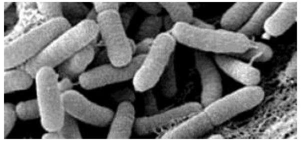
3rd European Conference on Xylella fastidiosa and XF-ACTORS final meeting

Using hyperspectral imagery and a multi-stage machine learning algorithm to distinguish infection symptoms caused by two xylem-limited pathogens

Poblete, T., Navas-Cortes, J.A., Camino, C., Calderón, R., Hornero, A., González-Dugo, V., Landa, B.B., Zarco-Tejada, P.J.

INTRODUCTION

***Xylella fastidiosa* and *Verticillium dahliae* infections trigger similar symptoms in olive trees**



Xylella fastidiosa (*Xf*)

Verticillium dahliae (*Vd*) Kleb

Both colonize vascular tissue →

Trigger similar symptoms

- General tree decline
- Foliar discoloration
- Wilting of apical shoots
- Dieback of twigs
- Dieback of branches

(Carlucci *et al*., 2013)

INTRODUCTION

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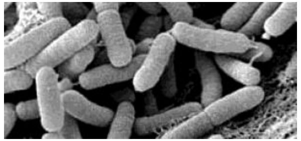

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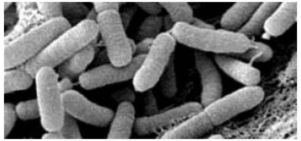
(Carlucci *et al.*, 2013)

Trees infected by *Xylella Fastidiosa*

Trees infected by *Verticillium dahliae*

INTRODUCTION

Symptoms triggered by both diseases can be confounded with water-induced stress responses



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Verticillium dahliae (*Vd*) Kleb

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Trigger similar symptoms

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- Dieback of branches

(Carlucci *et al*., 2013)

and similar

to water stress responses

Water induced stress

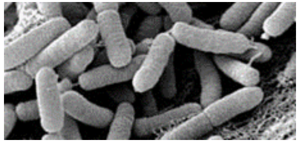
(Hopkins, 1989; Klosterman *et al*., 2009)

INTRODUCTION

Cost-effective approaches for large scale detection

Remote sensing technologies

Early detection



Xylella fastidiosa (*Xf*)

(Zarco-Tejada *et al.*, 2018)
(Poblete *et al.*, 2020)
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Verticillium dahliae (*Vd*) Kleb

(Calderón *et al.*, 2013)
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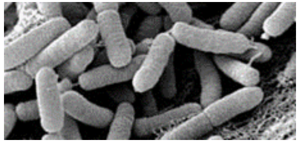

Xylella fastidiosa (*Xf*)

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(Hornero *et al.*, 2020)

Verticillium dahliae (*Vd*) Kleb

(Calderón *et al.*, 2013)
(Calderón *et al.*, 2015)

Nevertheless, no studies have attempted to discriminate symptoms caused by both pathogens

OBJECTIVE

1. To evaluate airborne **hyperspectral** and **thermal** imagery collected from ***Xf*-** and ***Vd*-infected** olive orchards to assess the potential **discrimination** of the physiological symptoms induced by each pathogen.

OBJECTIVE

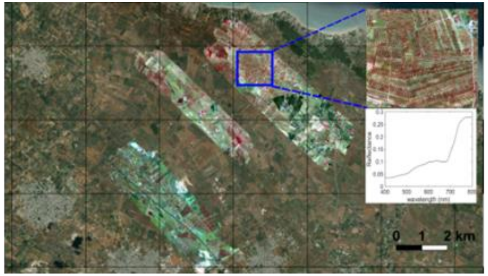
1. To evaluate airborne **hyperspectral** and **thermal** imagery collected from ***Xf***- and ***Vd*-infected** olive orchards to assess the potential **discrimination** of the physiological symptoms induced by each pathogen.

2. To assess the effect of plant **water status** on the detection of both diseases comparing **traits sensitive** to detect **water-induced stress** with those induced by the infections.

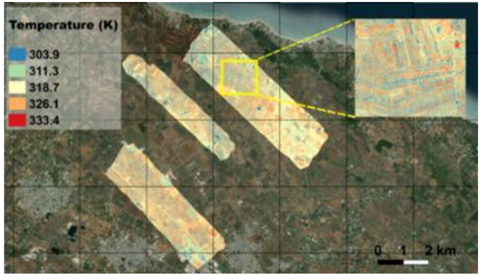
METHODOLOGY

Xylella fastidiosa infected zone

Puglia, Southern Italy



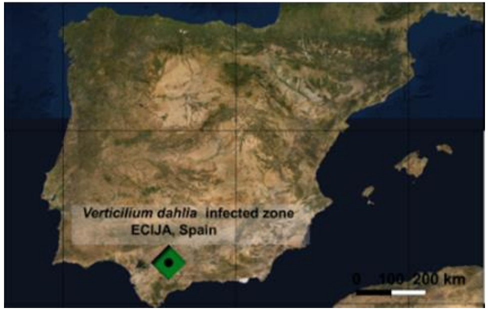
Hyperspectral imagery



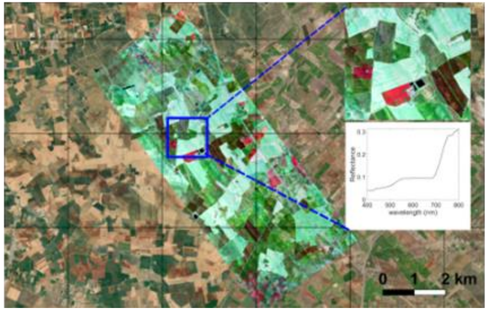
Thermal infrared imagery

- 15 olive orchards monitored
- 7296 olive trees assessed
- Monitored during 2016-2017

Verticillium dahliae infected zone



Castro del Río and Écija,
Southern Spain



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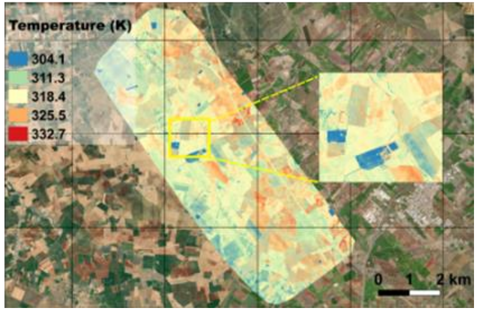


Thermal infrared imagery

- 11 olive orchards monitored
- 7101 olive trees assessed
- Monitored during 2011-2013

METHODOLOGY

Visual assessments of disease incidence and severity of olive trees infected by *Xf* and *Vd*

Asymptomatic (SEV=0)

Xylella Fastidiosa

Symptomatic (SEV=1)

Symptomatic (SEV=2)

Symptomatic (SEV=3)

Symptomatic (SEV=4)

Verticillium dahliae

Symptomatic (SEV=1)

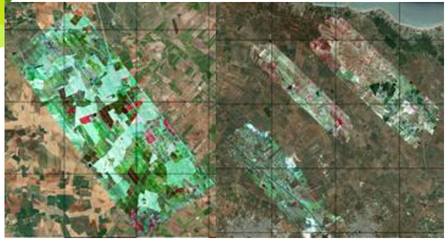
Symptomatic (SEV=2)

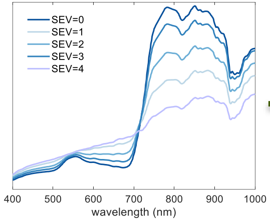
Symptomatic (SEV=3)

Symptomatic (SEV=4)

METHODOLOGY

Datasets and modelling parameters



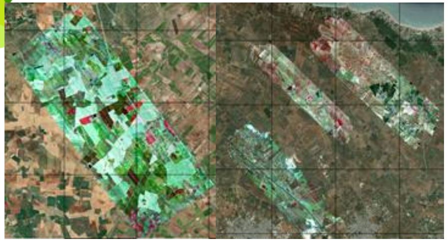


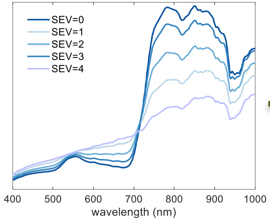
Hyperspectral imagery

Chlorophyll content **(C_{a+b})**
Anthocyanin content **(Anth.)**
Carotenoid content **(C_{x+c})**
Leaf Area Index **(LAI)**
Average leaf angle **(LIDF)**

METHODOLOGY

Datasets and modelling parameters





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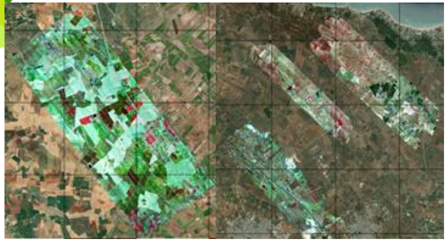
Radiative transfer model inversion
Support Vector machine (SVM)

METHODOLOGY

Datasets and modelling parameters



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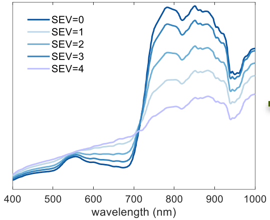

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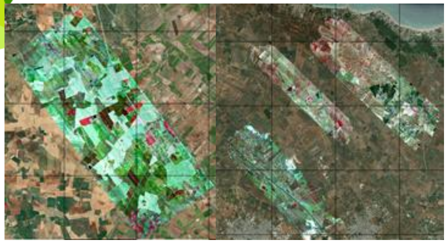
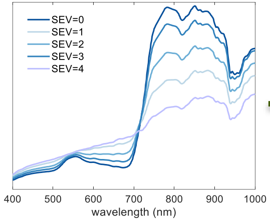
Radiative transfer model inversion

PRO4SAIL (PROSPECT-D + 4SAIL) (Feret *et al*., 2017 and Verhoef *et al*., 2007)

METHODOLOGY

Datasets and modelling parameters





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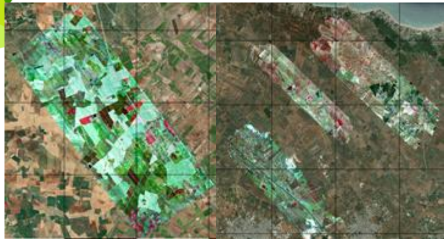
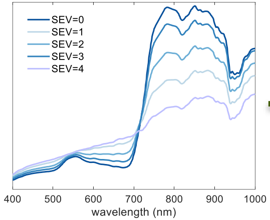
Sun-induced Chlorophyll Fluorescence **($SIF_{@760}$)**

O_2-A *in-filling* Fraunhofer line depth (FLD) method

METHODOLOGY

Datasets and modelling parameters





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Narrowband Hyperspectral Indices **(NBHI)**

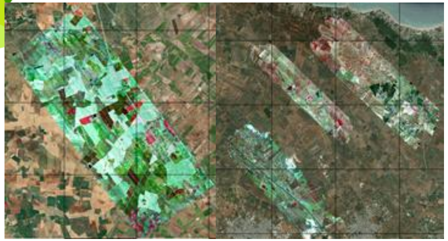
(Zarco-Tejada *et al*., 2018)

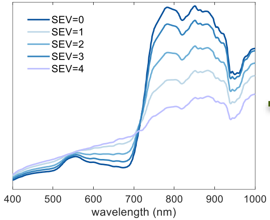
Variance Inflation Factor (VIF)

Non-collinear NBHI

METHODOLOGY

Datasets and modelling parameters





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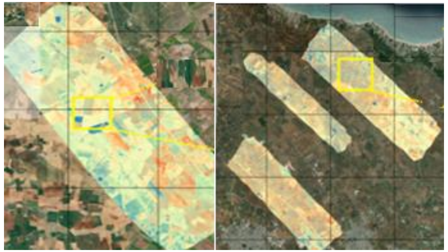
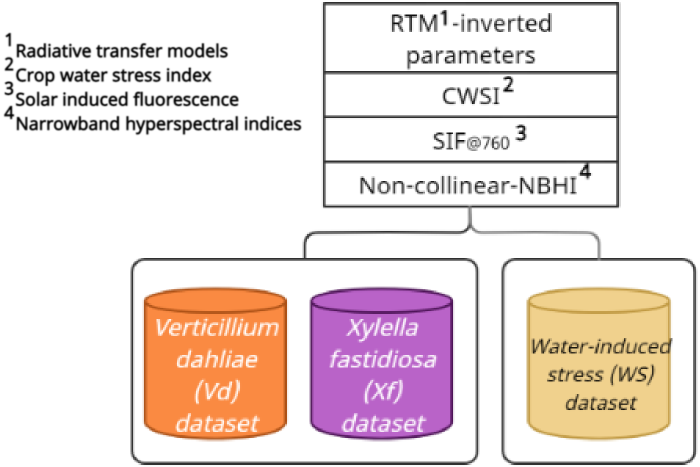


Thermal imagery

Crop Water Stress Index **(CWSI)**

METHODOLOGY

Datasets for the three-stage classification



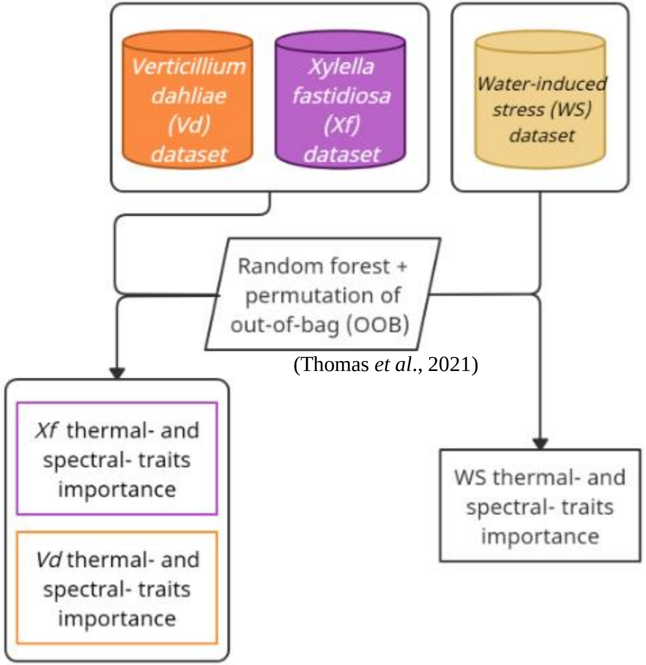
- **Independent datasets including the hyperspectral and thermal traits were built**
  - *Xylella fastidiosa* dataset

  - *Verticillium dahliae* dataset

  - Water-induced stress dataset

METHODOLOGY

Contribution of thermal and spectral traits on the detection



(Thomas *et al*., 2021)

- Contribution (importance) of each plant trait for detecting both infections and water-induced stress:

  - ***Xylella fastidiosa***

    Asymptomatic {**SEV**=0} vs. Symptomatic {**SEV**≥1} olive trees

  - ***Verticillium dahliae***

    Asymptomatic {**SEV**=0} vs. Symptomatic {**SEV**≥1} olive trees

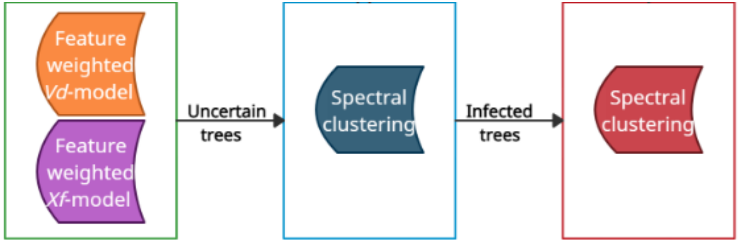
  - **Water-induced stress**

    Non-water stress vs. water-stress induced olive trees

METHODOLOGY

Feature-weighted models were built considering the traits importance

Stage I: Detection



Stage I
(Detection stage)

Feature-weighted classification models were implemented to include the importance of each trait on the detection of each disease

- ***Xylella fastidiosa feature-weighted model***

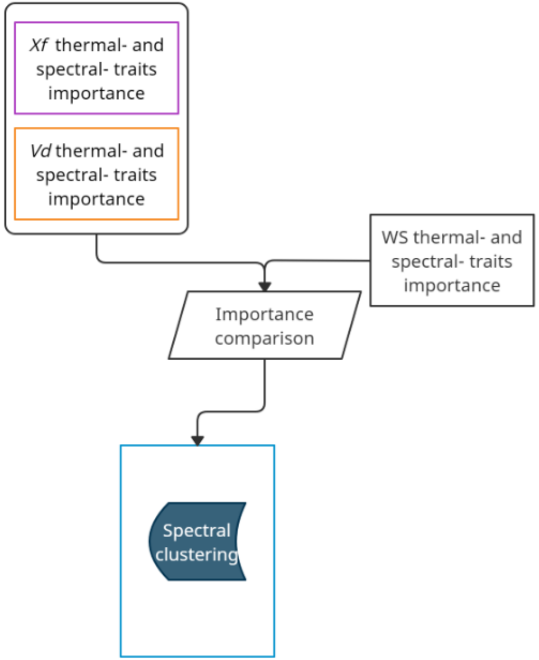
- ***Verticillium dahliae feature-weighted model***

METHODOLOGY

Reclassification of uncertain trees (Stage II)

To reduce the uncertainty produced by symptoms confounded with water-induced stress responses.

Stage II: Reclassification

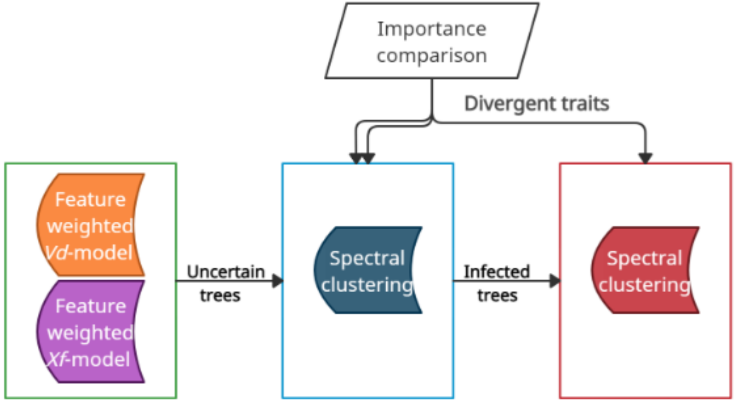


Stage II (Reclassification stage)

METHODOLOGY

Symptoms of trees detected as infected are compared to discriminate between both infections (Stage III)

Stage III: Discrimination



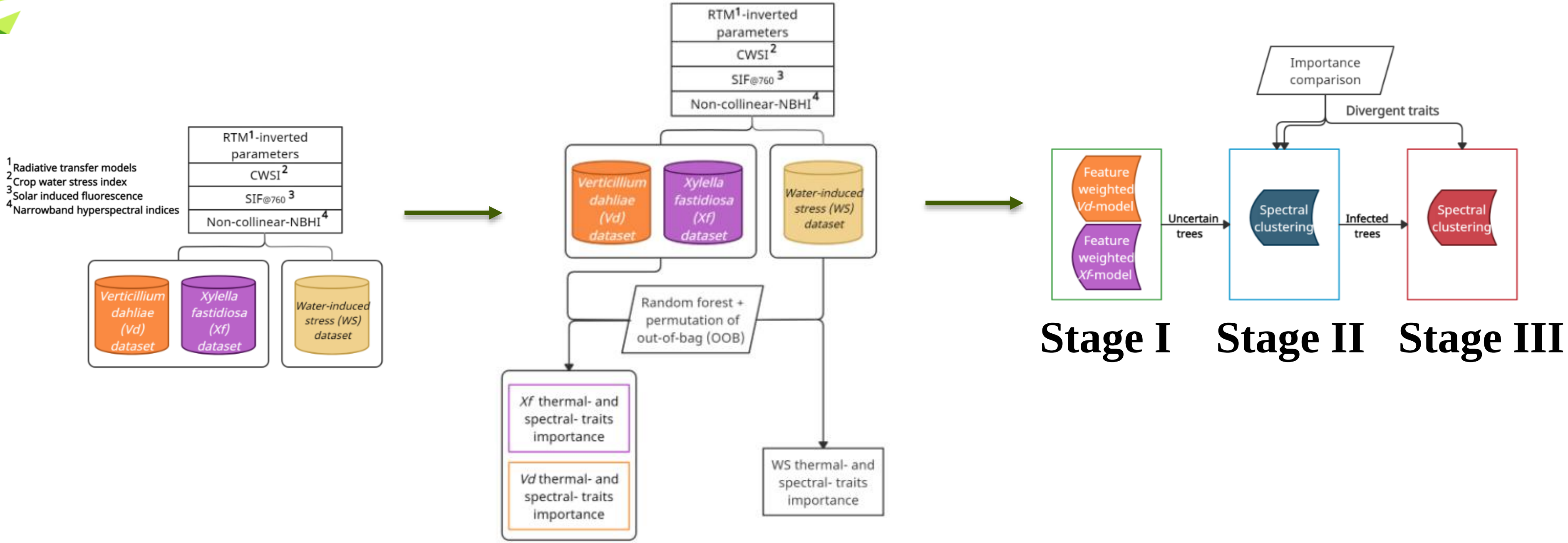
Stage III (Discrimination stage)

Divergent spectral traits were obtained to detect and discriminate:

- *Xylella fastidiosa* over *Verticillium dahliae* infected trees
- *Verticillium dahliae over Xylella fastidiosa* infected trees

METHODOLOGY

Schematic representation of the three-stages classification



(Thomas *et al.*, 2021)

METHODOLOGY

Assessing the accuracy on the detection and discrimination of both diseases

Sensitivity test

Sensitivity → Correctly identifying True Positives (TP) while avoiding False Negatives (FN)

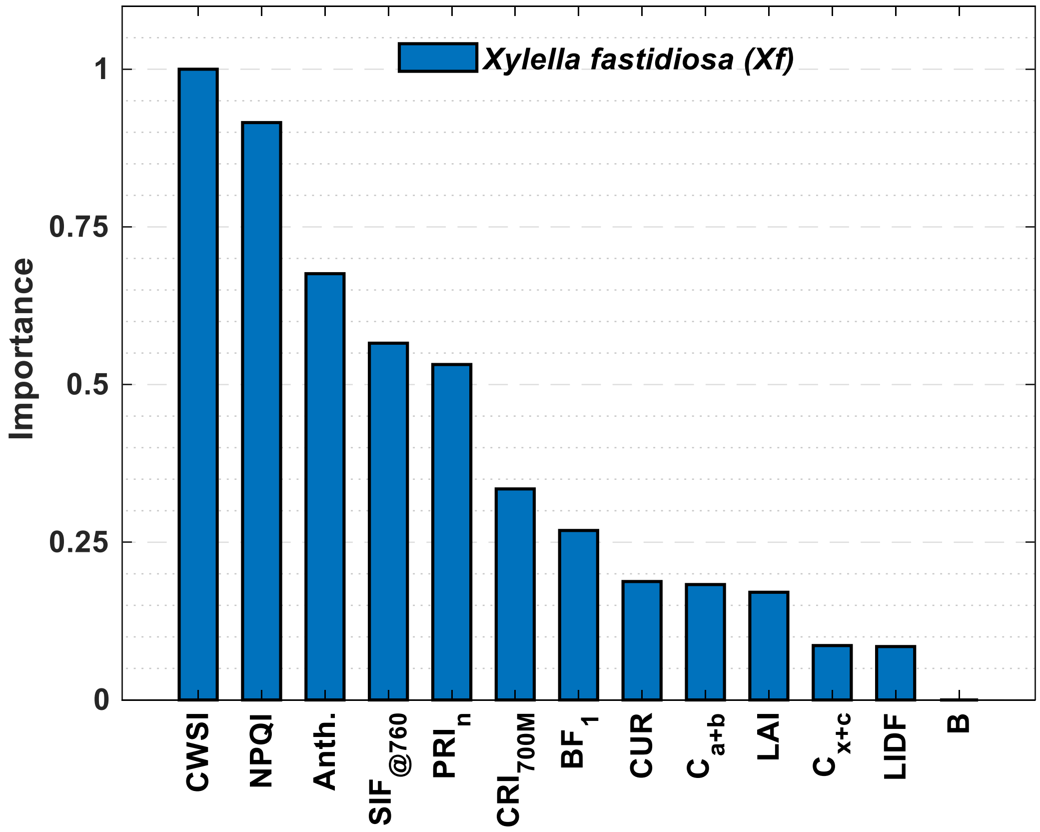
Specificity test

Specificity → Correctly identifying True Negatives (TN) while avoiding False Positives (FP)

Trevethan (2017)

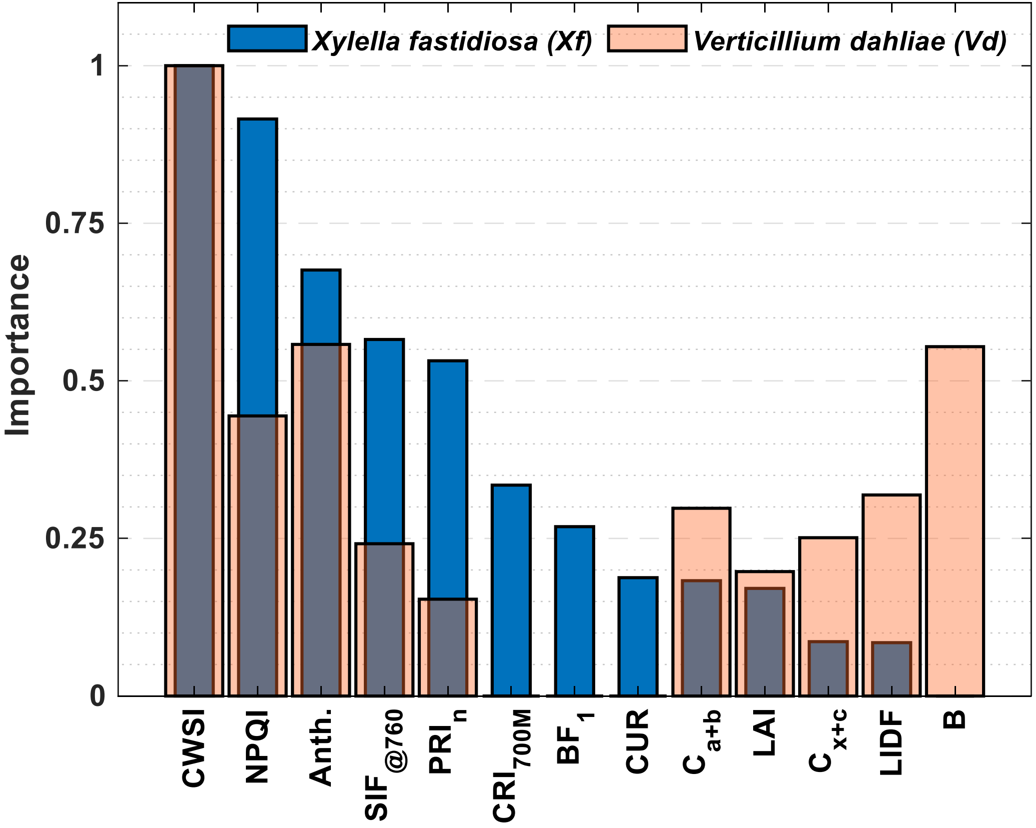
RESULTS

Importance of plant traits when detecting *Xf*–infected olive trees



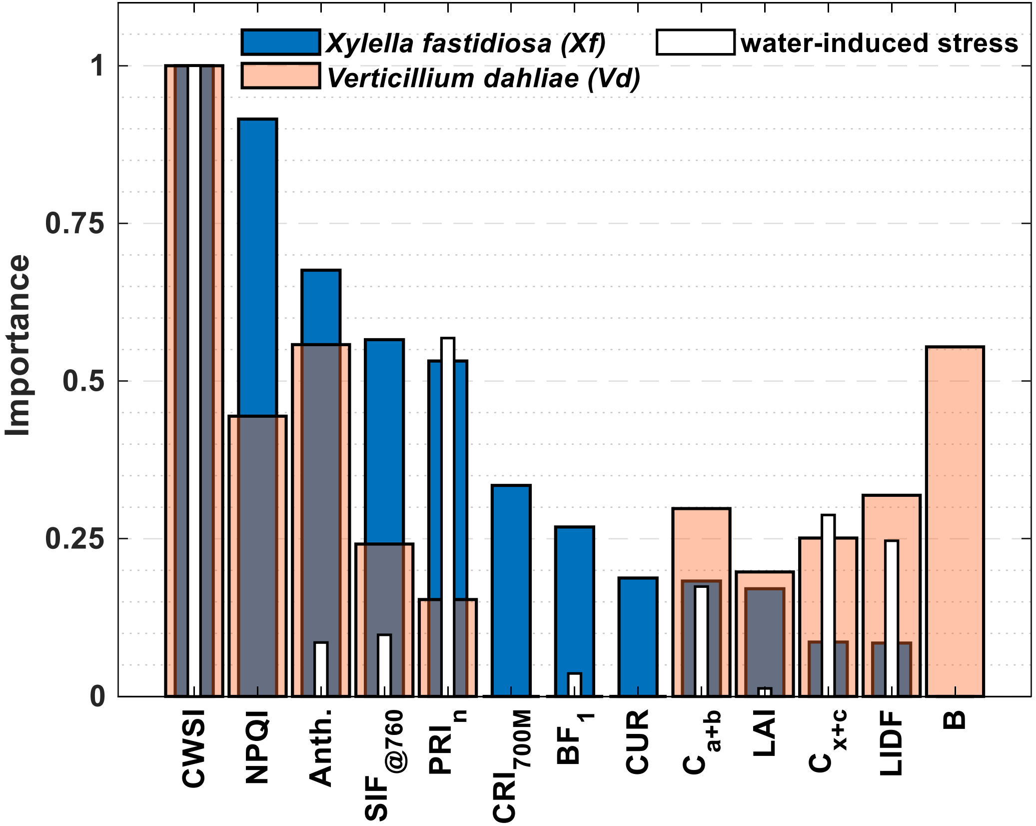
RESULTS

Importance of plant traits when detecting *Vd*–infected, *Xf*–infected olive trees



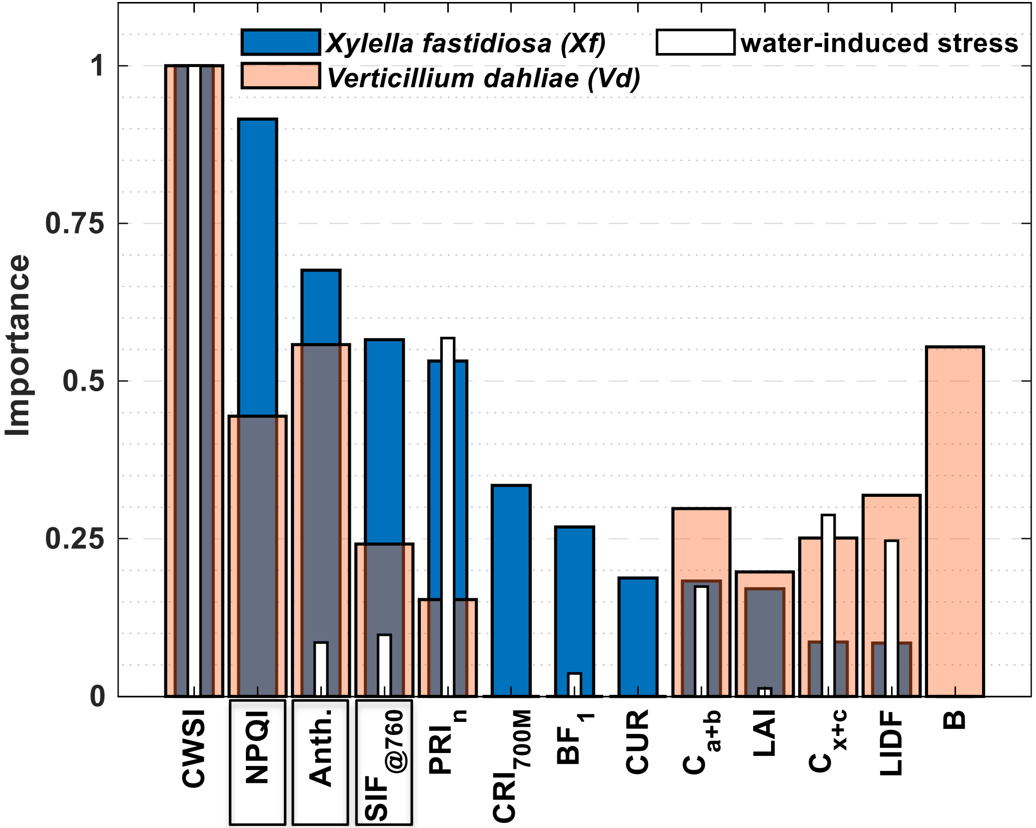
RESULTS

Importance of plant traits when detecting *Vd*–infected, *Xf*–infected, and water-stressed olive trees



RESULTS

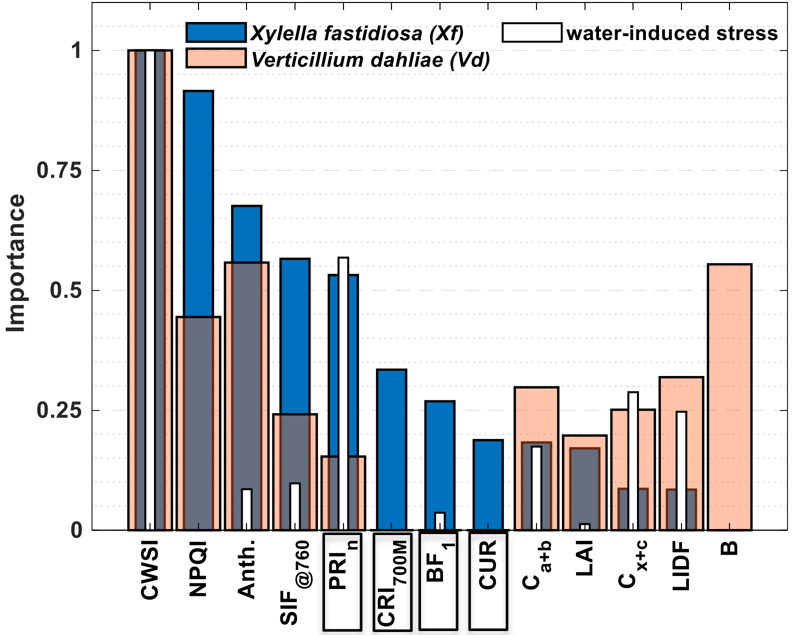
Plant traits used to differentiate both infections from water induced stress



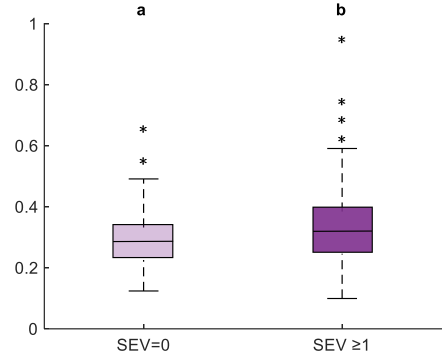
NPQI: *Normalized Phaeophytinization Index* **Anth.:** Anthocyanins content **SIF:** Solar Induced Fluorescence

RESULTS

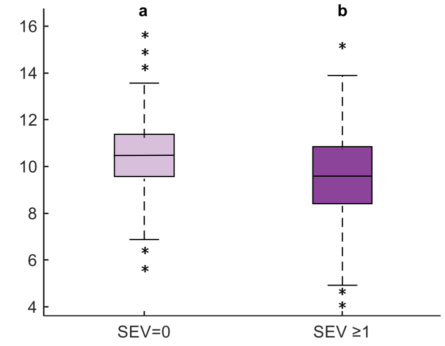
Plant traits used to differentiate *Xf*- over *Vd*- infections



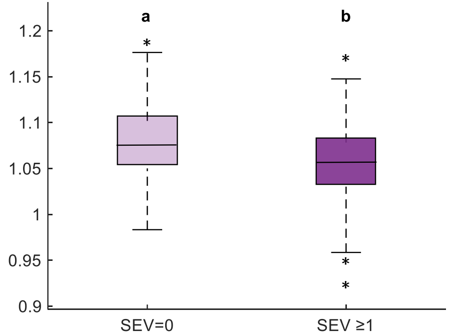
PRI_n



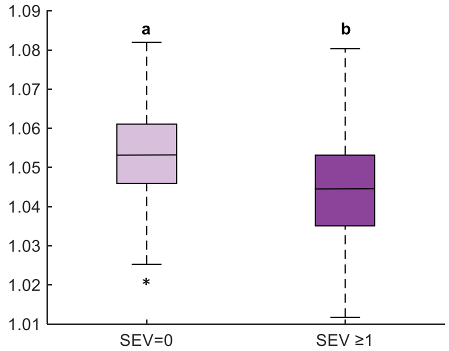
CRI_{700M}



BF_1



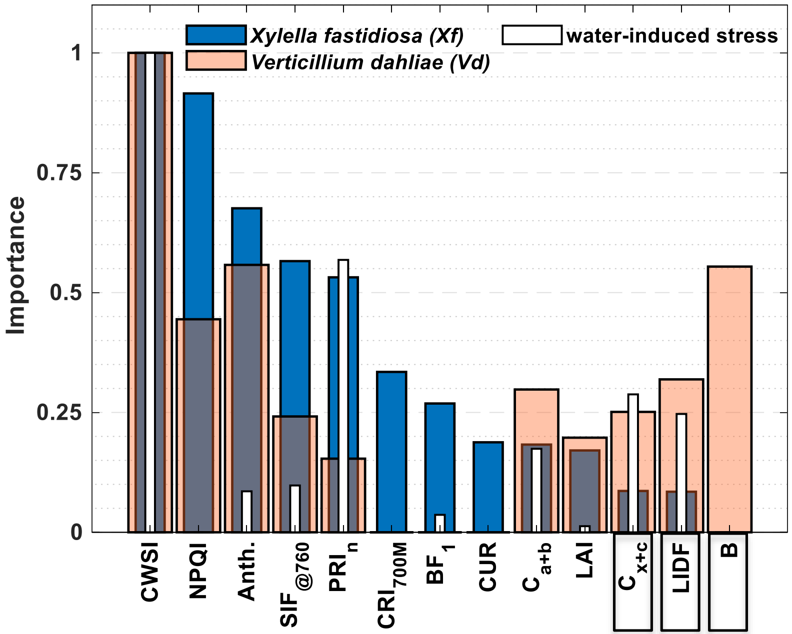
CUR

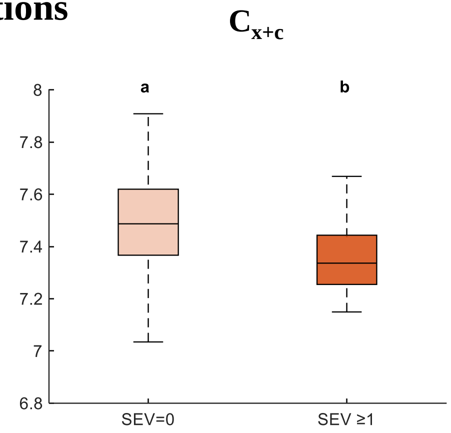


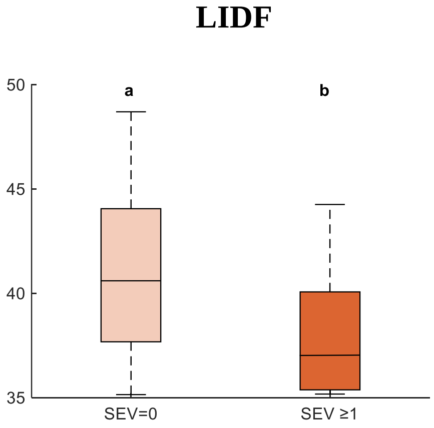
PRI_n: Normalized *Photochemical Refl. Index* **CRI_{700M}**: *Carotenoid Refl. Index* ***BF_1***: Blue Index ***CUR***: Refl. Curvature Index

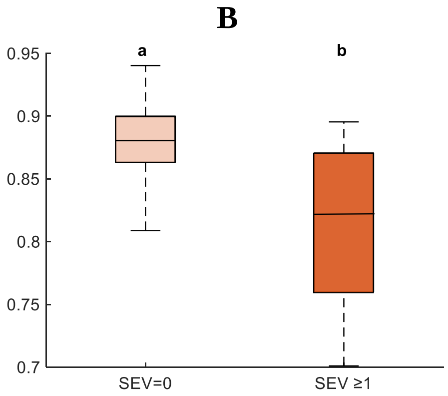
RESULTS

Plant traits used to differentiate *Vd*- over *Xf*- infections





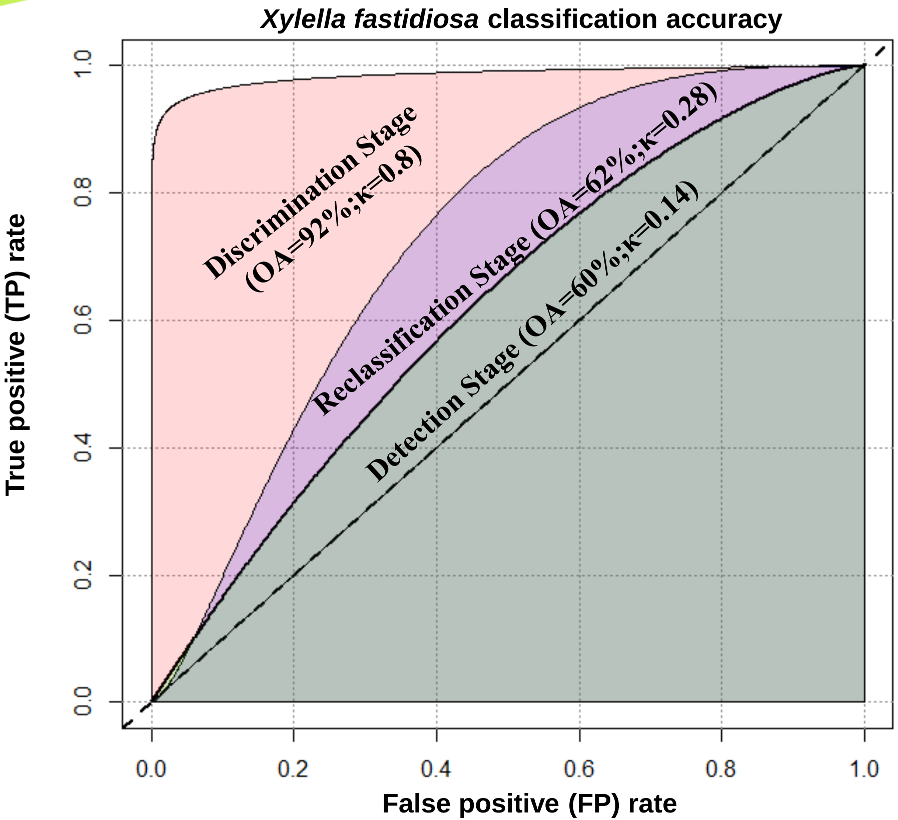




C_{x+c}: Carotenoids content **LIDF:** Average leaf angle ***B*:** Blue Index

RESULTS

Sensitivity tests for detecting *Xf*– and *Vd*–infected olive trees



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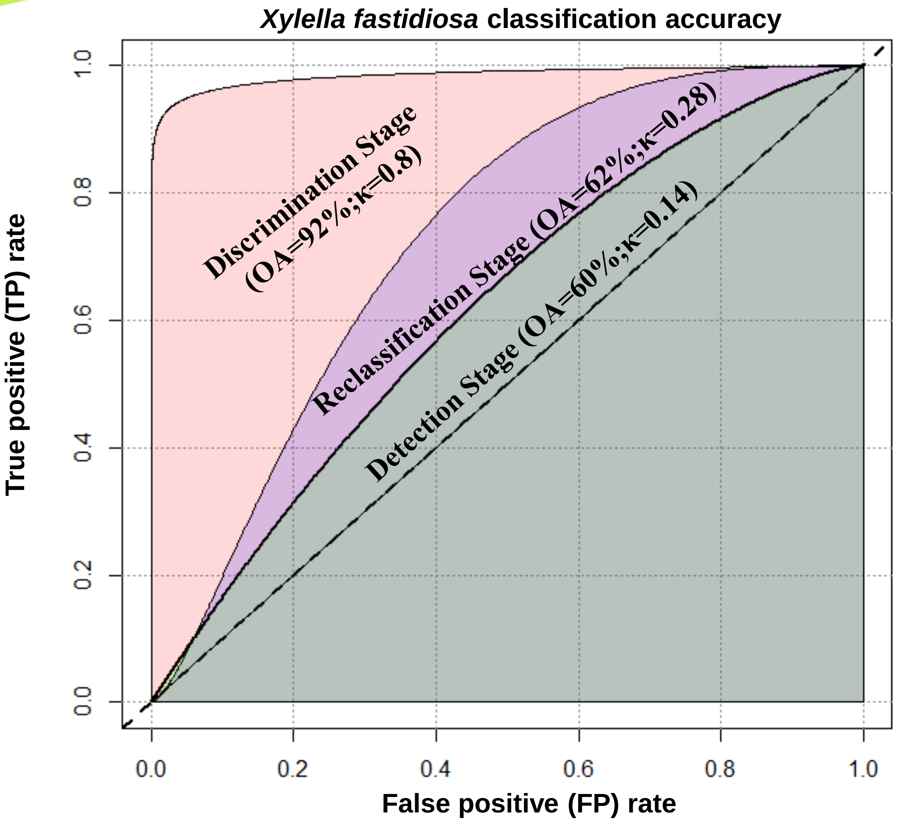
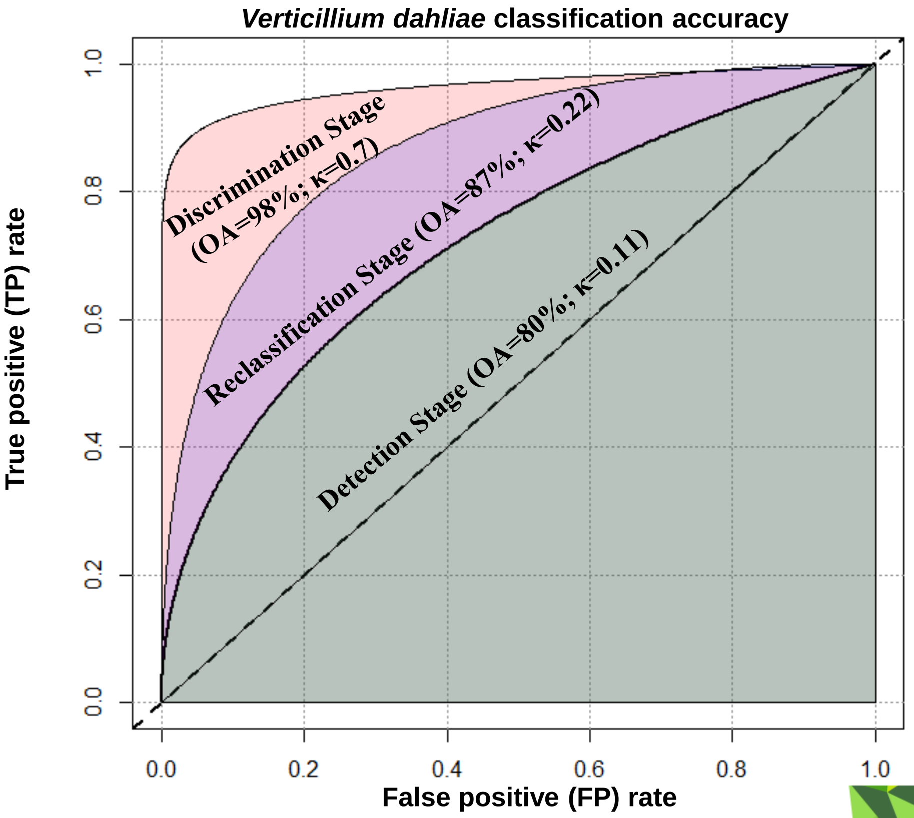
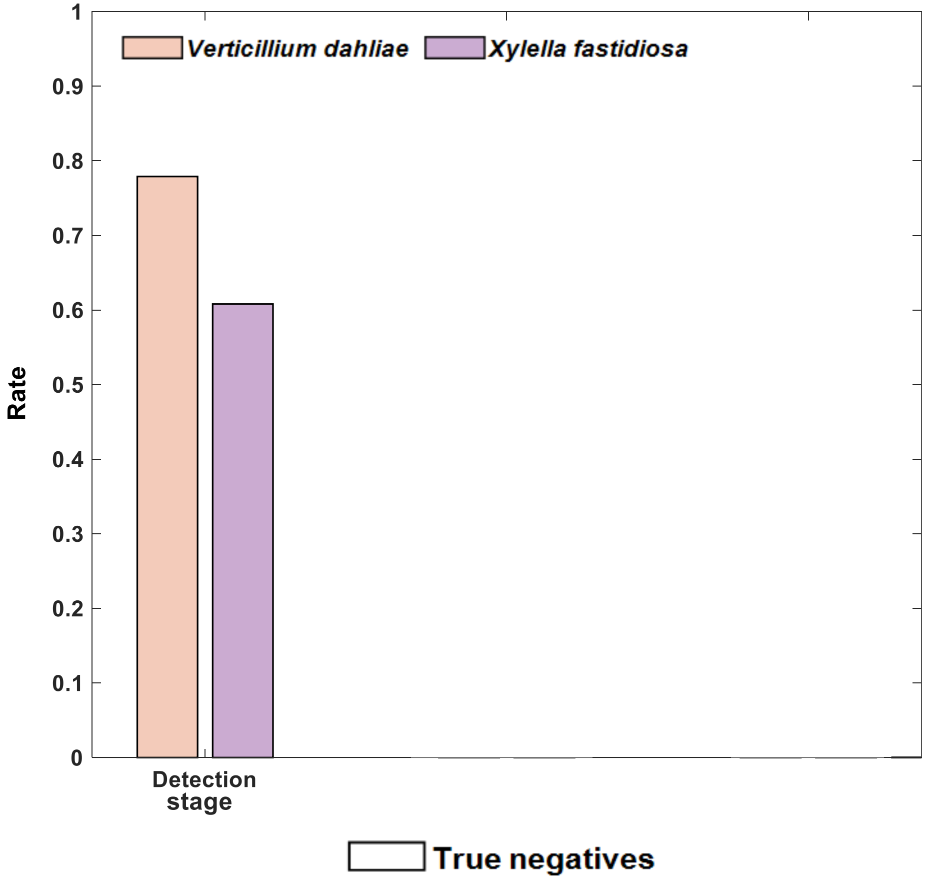




RESULTS

Specificity tests for detecting *Xf*– and *Vd*–infected olive trees (True negatives rate)



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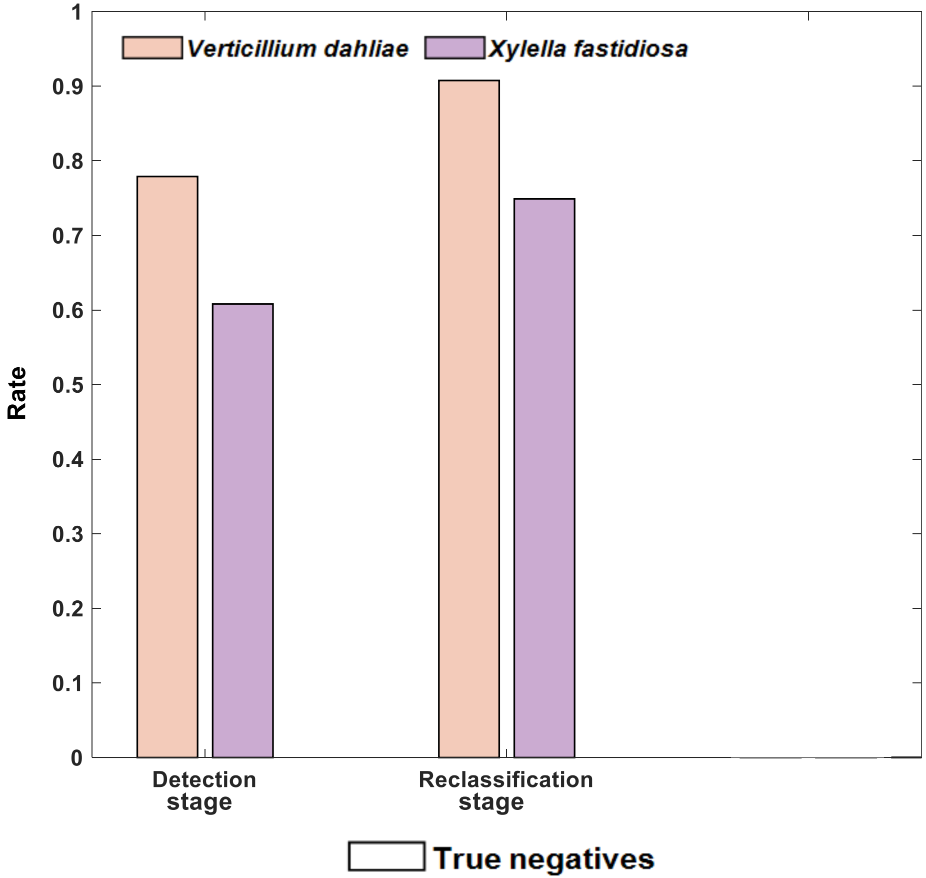

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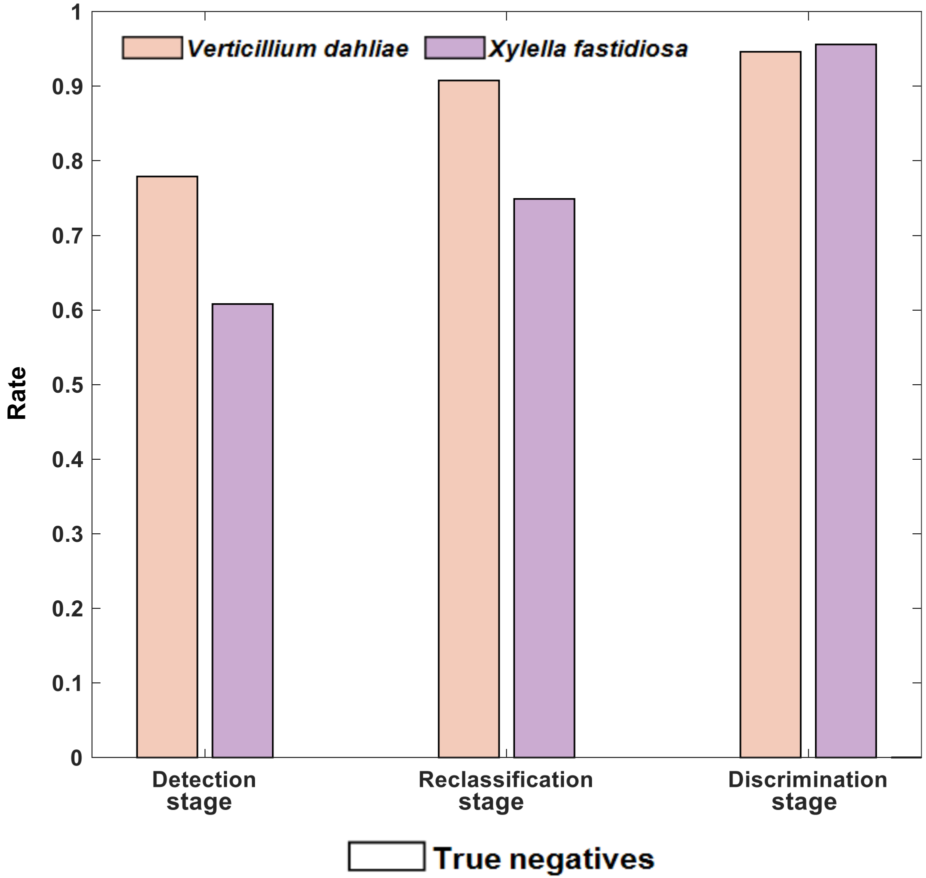
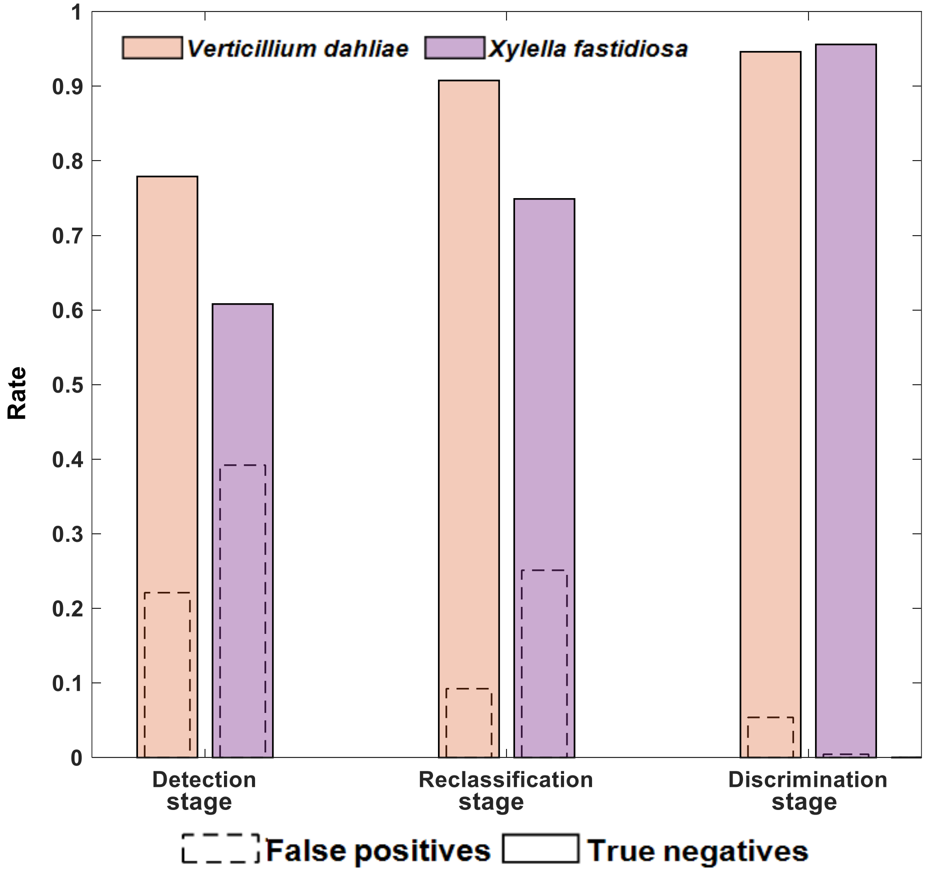


RESULTS

Specificity tests for detecting *Xf*– and *Vd*–infected olive trees (True negatives and False positives rate)



CONCLUSIONS

- Despite the **high similarity** between the symptoms triggered by both pathogens these results highlight that a **combination of spectral traits** and a **three-stage** machine learning algorithm can be used to accurately monitor, **detect**, and **differentiate** olive trees infected by ***Vd* or *Xf***.

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- When detecting ***Xf*** infections, the **false positive** rate decreased to **4%**, with **OA** of **92%**, and a **κ** of **0.8**.

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- Despite the **high similarity** between the symptoms triggered by both pathogens these results highlight that a **combination of spectral traits** and a **three-stage** machine learning algorithm can be used to accurately monitor, **detect**, and **differentiate** olive trees infected by ***Vd*** **or** ***Xf*.**

- When detecting ***Xf*** infections, the **false positive** rate decreased to **4%**, with **OA** of **92%**, and a **κ** of **0.8**.

- When detecting ***Vd*** infections, the **false positive** rate decreased to **9%**, yielding an overall accuracy (**OA**) of **98%** and a kappa coefficient (**κ**) of **0.7**.

3rd European Conference on Xylella fastidiosa and XF-ACTORS final meeting

Using hyperspectral imagery and a multi-stage machine learning algorithm to distinguish infection symptoms caused by two xylem-limited pathogens

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