Individualization of Banana Canopies Using Multispectral Vegetation Index and the Watershed Algorithm

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A paper from the Proceedings of the

17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture

13-15 July 2026

Porto Alegre, Brazil

Abstract.

The individualization of canopies in perennial crops is an essential step in precision agriculture, enabling plant counting, vigor monitoring, yield prediction, pest management, and harvest planning. Banana (Musa spp.), characterized by large leaves, closed canopy, and high biomass, presents specific challenges for automated segmentation. This study evaluated the performance of the watershed algorithm for canopy individualization, using different multispectral vegetation index, between them NDVI (Normalized Difference Vegetation Index), EVI2 (2-band Enhanced Vegetation Index), and NDRE (Normalized Difference Red Edge Index), combined with the Canopy Height Model (CHM). Multispectral images were acquired using a DJI Mavic 3M unmanned aerial vehicle (UAV) and processed in Agisoft Metashape, generating orthomosaics, a Digital Surface Model (DSM), and a Digital Terrain Model (DTM). Vegetation indices were calculated in Python from the Green, Red, RedEdge, and Near Infrared (NIR) bands. The CHM was obtained as the difference between the DSM and DTM, resampled to the same spatial resolution. Binary masks were generated based on specific thresholds for each index and combined with the CHM to exclude exposed soil and understory vegetation. To segment connected canopies, the distance transform was applied followed by the watershed algorithm, which interprets the image as an inverted topography: peaks correspond to canopy centers, while valleys delineate their edges. The watershed "floods" image from local peaks, separating connected regions and enabling individual plant delineation. Adjustments to the minimum distance between peaks were made to optimize segmentation in dense canopies. The analysis revealed differences among the indices. NDVI exhibited saturation in closed-canopy areas, connecting adjacent crowns and resulting in under-segmentation. EVI2, although less saturated, maintained lateral connectivity between crowns, limiting separation in dense canopies. NDRE fragmented the canopy more effectively, generating a higher number of local peaks prior to watershed application, due to the RedEdge band's sensitivity to chlorophyll variations, which preserves internal canopy heterogeneity and facilitates structural segmentation. The results indicate that in banana plantations with high biomass, Red-band-based index (NDVI and EVI2) lose internal contrast and connect adjacent plants, whereas NDRE maintains spectral and morphological variation, making it more suitable for canopy delineation. The integration of NDRE with the CHM effectively reduced noise from exposed soil and understory vegetation, *approximating the number of segmented canopies to that observed in the study area. Thus, it is concluded that the combination of NDRE with the CHM and the application of the watershed algorithm constitutes a robust and precise approach for banana canopy individualization, providing a valuable tool for precision agriculture applications.*

Keywords.
UAV, Multispectral Vegetation Index, Canopy Segmentation.

Introduction

Precision Agriculture (PA) requires technologies for acquiring and analyzing georeferenced data to characterize crop spatial variability and support site-specific decision-making. Among the technologies employed in PA, UAV have gained prominence due to their ability to acquire high-resolution imagery (Velusamy et al., 2022). The integration of UAV platforms with multispectral sensors allows the extraction of spectral and structural information from crops, facilitating the monitoring of plants, health, growth, productivity, and environmental conditions (Weiss et al., 2020).

In perennial crops, the individualization of plants from aerial imagery is a fundamental step for several agricultural applications, including plant counting, estimation of plant density, detection of missing plants, and vigor assessment. Accurate identification of individuals plants enables a more detailed understanding of crop variability and contributes plants to more efficient management practices. However, the segmentation of individual canopies remains a challenging task, particularly in crops characterized by dense vegetation and overlapping crowns. Banana (*Musa ssp.)* is one of the most important fruit crops worldwide, playing a significant economic and social role, especially in tropical and subtropical regions. Brazil is among the major banana-producing countries. Nevertheless, banana plantations present specific characteristics that complicate the automatic detection and delineation of individual plants using remote sensing data. The large leaf area, high biomass accumulation, closed canopy structure, and asynchronous plant development often result in overlapping crowns and spectral similarity among neighboring plants, masking individual canopy separation difficult (Aeberli et al., 2021; He et al., 2023).

Vegetation indices derived from multispectral imagery have been widely used to characterize crop conditions and support vegetation mapping (Radoˇcaj, et al., 2023, Pipatsitee et al., 2023). Among the most applied indices are the Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974), The Enhanced Vegetation Index 2 (EVI2) (Jiang et al., 2008), and the Normalized Difference Red Edge Index (NDRE) (Barnes et al., 2000). While NDVI and EVI2 are effective for general vegetation monitoring, they may exhibit saturation in dense canopies, reducing their ability to distinguish structural variations within dense crops. In contrast, NDRE incorporates information from the red-edge region of the electromagnetic spectrum, which is more sensitive to chlorophyll content cand canopy structure, potentially improving vegetation discrimination in high-biomass environments.

In addition to spectral information, structural information derived from photogrammetric products can enhance vegetation segmentation. The CHM, obtained from the difference between the DSM and the DTM, provides information about vegetation height and contributes to the separation of crop canopies from soil and vegetation. The integration of spectral and structural datasets has shown potential for improving object-based image analysis and individual plant detection (Aeberli et al., 2021). Among the available segmentation techniques, the watershed algorithm has been extensively applied in image analysis due to its ability to separate connected objects based on topographic principles (Bieniek et al., 2000). By interpreting an image as a relief surface, the algorithm identifies suitable for separating adjacent plant canopies. However, this performance depends on the quality of the input data and the characteristics of the vegetation indices used to generate the segmentation markers.

Therefore, this study aimed to evaluate the performance of the watershed segmentation algorithm for banana canopy individualization using different multispectral vegetation indices (NDVI, EVI2, and NDRE) integrated with a Canopy Height Model derives from UAV imagery. The study also investigates the influence of spectral and structural information on canopy delineation and assesses the suitability of these approaches for precision agriculture application in banana plantations.

Methodology

Study Area

The study area was in an experimental field of the Agency for Agribusiness Technology (APTA), located in the city of Pariquera-Açu, São Paulo State, in Brazil, within the popular name the Vale do Ribeira region. The experimental area comprised approximately 0.6 ha cultivated with banana (Musa ssp., Prata subgroup), a crop of significant economic importance in the region. The plantation presents a dense canopy structure and plants at different developmental stages, resulting in considerable variability in canopy size and height. These characteristics make the area suitable for evaluating methodologies aimed at individual plant detection and canopy delineation from aerial imagery (Figure 1).

Fig 1. Experimental area

UAV Data Acquisition and Photogrammetric Processing

Aerial data acquisition was performed using a DJI Mavic Multispectral (DJI Enterprise, 2023) an unmanned aerial vehicle equipped with both RGB and multispectral sensors. The flight mission was conducted at an altitude of 40 m above ground level, using 70% forward overlap and 80% side overlap to ensure adequate image coverage and photogrammetric reconstruction. A total of 265 images were acquired during the flight operation, which lasted approximately five minutes. Prior to mage acquisition, radiometric calibration was performed using a Parrot Sequoia calibration panel to improve the consistency of reflectance values among the multisectoral bands. The multispectral sensor provides information in the Green, Red, Red Edge, and Near Infrared (NIR) spectral regions, which were subsequently used for vegetation index calculation and crop characterization.

The acquired images were processed using Agisoft Metashape Professional version 2.2.2. The photogrammetric workflow included image alignment, point cloud generation, digital surface reconstruction, and ortomosaico generation. The RGB ortomosaico was used for visual interpretation, while the multispectral orthomosaic provided the spectral information required for vegetation index computation. The Digital Surface Model (DSM) and Digital Terrain Model (DTM) were used to derive structural information related to crop height. Further, all raster products were exported and processed in the Python programming environment for canopy segmentation and individual plant detection.

Vegetation Indices

The multispectral orthomosaic was imported into the Python programming environment. Vegetation indices were calculated using reflectance values from the Green, Red, Red Edge, and Near Infrared (NIR) bands. Three vegetation indices were evaluated in this study: the NDVI (Equation 1), the EVI2 (Equation 2), and NDRE (Equation 3). These indices were selected due to their widespread use in vegetation monitoring and their potential to characterize canopy vigor and structure. The resulting vegetation index maps were used as spectral information for canopy detection and segmentation. The indices were calculated according to Equations 1-3.

$$NDVI = (NIR - Red)/(NIR + Red) \tag{1}$$

$$EVI2 = 2.5 \times (NIR - Red)/(NIR + 2.4 \times Red + 1) \tag{2}$$

$$NDRE = (NIR - RedEdge)/(NIR + RedEdge) \tag{3}$$

Canopy Height Model (CHM)

Structural information's was incorporated through the generation of a CHM, that was obtained by Equation (4). Prior to subtraction, both raster products were resampled to the same spatial resolution to ensure spatial compatibility. A minimum height threshold of 1.2 meters was subsequently applied to remove exposed soil understory vegetation, and other low objects that could interference with canopy delimitation.

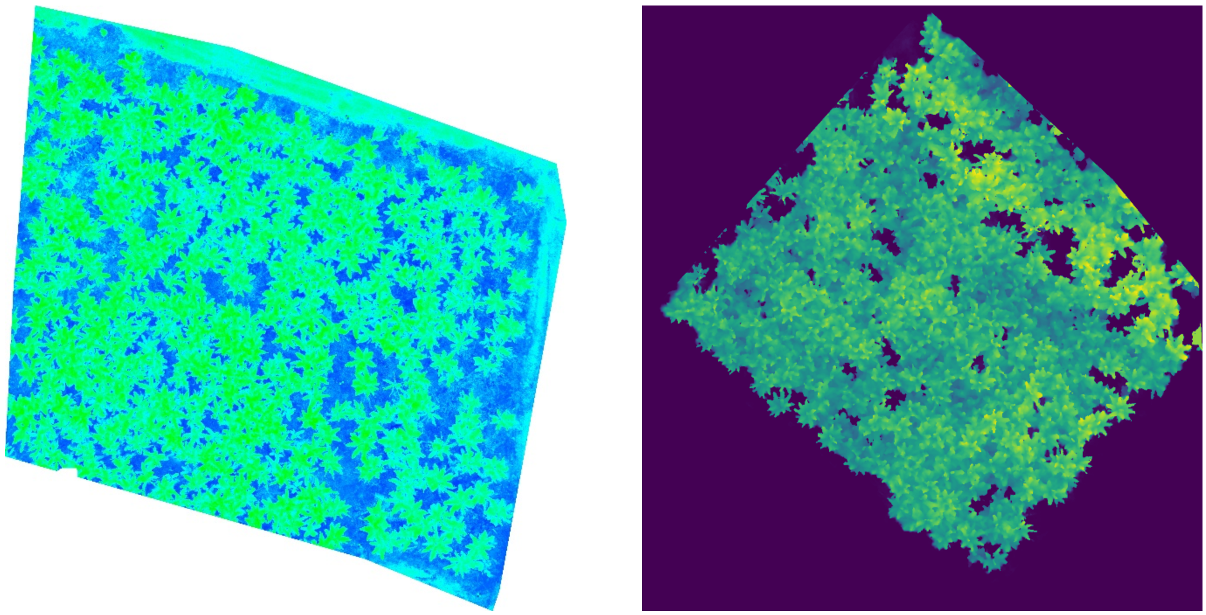
$$CHM = DSM - DTM \tag{4}$$

Canopy Segmentation and Individual Plant Detection

For each vegetation index, a binary vegetation mask was generated and combined with the corresponding CHM mask. To reduce artificial connections between adjacent canopies, a morphological erosion operation using a 3x3 structural element was applied. Subsequently, the Euclidean Distance Transform was computed to identify potential canopy centers. The distance transform assigns to each pixels its distance from the from the nearest canopy boundary, production local maxima that correspond to potential plant centers. These local maxima were used as markers for the watershed segmentation algorithm. The watershed method interprets the distance map as an inverted topographic surface, where peaks correspond to canopy centers and valleys represent canopy boundaries. Starting from the identified markers, the algorithm simulates a flooding process that progressively separates connected regions and delineates individual plant canopies. Following segmentation, small objects considered noire were based on a minimum height threshold. Finally, the geometric center of each segmented canopy was converted into geographic coordinates using the raster spatial transformation, enabling the generation of a shapefile containing the individual location of each detected banana plant.

Results and Discussion

The multispectral orthomosaic provides a detailed representation of the banana crop, allowing the visualization of canopy distribution and variability of the area (Figure 2a). Differences in canopy size and plant development stage were observed, reflecting the asynchronous growth pattern commonly found in banana crops. The CHM generated from represents the vertical structure of the crop and enables the discrimination of banana plants from exposed soil and low vegetation (Figure 2b). The application of a minimum height threshold reduced the influence of understory vegetation and background elements, improving the quality of the segmentation data.



(a) (b)

Fig 2. Processing area: in (a) multispectral orthomosaic and (b) CHM.

The integration of vegetation indices with the CHM generated binary masks that isolated the banana canopy while minimizing interference from non-target objects. However, significant differences were observed among the evaluated indices regarding canopy representation and subsequent segmentation performance. For NDVI, the binary mask produced extensive connectivity among neighboring plants (Figure 3a). The high biomass and closed canopy structure of the banana plantation resulted in spectral saturation, reducing internal variability within the canopy and causing adjacent plants to appear as continues vegetation patches. This behavior limited the generation of local maxima in the inverted Euclidian Distance transform (Figure 3d), reducing the numbers of markers available for watershed segmentation. Consequently, the final segmentation detected only one canopy object (Figure 3g), despite the presence of approximately 300 plants in the study area. These results demonstrate severe under-segmentation and confirm the limitation of NDVI for canopy individualization in dense banana plantations (Vera-Esmeraldas et al 2025).

A similar pattern was observed for EVI2 (Figure 3b). Although this index reduced part of the saturation effect observed for NDVI and provided greater contrast within the canopy, neighboring banana plants remained laterally connected, particularly in regions characterized by canopy overlap. The distance transform generated a larger number of local maximum than NDVI (Figure 3e), but canopy connectivity still restricts complete plant separation. As a result, the watershed segmentation identified 24 individual plants (Figure 3h), representing an improvement compared to NDVI but still substantially the number of plants observed in the field. These findings indicate that EVI2, despite improving vegetation discrimination, was unable to preserve sufficient internal variability to support accurate canopy delineation.

In contrast, NDRE produced a markedly different canopy representation (Figure 3c). The index preserved grater spectral heterogeneity within the plantation and enhanced distinction between adjacent plants. The incorporation of the red-edge spectral band increase sensitivity to variations in chlorophyll concentration and canopy structure, generating a substantially larger number of local maxima in the inverted distance transform (Figure 3f). This characteristic facilitated marker generation prior to watershed application and improved the separation of connected canopy regions.

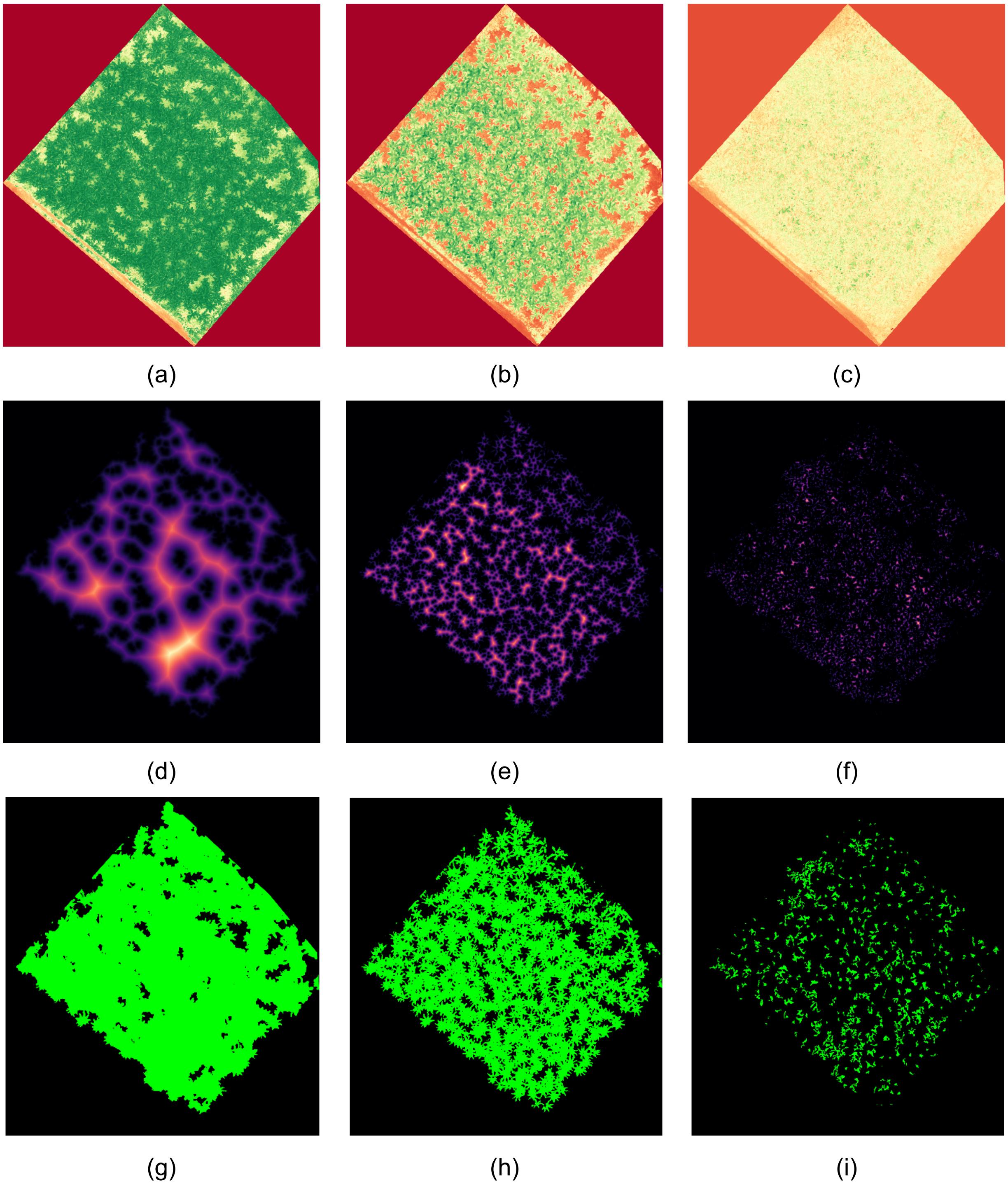


Fig 3. Binary masks generated from (a) NDVI, (b) EVI2, and (c) NDRE. Corresponding inverted Euclidean distance transforms shown in (d), (e), and (f), respectively. Watershed segmentation results obtained from each vegetation index are presented in (g), (h), and (i).

The watershed segmentation derives from NDRE (Figure 3i) dated 292 individual plants using a minimum distance parameter of 57 pixels. Considering that approximately 300 banana plants were present in the study area, the segmentation closely approximated field observations. The larger number of local peaks generated from NDRE demonstrated its ability to preserve internal canopy heterogeneity and provide suitable markers for structural segmentation. Table 1 presents the minimum distance values and the number of plants identified using the different vegetation indices.

Table 1. Minimum distance parameter and corresponding number of plants detected for each vegetation index.

Vegetation Index	Minimum Distance	Plants Detected
NDVI	21	2
EVI2	48	24
NDRE	57	292

The superior performance of NDRE can be attributed to the characteristics of the red-edge spectral region. While NDVI and EVI2 are based on the red band tend to lose sensibility in high-biomass environments, NDRE remains responsive to variations in chlorophyll content and canopy architecture. Consequently, NDVI and EVI2 generated connected canopy regions with limited internal contrast, whereas NDRE maintained both spectral and morphological variability, facilitating the separation of adjacent crown and improving watershed performance (Veras-Esmeraldas et al., 2025). The integration of CHM information proved essential for all evaluated indices (Weiss, et al., 2020). The application of height threshold effectively reduced noise associated with exposed soil, understory vegetation, and low-high artifacts, restricting the analysis to regions corresponding to banana plants. This combination of spectral and structural information increased the robustness of the segmentation workflow and contributed to more reliable canopy delineation.

Conclusion

Overall, the results indicates that vegetation indices based on the red spectral region are not suitable for individual banana plants in dense high-biomass plantation due to saturation effects and canopy structure, generated a larger number of segmentations market and produced delineations thar closely matched filed observations. Therefore, the integration of NDRE with CHM and the application of the watershed algorithm constitute a robust and precise approach for banana canopy individualization, proving a valuable tool for crop inventory, planting density estimation, and precise agriculture applications.

Acknowledgments

The authors would like to thank Fapesp (Proc. 2022/09319-9; Proc. 2025/01992-4) for the funding. The authors thank to researcher area APTA – Pariquera-Açu for allowing image acquisition.

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