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Correlation of RGB Drone Indices and Sentinel-2 in Rice (Oryza sativa L.) at UBPC Las Nuevas, Sancti Spíritus

Correlación de índices RGB de dron y Sentinel-2 en arroz (Oryza sativa L.) en la UBPC Las Nuevas, Sancti Spíritus

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ABSTRACT: Rice production in Cuba faces a significant gap between national demand and domestic supply, aggravated by technological and input limitations. In this context, the present study aimed to evaluate the correlation between spectral indices derived from RGB orthophotography captured with a Phantom 4 drone and multispectral indices obtained from Sentinel-2 L2A images, in rice (Oryza sativa L.) at the seedling stage, in plot 6 of UBPC Las Nuevas, during the dry season of 2020. The methodology included the use of QGIS 3.40 for image processing, calculation of spectral indices (NDVI, GNDVI, NDRE, VARI, ExG, CIVE), and statistical analysis using Pearson's correlation coefficient in Statgraphics. The results showed significant correlations between RGB indices and satellite indices: VARI-NDVI ($r \approx 0.74$), ExG-GNDVI ($r \approx 0.67$), and CIVE-NDRE ($r \approx -0.63$). Field validation confirmed the homogeneity of the seedling stage and the absence of water stress, in agreement with the spectral values obtained. It is concluded that RGB indices can be used as reliable proxies for multiscale agricultural monitoring under resource-limited conditions. It is recommended to extend the analysis to time series, incorporate new indices such as SAVI and BSI, and strengthen technical training in tools such as QGIS and Statgraphics to improve agricultural management in Cuba.
Keywords: precision agriculture, drone, multiscale monitoring, QGIS, remote sensing.

RESUMEN: La producción de arroz en Cuba enfrenta una brecha significativa entre la demanda nacional y la oferta interna, agravada por limitaciones tecnológicas y de insumos. En este contexto, el presente estudio tuvo como objetivo evaluar la correlación entre índices espectrales derivados de ortofotografía RGB capturada con dron Phantom 4 y los índices multiespectrales obtenidos de imágenes Sentinel-2 L2A, en arroz (Oryza sativa L.) en estado de plántula, en el lote 6 de la UBPC Las Nuevas, durante la época seca de 2020. La metodología incluyó el uso de QGIS 3.40 para el procesamiento de imágenes, cálculo de índices espectrales (NDVI, GNDVI, NDRE, VARI, ExG, CIVE), y análisis estadístico mediante el coeficiente de correlación de Pearson en Statgraphics. Los resultados evidenciaron correlaciones significativas entre los índices RGB y los índices satelitales: VARI-NDVI ($r \approx 0.74$), ExG-GNDVI ($r \approx 0.67$) y CIVE-NDRE ($r \approx -0.63$). La validación en campo confirmó la homogeneidad del estado de plántula y la ausencia de estrés hídrico, en concordancia con los valores espectrales obtenidos. Se concluye que los índices RGB pueden ser utilizados como proxies confiables para el monitoreo agrícola multiescalar en condiciones de recursos limitados. Se recomienda ampliar el análisis a series temporales, incorporar nuevos índices como SAVI y BSI, y fortalecer la capacitación técnica en herramientas como QGIS y Statgraphics para mejorar la gestión agrícola en Cuba.
Palabras clave: agricultura de precisión, dron, monitoreo multiescalar, QGIS, teledetección.

INTRODUCTION

Rice (*Oryza sativa L.*) constitutes one of the pillars of food security in Cuba and much of the world. In the Cuban diet, this cereal is irreplaceable: it is estimated that each person consumes around 60 kg annually, one of the highest figures in the region (Monreal, 2025). To meet national demand, the country requires about 600,000 tons per year, but in 2024 it barely managed to produce 80,000 tons, representing only 13% of the demand and forcing reliance on costly imports (Infobae, 2025). This situation reflects the vulnerability of the Cuban agri-food system and the need to optimize production through advanced technologies.

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The rice production crisis in Cuba has been highlighted by various specialists as the result of an inefficient agricultural model dependent on external inputs (Periódico Girón, 2025). In this context, the search for technological alternatives to improve crop management becomes a strategic imperative.

Remote sensing has been consolidated as a key tool for modern agriculture. The use of satellites, drones, and remote sensors makes it possible to monitor the physiological status of crops, detect water stress, estimate biomass, and assess plant health quickly and non-destructively. In Cuba, the introduction of these technologies has been progressive, with projects promoted by universities and the Ministry of Science, Technology and Environment (Ruiz *et al.*, 2024).

Drones provide high spatial resolution images, useful for characterizing specific plots and detecting local variations in crops. Meanwhile, Sentinel-2 satellites provide multispectral data with broad coverage and adequate temporal frequency for regional monitoring. The combination of both sources of information opens the possibility of establishing multiscale models that integrate local detail and global vision (Ponvert y Lau, 2018).

Spectral indices derived from satellite images, such as NDVI, GNDVI, and NDRE, have proven to be robust indicators of plant vigor and chlorophyll content. However, their spatial resolution (10-20 m) may limit precision in small plots. In contrast, indices calculated from drone RGB orthophotography, such as VARI, ExG, and CIVE, offer a higher level of detail, although they lack the spectral breadth of satellite sensors. The correlation between both sets of indices allows validation of the usefulness of RGB images as a substitute or complement to satellite data. Recent studies have shown that indices such as VARI present significant correlations with NDVI, confirming the possibility of using drones for agricultural monitoring under resource-limited conditions (Famartínez, 2023).This integration is especially relevant in Cuba, where access to high-resolution satellite images may be restricted, but the use of drones has expanded in academic and productive projects.

The objective of this research is to evaluate the correlation between spectral indices derived from Phantom 4 drone RGB orthophotography and Sentinel-2 L2A in rice (*Oryza sativa L.*) at the seedling stage.

MATERIALS AND METHODS

Study Area

The study was conducted in plot 6 of the Basic Cooperative Production Unit (UBPC) *Las Nuevas*, belonging to the Sur del Jíbaro Rice Company, located in the municipality of La Sierpe, Sancti Spíritus Province. This plot is part of one of the main rice-growing areas of the country, characterized by fertile soils, flat topography, and the availability of irrigation infrastructure. The study period corresponds to the dry season of the year 2020 (Figure 1).

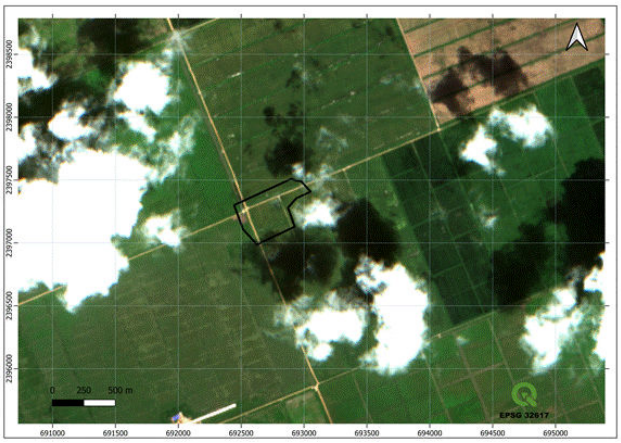


Figure 1. Plot 6 of the Basic Cooperative Production Unit (UBPC) *Las Nuevas*, belonging to the Sur del Jíbaro Rice Company.

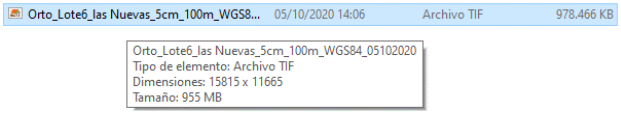
Methodology

For the development of the study, the following materials and tools were used:

- QGIS v3.40 Bratislava software (OSGeo, 2024).
- Sentinel-2 L2A satellite image (resolution of 10 to 20 meters, acquired on October 4, 2020) (Copernicus, 2024).



- RGB orthophotography captured with Phantom 4 drone (resolution of 5 cm/pixel, acquired on October 5, 2020), Figure 2.



- QGIS plugins: Semi-Automatic Classification Plugin (SCP), Raster Calculator, Field Calculator.
- Hardware: workstation with processing capacity for multispectral images.

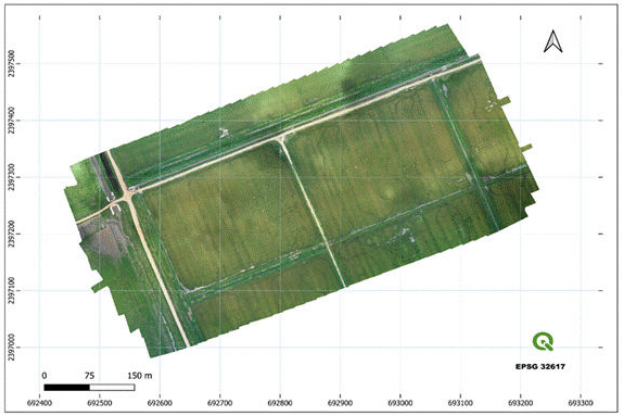


Figure 2. RGB orthophotography captured with Phantom 4 drone (resolution of 5 cm/pixel, October 5, 2020).

Image Preprocessing

Sentinel-2 images were subjected to atmospheric correction (level L2A), clipping of the study area, and reprojection to the UTM coordinate system. The RGB orthophoto was orthorectified and mosaicked to generate a single raster in QGIS.

Spectral Indices Calculation

The following spectral indices were calculated using the QGIS Raster Calculator:

- Sentinel-2 indices: NDVI, GNDVI, NDRE.
- RGB indices: VARI, ExG, CIVE, GLI.

Integration and Analysis in QGIS

Raster layers were integrated into the QGIS environment through spatial overlay. A systematic sampling grid was generated according to the spatial resolution of the data sources. For Sentinel-2 imagery (10-20 m/pixel), a spacing of 20 meters was applied, ensuring that each point represented an independent pixel and avoiding spatial redundancy. For RGB drone orthophotographs (0.05-0.20 m/pixel), a spacing of 5-10 meters was used, allowing the internal variability of the crop to be captured. In this case, 415 points were sampled, from which spectral index values were extracted for correlation analysis. This definition followed FAO (2023) methodological recommendations for agricultural remote sensing and recent precision agriculture studies, ensuring reproducibility of the analysis.

Field Validation

The results were contrasted with direct field observations of the physiological status of rice at the seedling stage.

Statistical Analysis

Statistical analysis was performed using Statgraphics Centurion v15.0. Pearson's correlation coefficient (r) was applied to evaluate the linear relationship between RGB spectral indices and those derived from Sentinel-2. The r values were interpreted according to Cohen (2013). The results were validated with field observations of the physiological status of the rice crop.

Cohen (2013) Scale:

- 0.10-0.29: weak correlation
- 0.30-0.49: moderate correlation
- 0.50-0.69: strong correlation
- ≥ 0.70: very strong correlation

Methodological Flow Diagram

The methodological flow followed in the study is summarized in the following steps:

- Phantom 4 drone capture (RGB): A flight was carried out with the Phantom 4 drone on October 5, 2020 to obtain a high-resolution RGB orthophoto (5 cm/pixel) of plot 6.
- Sentinel-2 L2A image: A Sentinel-2 L2A image corresponding to October 4, 2020 was downloaded, with spectral bands at 10 m and 20 m resolution.
- Spectral indices calculation: RGB indices (VARI, ExG, CIVE, GLI) and Sentinel-2 indices (NDVI, GNDVI, NDRE) were calculated to characterize the crop status (Figure 3).

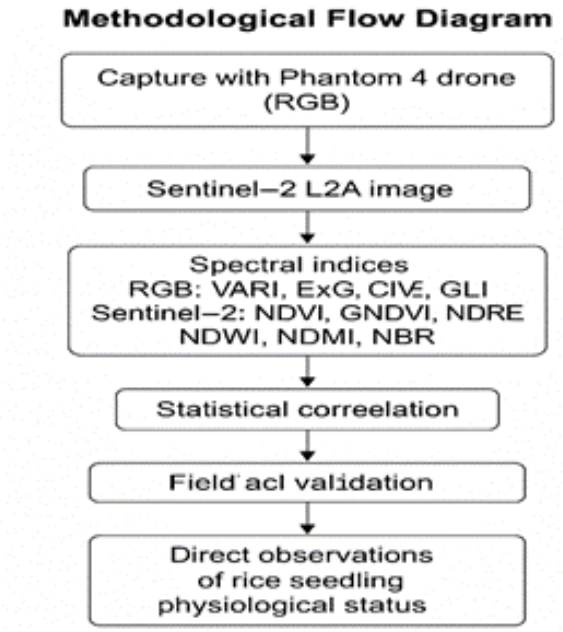


Figure 3. Representative diagram of the methodological workflow.

Technical Considerations

QGIS v3.40 Bratislava offers robust tools for raster image processing, spectral index calculation, and spatial analysis, facilitating reproducibility of the workflow (OSGeo, 2024). Meanwhile, Statgraphics provides a user-friendly interface for statistical correlation analysis, allowing precise interpretation of relationships between spectral variables. The combination of both platforms enables efficient and accessible multiscale analysis for agricultural monitoring.

RESULTS AND DISCUSSION

Field Photographs

This section presents visual evidence of the physiological status of rice crops at the seedling stage (Figure 4), as well as the conditions of plots flooded by gravity irrigation in plot 6 of UBPC *Las Nuevas* (Figure 5). The images allow visual validation of crop uniformity, seedling density, and absence of water stress during the dry season of 2020 (Figure 6).



Figure 4. General view of plot 6 showing high seedling density distributed homogeneously. A uniform initial crop development is observed.



Figure 5. Detail of a plot flooded by gravity irrigation. The presence of surface water is evident, with no signs of water stress in the plants.



Figure 6. Aerial perspective of plot 6 captured with a drone, showing the regular distribution of seedlings and the partial soil coverage characteristic of the seedling stage.

This index presents thematic maps generated from spectral data obtained in plot 6 of UBPC *Las Nuevas*, Sur del Jíbaro Rice Company, during the dry season of 2020. The maps allow spatial visualization of the distribution of different spectral indices that characterize the status of the rice crop at the seedling stage (Figure 7).

CIVE is an empirical index that combines RGB bands with specific coefficients: CIVE=0.441R−0.811G+0.385B+18.78745

- Due to this formula, CIVE values depend directly on the scale of RGB values (for example, 0-255 if the image is in 8-bit format).
- Therefore, CIVE values may vary widely, from negative (when green predominates) to positive (when red or blue predominates), and are not constrained between −1 and 1.

RGB vs Sentinel-2 Correlation Report

This report presents the Pearson correlation analysis between spectral indices derived from RGB drone images (VARI, ExG, CIVE) and multispectral indices obtained from Sentinel-2 imagery (NDVI, GNDVI, NDRE). The objective is to evaluate the linear relationship between these pairs of indices to validate the use of RGB indices as reliable proxies in multiscale agricultural monitoring of rice crops.

Correlation Analysis Results

The Pearson correlation coefficients obtained indicate a significant correlation between RGB indices and satellite indices (Table 1). In particular, the correlation between VARI and NDVI is high, suggesting that the VARI index may serve as a strong proxy for vegetation vigor. The correlations between ExG-GNDVI and CIVE-NDRE are moderate, further supporting their usefulness in agricultural monitoring (Figures 9, 10, 11). Sampled values for each index in the pixel grid were extracted using the QGIS *Simple Raster Values* tool.

Scatter Plots

Pattern description: The scatter plot shows a positive and consistent relationship between VARI (RGB) and NDVI (Sentinel-2), with points concentrated along an upward trend. The Pearson coefficient obtained ($r \approx 0.74$) indicates a very strong correlation, consistent with the sensitivity of both indices to vegetation vigor and canopy greenness. This behavior supports the use of RGB orthophotos as a proxy for vigor when NIR data is not available.

Pattern description: The scatter plot of ExG (RGB) vs GNDVI (Sentinel-2) shows a positive relationship with moderate dispersion and a clear linear trend. The Pearson coefficient ($r \approx 0.67$) indicates a moderate correlation, consistent with the sensitivity of GNDVI to chlorophyll content (green band) and the ability of ExG to emphasize the green component in RGB images.

Pattern description: The scatter plot of CIVE (RGB) vs NDRE (Sentinel-2) shows an inverse relationship with a downward trend; the Pearson coefficient ($r \approx -0.64$) indicates a moderate negative correlation. This reflects that CIVE-by combining RGB channels to extract vegetation-does not directly capture the sensitivity of the Red Edge to chlorophyll and nitrogen, but is inversely related to physiological variations detected by NDRE.

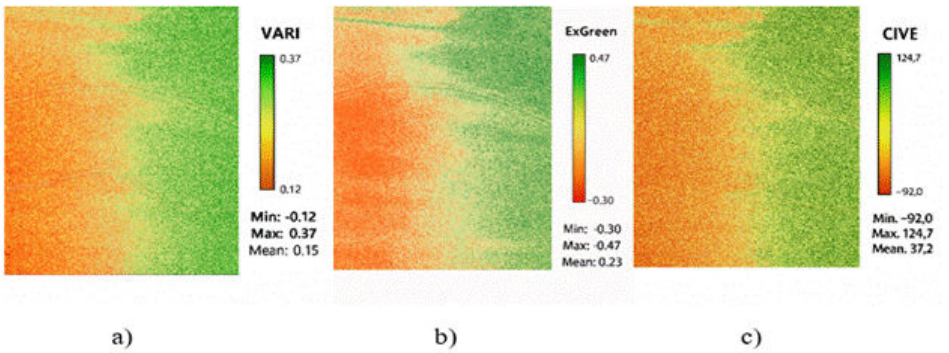


Figure 7. RGB thematic maps (Phantom 4 drone): VARI, ExG, CIVE. a) Thematic map of the VARI index in PNG format, with its numerical legend (minimum = −0.12, maximum = 0.37, average = 0.15) and color scale red→ yellow → green. b) Thematic map of the ExGreen index, color scale: red (low) → yellow (medium) → green (high). c) Thematic map of the CIVE index, color scale: red (−92.0) → yellow (≈0) → green (124.7).

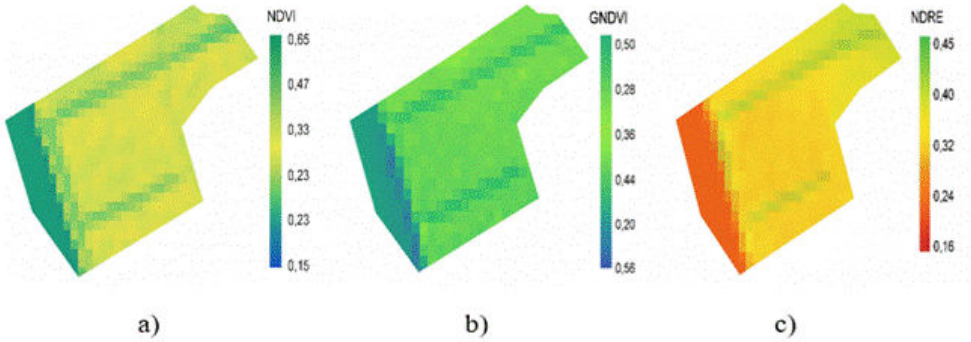


Figure 8. Thematic maps of Sentinel-2 indices: a) NDVI. Brown/gray → negative values or close to 0 (bare soil, water); Yellow → 0.1-0.3 (sparse vegetation); Light green → 0.3-0.6 (moderate vegetation); Dark green → 0.6-0.9 (vigorous vegetation). b) GNDVI. Light blue → 0.20 (low chlorophyll, reduced vigor); Light green → 0.35 (moderate vegetation); Intense green → 0.56 (high chlorophyll, optimal vigor). c) NDRE. Intense red → low values (~0.16): areas with low vigor or stress; Orange → medium values (~0.30): moderate vegetation; Yellow-green → transition towards vigor; Light to intense green → high values (~0.45): vigorous and healthy vegetation.

Table 1. Pearson correlation coefficients obtained indicate a significant correlation between RGB indices and satellite indices

Pair of Indices	Pearson Coefficient (r)	Interpretation
VARI vs NDVI	0.741	Very strong correlation
ExG vs GNDVI	0.672	Moderate correlation
CIVE vs NDRE	−0.635	Moderate correlation

Map Interpretation

- The NDVI map showed predominantly high values in plot 6, indicating elevated and homogeneous vegetation vigor, characteristic of the seedling stage without water stress. These results are consistent with studies in Peru, where Sentinel-2 NDVI has been used to predict rice yield and monitor vigor across different phenological phases (Quille *et al.*, 2024).
- The VARI map, derived from RGB drone orthophotos, reflected similar patterns to NDVI, with areas of greater greenness in the center of the plot, suggesting a strong correlation between both indices. Previous research has demonstrated that VARI can be a reliable proxy for NDVI in rice and wheat crops, especially when using low-cost UAVs (García *et al.*, 2018; MDPI., 2019).
- The NDRE map revealed subtle variations in chlorophyll content and initial vigor, with higher values in the central and eastern areas of the plot, possibly associated with greater leaf density. These findings are consistent with studies in Iran and Indonesia, where Sentinel-2 NDRE has been correlated with chlorophyll and nitrogen content in rice, showing sensitivity in early growth (Wijayanto *et al.*, 2024; Ehsanpour *et al.*, 2025).

Index Interpretation

- NDVI showed high and homogeneous values in plot 6, indicating vegetation vigor. This behavior has been widely documented in studies of rice and other crops, where NDVI is used as a robust indicator of biomass and vigor (Tucker, 1979; Quille *et al.*, 2024a).

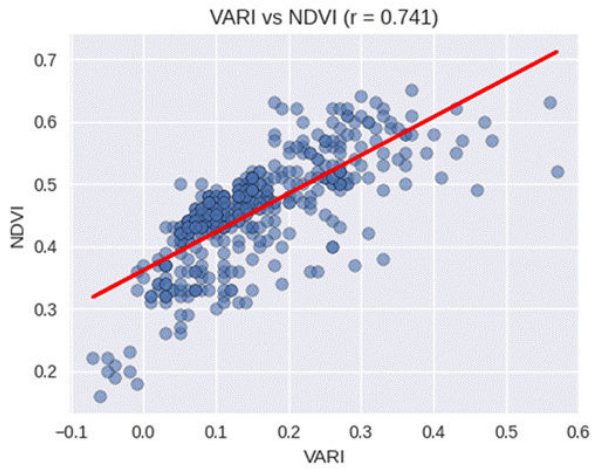


Figure 9. VARI vs NDVI correlation.

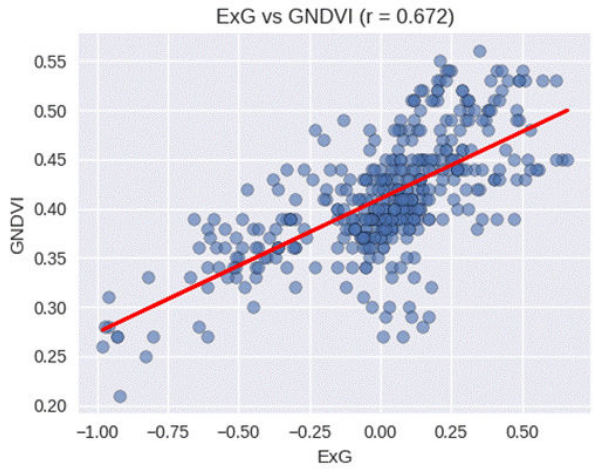


Figure 10. ExG vs GNDVI correlation.

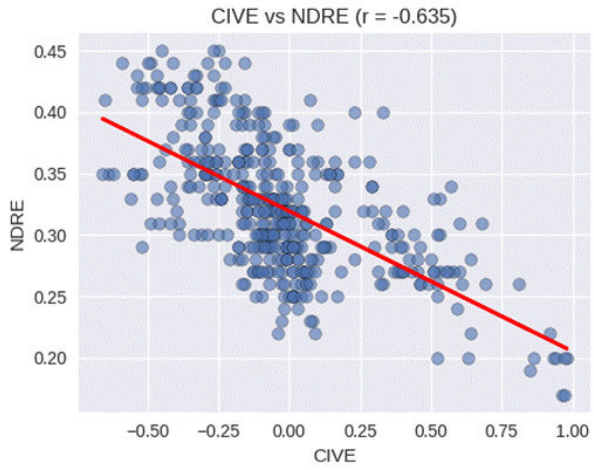


Figure 11. CIVE vs NDRE correlation

- NDRE revealed subtle variations in chlorophyll in central and eastern areas. Research in Iran and Indonesia has demonstrated that NDRE is sensitive to chlorophyll and nitrogen content in rice, especially in early stages (Wijayanto *et al.*, 2024; Ehsanpour *et al.*, 2025).
- The strongest correlation is between VARI and NDVI, validating the use of RGB orthophotos for early monitoring. Studies in Colombia and Mexico have confirmed that VARI can be a reliable proxy for NDVI in rice and maize, even with low-cost RGB cameras (García *et al.*, 2018; MDPI., 2019).
- VARI is confirmed as the most robust RGB index for estimating vegetation vigor, consistent with international findings in wheat and rice crops (Ruiz *et al.*, 2024).
- The moderate correlation of CIVE with NDRE suggests that RGB can capture chlorophyll variations, though with less precision than satellite indices. This result aligns with studies highlighting the usefulness of RGB indices for vegetation discrimination in the absence of NIR bands (Famartínez, 2023).
- NDRE, although less correlated, provides additional sensitivity to chlorophyll and vigor, reinforcing its value as a complement to NDVI and VARI in agricultural monitoring (Huete, 1988).
- RGB indices show significant correlations with satellite indices, confirming their utility as proxies at the seedling stage, as reported in precision agriculture projects in Latin America (FEDEARROZ, 2018; EcoTV Panamá., 2025).
- The scatter plots confirm that RGB indices can be used as proxies for satellite indices at the seedling stage, validating drone-satellite integration for multiscale monitoring (AgroLatam, 2025).

Correlation Interpretation

VARI-NDVI

- *Agronomic interpretation:* The association between VARI and NDVI suggests that greenness captured in the visible spectrum (VARI) adequately reproduces the variability of vigor detected by NDVI with NIR, especially at the seedling stage where coverage is homogeneous and soil exposure is limited. UAV studies have shown that high-resolution NDVI correlates with fertilization management and yield in rice and wheat, reinforcing the validity of RGB proxies in low-cost monitoring schemes.
- *Technical interpretation:* VARI, calculated from RGB images, consistently reproduces vegetation vigor captured by NDVI, which includes the NIR band. This validates the use of RGB drones as proxies under resource-limited conditions.
- Guan *et al.* (2019) demonstrated that UAV-derived NDVI correlates with yield and fertilization in rice and wheat. Goigochea *et al.* (2024) confirmed that multitemporal indices such as NDVI predict rice yield with high accuracy.

ExG-GNDVI

- *Agronomic interpretation:* The correspondence between ExG and GNDVI is expected in early rice stages, where vegetation-soil contrast and chlorophyll variability are strongly reflected in the green channel. UAV multispectral studies in rice have reported useful relationships between green-based indices and yield metrics, supporting the use of ExG as an operational indicator when spatial resolution and cost are prioritized.
- *Technical interpretation:* ExG emphasizes the green component in RGB images, while GNDVI is sensitive to chlorophyll content. The correlation confirms that both indices capture nutritional variations in early rice stages.
- García *et al.* (2018) reported significant correlations between GNDVI and vigor in rice using UAVs. Goigochea *et al.* (2024) validated that green-based indices predict yield in the Peruvian Amazon.

CIVE-NDRE

- Agronomic interpretation: NDRE is more sensitive to subtle changes in chlorophyll and nutritional status than RGB indices, especially in early stages and under slight variations in leaf density. The negative relationship suggests that increases in NDRE (higher chlorophyll) are associated with lower CIVE values under certain lighting and contrast conditions, consistent with studies recommending NDRE for physiological monitoring and water management in rice.
- Technical interpretation: NDRE, derived from the red edge, is highly sensitive to chlorophyll and nitrogen, while CIVE combines RGB channels to extract vegetation. The inverse relationship reflects that increases in chlorophyll (high NDRE) are associated with lower CIVE values, due to differences in spectral sensitivity.
- Nageswara et al. (2023) confirmaron la utilidad de NDRE para detectar variaciones fisiológicas confirmed the usefulness of NDRE for detecting physiological variations in rice. Pedroso de Lima et al. (2021) highlighted NDRE as key for evaluating irrigation and nutrition practices in rice.

Field Validation

- Direct observations in plot 6 confirmed the absence of water stress, consistent with the high NDVI and VARI values that reflected homogeneous vegetation vigor across the plot.
- The homogeneity of the seedling stage observed in the field corresponded with the spectral patterns of the thematic maps, where NDVI and VARI showed high and consistent values in the center and edges of the plot.
- Subtle NDRE variations in central and eastern areas were related to slight differences in leaf density observed in the field, confirming its sensitivity to chlorophyll content.
- This correspondence between field observations and spectral results validates the use of RGB indices as reliable proxies for satellite indices, in line with international studies reporting similar correlations in rice and other crops (García *et al.*, 2018; Quille *et al.*, 2024; Wijayanto *et al.*, 2024).

CONCLUSIONS

- RGB indices derived from drone imagery showed significant correlations with Sentinel-2 multispectral indices, validating their use as reliable proxies under resource-limited conditions.
- The correlation between VARI and NDVI reached $r \approx 0.74$, which corresponds to a very strong correlation according to Cohen's (1988) scale.
- The integration of drone and satellite imagery constitutes an effective strategy for multiscale agricultural monitoring, enabling characterization of rice physiological status at early stages.
- Limitations of RGB cameras were identified, related to their reduced sensitivity to specific spectral variations, suggesting the need to complement them with multispectral sensors in future studies.

RECOMENDATIONS

- Implement the combined use of RGB drone and Sentinel-2 imagery for multiscale agricultural monitoring under resource-limited conditions.
- Extend correlation validation to different phenological stages of rice and to other strategic crops in the region.
- Complement RGB cameras with multispectral or hyperspectral sensors in future studies to improve sensitivity to specific spectral variations.
- Integrate results into local precision agriculture programs, strengthening decision-making on irrigation and fertilization.
- Promote training of technicians and producers in the use of remote sensing tools (QGIS, drones, Sentinel-2) to ensure sustainability and replicability.

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