1081/JFP-200060250

Swetha, R. K., Dasgupta, S., Chakraborty, S., Li, B., Weindorf, D. C., Mancini, M., Silva, S. H. G., Ribeiro, B. T., Curi, N., & Ray, D. P. (2022). Using Nix color sensor and Munsell soil color variables to classify contrasting soil types and predict soil organic carbon in Eastern India. *Computers and Electronics in Agriculture*, *199*, Article 107192. https://doi.org/10.1016/j.compag.2022.107192

Thewes, F. R., Berghetti, M. R. P., Schultz, E. E., Ludwig, V., Prestes, S. L. C., Wendt, L. M., Thewes, F. R., & Brackmann, A. (2021). The isolated effect of low oxygen and high carbon dioxide on yerba mate quality keeping. *Bragantia*, *80*, Article e1021. https://doi.org/10.1590/1678-4499.20200273

Valduga, A. T., Gonçalves, I. L., Borges, A. C. P., Mielniczki-Pereira, A. A., & Picolo, A. P. (2016). <b>Cytotoxic / antioxidant activity and sensorial acceptance of yerba-mate development by oxidation process. *Acta Scientiarum. Technology*, *38*(1), 115–121. https://doi.org/10.4025/actascitechnol.v38i1.26033

Yagiz, Y., Balaban, M. O., Kristinsson, H. G., Welt, B. A., & Marshall, M. R. (2009). Comparison of Minolta colorimeter and machine vision system in measuring colour of irradiated Atlantic salmon. *Journal of the Science of Food and Agriculture*, *89*(4), 728–730. https://doi.org/10.1002/jsfa.3467