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Detection of plants with *xylella fastidiosa* in olive orchards using aerial multispectral, thermal imagery and machine learning

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Abstract.

Early detection of Xylella fastidiosa in olive orchards remains a significant phytosanitary challenge due to the difficulty of identifying infected plants during the initial symptom development phase. Remote sensing using unmanned aerial vehicles (UAVs) combined with machine learning techniques offers a scalable approach for disease monitoring at field scale. This study evaluated the potential of spectral indices derived from multispectral and thermal imagery for classifying the occurrence of Xylella fastidiosa in a commercial olive orchard. Aerial surveys were conducted using a Matrice 350 RTK plataform equipped with a MicaSense Altum-PT multispectral and thermal sensor. Flights were performed in February 2025, September 2025, and February 2026 at an altitude of 60 m above ground level, with 85% forward and side overlap to ensure radiometric and geometric consistency. Radiometrically calibrated orthomosaics were generated through photogrammetric processing, and 56 spectral indices associated with canopy vigor, chlorophyll content, structural properties, and physiological responses to plant stress were computed. Ground truth data were obtained through field phytosanitary inspections. Each tree was visually evaluated for the presence or absence of characteristic branch dieback symptoms associated with Xylella fastidiosa. Trees exhibiting typical branch dieback symptoms were classified as infected, while asymptomatic trees were classified as healthy. This binary classification was used as the response variable for supervised machine learning models. Data preprocessing included variable selection and hyperparameter optimization. An optimal subset of 20 variables was identified, including RedEdge, NIR, and thermal bands, as well as vegetation indices such as NDRE, CCCI, EVI-2, OSAVI, SAVI, and MTCI. The development and evaluation of machine learning models were conducted through the following stages: (1) exploratory data analysis; (2) selection of the most significant variables through feature selection; (3) hyperparameter optimization; (4) model training; and (5) evaluation of model performance using accuracy, precision, recall, F1-score, and

ROC-AUC metrics on an independent test dataset. Ensemble-based classifiers were evaluated, including Random Forest, Gradient Boosting, XGBoost, and LightGBM. LightGBM achieved the best overall performance, with an accuracy of 0.66, precision of 0.67, F1-score of 0.54, and ROC-AUC of 0.62. Gradient Boosting showed higher sensitivity in detecting symptomatic plants (recall = 0.62), while the optimized Random Forest model achieved an accuracy of 0.53 and ROC-AUC of 0.52. Although these performance metrics are relatively moderate, they reflect the inherent complexity of identifying Xylella fastidiosa infections. A primary limitation is the challenge of distinguishing early-stage, asymptomatic, or mild symptoms from other biotic or abiotic stresses, whereas advanced symptoms present much clearer spectral signatures. Variable importance analysis indicated stronger contributions from red-edge–based indices, chlorophyll-sensitive metrics, and thermal information, confirming that physiological stress produces detectable alterations prior to severe canopy degradation. From a practical perspective, despite the moderate accuracy, this methodology provides actionable insights for decision-making. By mapping areas with a higher probability of infection, growers can prioritize targeted field scouting, optimize the sampling for molecular testing, and implement localized containment measures. Therefore, integrating UAV-based multispectral and thermal imagery with machine learning represents a valuable spatial screening tool that supports precision phytosanitary management in olive production systems.

Keywords.
Keyword: Spectral classification, Vegetation indices, Phytosanitary monitoring, UAVs

Introduction

The *Xylella fastidiosa* is considered one of the most destructive bacterial pathogens affecting olive production worldwide, causing Olive Quick Decline Syndrome (OQDS), which has led to severe economic, environmental, and cultural losses in Mediterranean olive-growing regions (Saponari et al., 2019; Schneider et al., 2021). The rapid spread of the pathogen and the difficulty of identifying infected trees during the early stages of infection make disease monitoring and containment particularly challenging.

Recent advances in precision agriculture have enabled the use of unmanned aerial vehicles (UAVs) equipped with multispectral and thermal sensors for large-scale crop monitoring. Previous studies have demonstrated that spectral and thermal information can detect physiological alterations associated with *X. fastidiosa* infection before severe visual symptoms become evident, providing a promising tool for early disease surveillance (Di Nisio et al., 2020; Castrignanò et al., 2021).

Combined with machine learning algorithms, UAV-based remote sensing offers the potential to improve disease detection and support precision phytosanitary management.

Therefore, this study aimed to evaluate the potential of spectral indices derived from multispectral and thermal imagery to classify the occurrence of *Xylella fastidiosa* in a commercial olive orchard.

Materials and methods

The study was conducted in a commercial olive orchard affected by *Xylella fastidiosa*. UAV surveys were performed using a Matrice 350 RTK platform (DJI, Shenzhen, China) equipped with a MicaSense Altum-PT sensor (MicaSense Inc., Seattle, USA), which integrates multispectral and thermal imaging capabilities. Data acquisition was carried out in February 2025, September 2025, and February 2026.

Flights were conducted at an altitude of 60 m above ground level with 85% forward and side overlap to ensure adequate image coverage and radiometric consistency. Multispectral and thermal imagery were processed through photogrammetric workflows to generate radiometrically calibrated orthomosaics. From these products, 56 spectral indices related to canopy vigor, chlorophyll content, structural characteristics, and plant stress responses were calculated. Ground truth information was obtained through field phytosanitary inspections, where individual olive trees were visually classified as healthy or infected based on the presence of characteristic branch dieback symptoms associated with *X. fastidiosa*. The resulting binary classification was used as the response variable for supervised machine learning analysis. Data preprocessing included exploratory analysis, feature selection, and hyperparameter optimization. An optimal subset of 20 variables was selected, including RedEdge, near-infrared (NIR), and thermal bands, as well as vegetation indices such as NDRE, CCCI, EVI-2, OSAVI, SAVI, and MTCI. Four ensemble-based machine learning algorithms were evaluated: Random Forest, Gradient Boosting, XG Boost, and Light GBM. Model performance was assessed using an independent test dataset and evaluated through accuracy, precision, recall, F1-score, and ROC-AUC metrics.

Results and discussion

Among the evaluated machine learning algorithms, Light GBM achieved the best overall performance for classifying *Xylella fastidiosa* occurrence, reaching an accuracy of 0.66, precision of 0.67, F1-score of 0.54, and ROC-AUC of 0.62. Gradient Boosting exhibited greater sensitivity for identifying symptomatic trees (recall = 0.62), whereas Random Forest showed lower predictive performance, with an accuracy of 0.53 and ROC-AUC of 0.52. Although the classification metrics were moderate, they demonstrate the potential of integrating UAV-based multispectral and thermal imagery with machine learning techniques for large-scale phytosanitary monitoring.

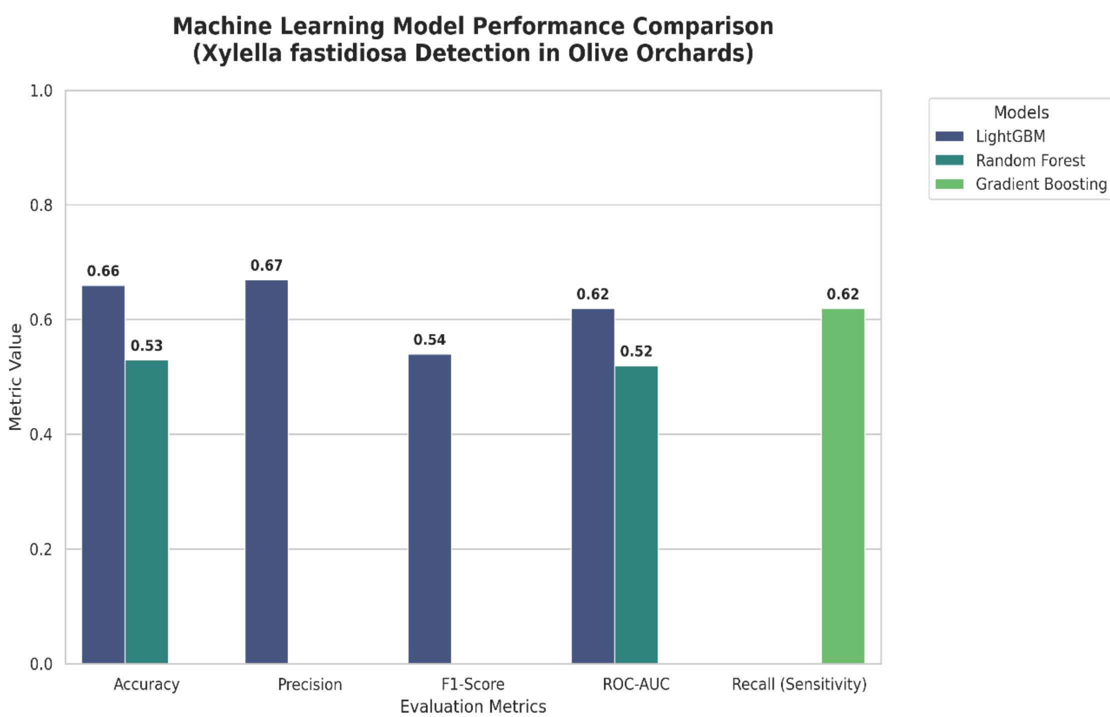

Figure 1: Performance comparison of machine learning models for *Xylella fastidiosa* detection in

olive orchards based on classification metrics.

Feature importance analysis revealed that variables associated with red-edge, near-infrared, and thermal wavelengths contributed most strongly to model performance. Vegetation indices such as NDRE, CCCI, EVI-2, OSAVI, SAVI, and MTCI were among the most relevant predictors, indicating that alterations in chlorophyll content, canopy structure, and plant temperature are closely associated with the physiological responses induced by *X. fastidiosa* infection. These findings are consistent with previous studies that reported the effectiveness of multispectral and thermal remote sensing for detecting stress-related changes in olive trees before severe visual symptoms become apparent (Di Nisio et al., 2020; Castrignanò et al., 2021).

The moderate predictive performance observed in this study reflects the inherent complexity of detecting early-stage infections. Asymptomatic or mildly affected trees often exhibit spectral responses similar to those caused by other biotic and abiotic stress factors, reducing model discrimination capability. In contrast, trees with advanced symptoms tend to present more distinct spectral and thermal signatures, facilitating classification. Nevertheless, the proposed methodology provides valuable information for precision phytosanitary management by enabling the identification of areas with a higher probability of infection, thereby supporting targeted scouting, optimized molecular sampling, and localized disease containment strategies.

Conclusions

The Variable importance analysis indicated stronger contributions from red-edge–based indices, chlorophyll-sensitive metrics, and thermal information, confirming that physiological stress produces detectable alterations prior to severe canopy degradation. From a practical perspective, despite the moderate accuracy, this methodology provides actionable insights for decision-making. By mapping areas with a higher probability of infection, growers can prioritize targeted field scouting, optimize the sampling for molecular testing, and implement localized containment measures. Therefore, integrating UAV-based multispectral and thermal imagery with machine learning represents a valuable spatial screening tool that supports precision phytosanitary management in olive production systems.

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