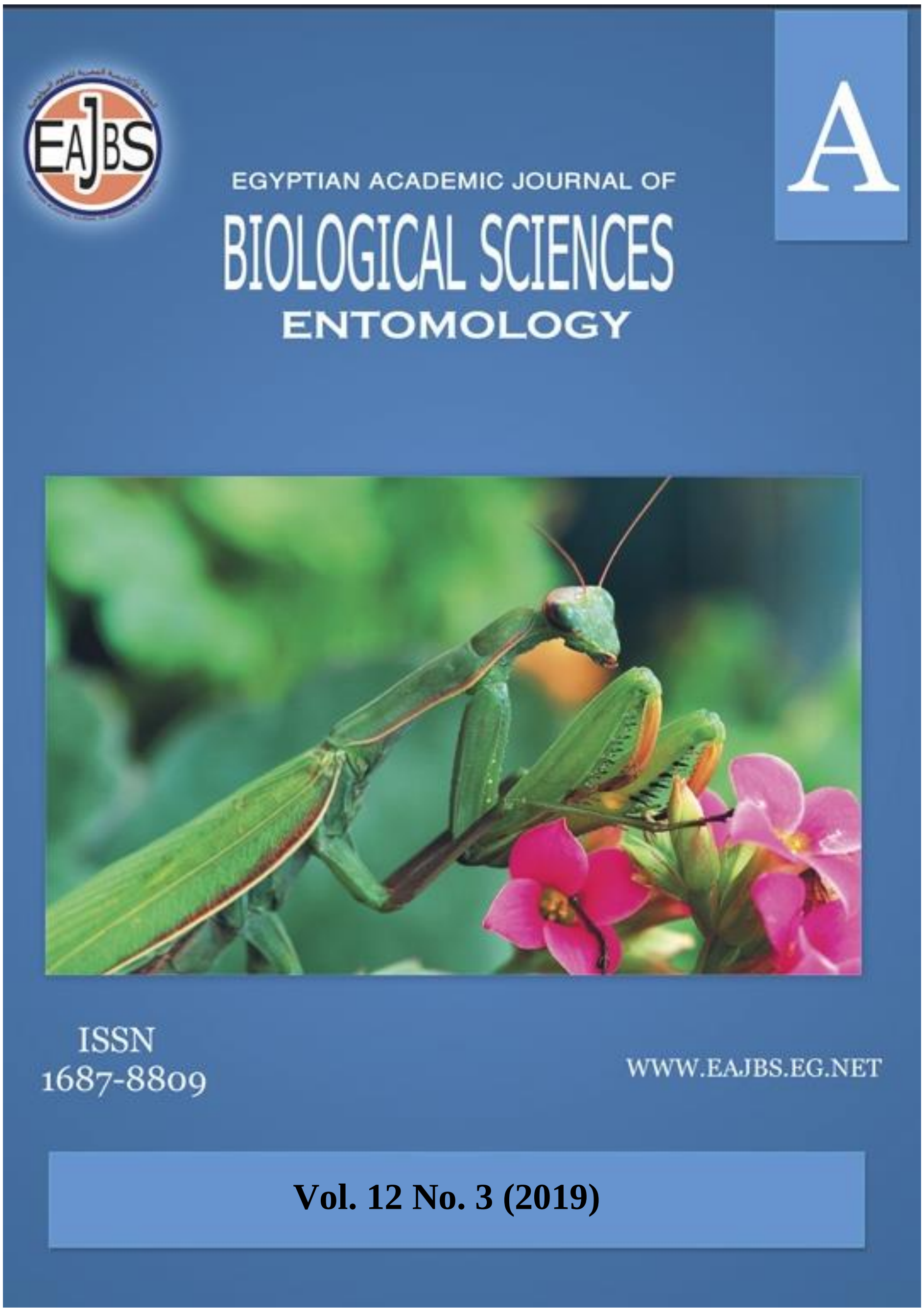

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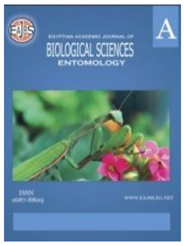

Spectral Signature for Detecting Pest Infestation of Some Cultivated Plants in the Northern West Coast of Egypt.

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ABSTRACT

Early detection of pest infestation is essential for determining the optimal time for control application. Many studies indicated the effectiveness of remote sensing technology as a tool to identify plants stressed by pest infestation. In the current study, we observed using hyper spectral remotely sensed data for discrimination between healthy and pest infested plants. Three arid-land plants were selected in the current study: sweet almond, citrus lemon trees and olives. As the first step of the analysis, spectral reflectance pattern for the three plants healthy and infected was identified. The optimal waveband and wavelength/s to differentiate between healthy and infected plants were identified. Different vegetation indices: Modified Chlorophyll Absorption in Reflectance Index (MCARI), Transformed Chlorophyll Absorption in Reflectance Index (TCARI), and Normalized Pigment Chlorophyll Index (NPCI) were calculated and compared between the values of these indices under infestation stress was examined. The results showed that healthy plants give higher reflectance values in visible spectral bands than infected plants with olives, however, healthy plants showed higher reflectance than infected plants throughout the whole spectrum with the other two plants. Vegetation indices values showed less value with healthy plants with sweet almond and citrus lemon but an opposite trend was found with olives. Blue and red spectral zones were optimal to differentiate between healthy and infected sweet almond and citrus lemon trees when all spectral zones except SWIRI were effective to differentiate between healthy and infected olives.

INTRODUCTION

The measurements of spectral reflectance of vegetation contain information on plant pigment concentration, cellular structure, plant anomalies and moisture content, Wu et al 2008. Spectral reflectance was previously reported to determine pest infection in palm (Yones *et al.,* 2014), in strawberry (Abdel Wahab *et al.,* 2017) also in sugar beet (Yones *et al.,* 2019) which found that NIR and Blue spectral zone are the best for the discrimination between healthy sugar beet plant and the different infections as each infection has it specific own spectral zone that distinguishes it from other infection due to each infection has its own causative condition and symptoms, so remote sensing technologies can be used for early detection for plants infections, and thus can be used for integrated pest management programs.

It was found that hyperspectral data assist in early identification for a diseased plant (Rumpf *et al.,* 2010).

In progress for sensors tools and Techniques Improve the ability of obtaining hyper spectral data and specify the amount of plant pigments and its change (Blackburn, 2007).

Quick predictions and control timing act as a valuable tool used in an integrated control program for managing Pests in Egypt also the early prediction of insects to help the farmers to avoid heavy sprays of pesticides and take the necessary actions to restrict dangerous infestations (Yones *et al*., 2012).

Crop pest detection by using remote sensing technologies depend upon the hypothesis of its stress conflict with plant physical structure and chlorophyll content so change plant reflecting characteristics (Hatfield and Pinter, 1993).

So it's achievable to distinguish healthy and diseased crops, so there is a high expectation for measure diseases and insect pest distribution on the crop (West *et al*., 2003).

Spectral signature is the specific combination of reflected and absorbed electromagnetic radiation at varying wavelengths, which can uniquely identify an object (Aboelghar and Abdel Wahab, 2013).

This research aims to detect and differentiate healthy and infected plants and at the same time to determine which pest infect plants, which act as guidance for the decision maker in timing control programs.

MATERIALS AND METHODS

Study Area:

The study area is located in the north west coast of Egypt that extend from Eldabaa in the east to the west of Fuka (30º 28` 57.99`` to 31º 41` 32.01`` North) and from (26º 33` 35.36`` to 28º 21` 25.41``East) (Fig. 1). The study area covers forty-two villages and local districts in Matrouh governorate with a total area of 17019 km2. The study area is a coastal area that is characterized by a humid climate. During December, the average air temperature is 15°C. The average rainfall is approximately 11.42 mm.

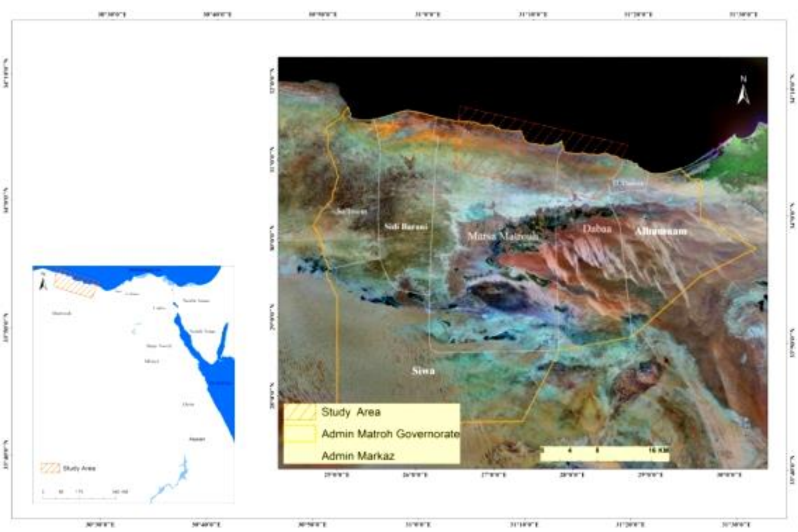

Fig.1: Location map of the study area.

Assessment and detection of pest infestation was carried out in the study area from Dabaa to Foca. Twelve stands have been selected for measuring plants spectrally. These stands were randomly chosen at locations where considerable vegetation cover was encountered. Survey of pest infestation on sweet almond, citrus lemon trees and olives carried out during field observation. Spectral reflectance of all surveyed samples was laboratory measured by ASD spectroradiometer device to investigate healthy and infected plants.

For each plant type, measurements were executed on plants of the same age, on the same soil and on the same environmental conditions for each plant type.

The objective of this work is to identify spectral reflectance characteristics of the most important and economic vegetation cover types in the study area and determine if it healthy or infected in order to facilitate surveying healthy and infected vegetation over a large area through satellite imagery using Tukey and linear discriminate analysis methods.

The methodology of this work focused on field hyper spectral measurements and statistical analysis for the output measurements in order to choose the optimal spectral and then the optimal waveband/s inside each spectral zone that can be used to detect an infestation. The full description of the used methodology is explained in the following subsections.

Field Spectral Measurements:

High-Resolution Spectroradiometer (ASD Field Spec 4 Hi-Res) was used for measuring the reflectance of plant leaves under field condition. 3 kind of plant were visited (4 replicates for each plant kind) and reflectance measurements were obtained.

Measuring of plant leave samples were done on spectral range from 350 nm to 2500 nm [visible – NIR – SWIR]. The spectral range from 350 nm to 1050 nm had a sampling interval of 1.4 nm. However, the sampling interval of the spectral range from 1000 nm to 2500 nm is 2 nm. Final data output is given with 1 nm interval to the full spectral range, as the instrument automatically executes an interpolation for all data.

Table 1 shows the spectral characteristics of ASD Field Spec 4 Hi-Res. The measurement protocol utilized to collect the spectral data is depending on the measurement of reflectance from the white panel. A probe was attached to the instrument's fiber-optic cable for ensuring standard environmental conditions; reflectance measurements. Twenty-five degrees lens was used for outdoor measurements with a circular field of view with 3 cm diameter (90 degrees) nadir position over the measured object, ASD, Boulder, CO, United States (Pimstein *et al.*, 2011).

Table 1: Specifications of ASD Field Spec 4 Hi-Res.

Full Range	From 350 : 2500 nm
Spectral Resolution	700 nm is 3 nm 1400 nm is 8.5 nm 2100 nm is 6.5 nm
Sampling Interval	From 350 : 1050 nm is 1.4 nm From 1000 : 2500 nm is 2 nm

Data Analysis Techniques:

Data analysis was conducted using spectral data measurements; to analyze the data, JMP ver. 25 program was used.

To detect plant diseases, the three vegetation indices MCARI (Modified Chlorophyll Absorption in Reflectance Index) (Daughtry, 2000), TCARI (Transformed Chlorophyll Absorption in Reflectance Index) (Haboudane, 2002), and NPCI (Normalized Pigment Chlorophyll Index) (Penuelas, 1994) were used in this study.

MCARI = [(R700 - R670) – 0.2 (R700 –R550)] (R700/R670) (1)
TCARI = 3 [(R700 - R670) – 0.2 (R700 – R550) (R700/R670)] (2)
NPCI= (R680 – R430) / (R680 + R430) (3)
Where;
R430 reflectance at 430 nm [%], R550 reflectance at 550 nm [%], R670 reflectance at 670 nm [%], R680 reflectance at 680 nm [%], R700 reflectance at 700 nm [%] and R800 reflectance at 800 nm [%].
MCARI gives a measure of the depth of chlorophyll absorption and is very sensitive to variations in chlorophyll concentrations, TCARI Tools for canopy health monitoring, NPCI estimate plant nitrogen status.

RESULTS AND DISCUSSION

This research aim is an identification of the best spectral zone and then optimal waveband for each plant infection, thus we can easily differentiate between healthy and infected plants. This work can help in integrated pest management programs.

The three cultivated plants Reflectance pattern was illustrated in Figure 2; *Prunus dulcis* healthy and infected show high similarity manner in reflectance but healthy *Prunus dulcis* reflectance is higher. This trend repeated in *Citrus limon* and *Olea europaea*.

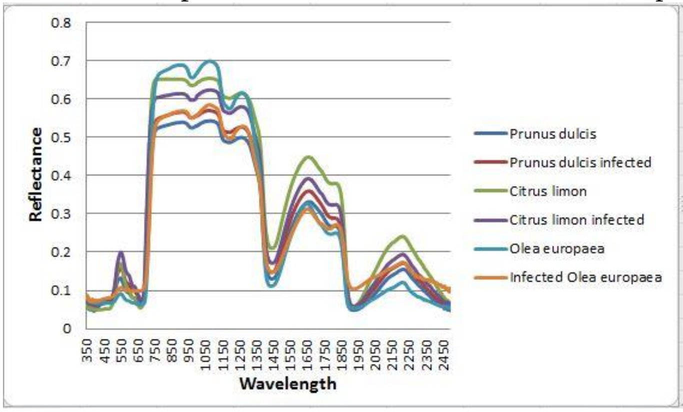

Fig. 2: Spectral reflectance pattern for the three cultivated plants (healthy and infected)

The difference in reflectance pattern is as a result for insect devastation that results in somehow loss or increase in leave elements.

Spectral Reflectance analysis for *Prunus dulcis* Figure 3, indicates chlorophyll decrease at 550 nm, this result agreed with Elkins *et al*., 2002, as mites attacking almond trees, feeding on the leaves and remove chlorophyll.

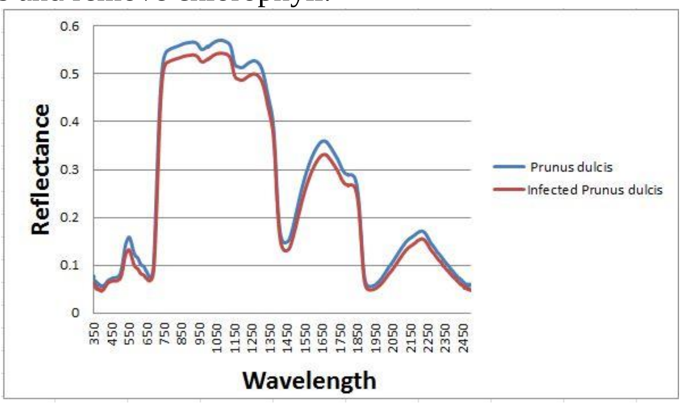

Fig. 3: The Spectral Reflectance manner to Healthy and infected *Prunus dulcis* by mite

Tukey's HSD test for *P. dulcis* illustrated that red and green spectral zones are the best in discrimination between healthy and infected *P. dulcis*. Other spectral zones showed relatively high potentiality to discriminate between them, as showed in Figure 4.

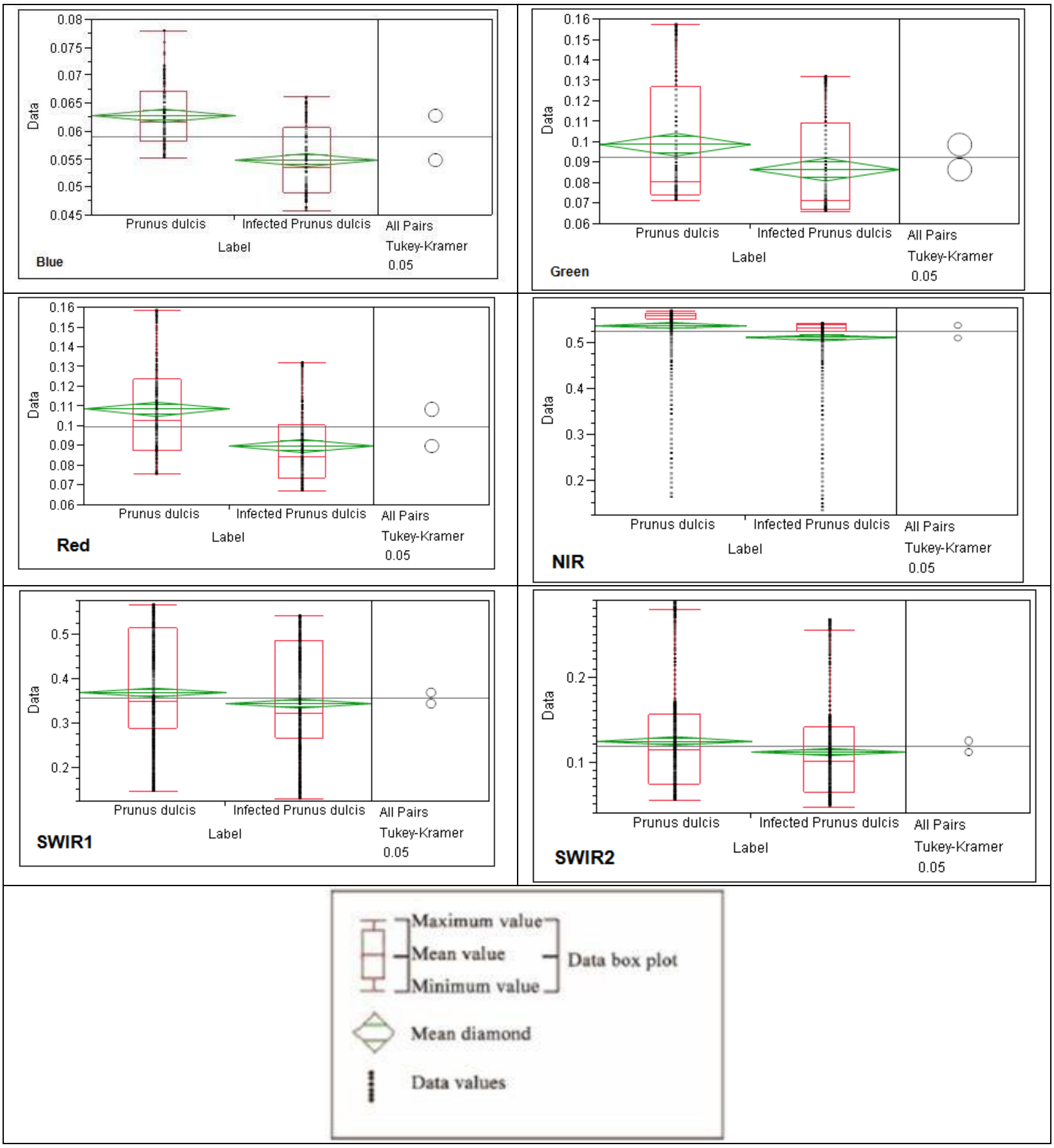

Fig. 4: ANOVA and Tukey's HSD analysis to discriminate between Healthy and infected *Prunus dulcis* by mites.

Spectral analysis for the *C. limon* indicates water stress, Figure 5 this obvious also at 950, 1150 and 1450 nm this result agreed with El-Shirbeny, 2012 and there is indication for chlorophyll stress found at 550 nm, this result agreed with Onillon, 1990 as whitefly, Feeding causes direct damage, and sooty moulds growing on honeydew deposits block light and air from the leaves, reducing photosynthesis and productivity, Heavy infestation and associated sooty mould development may cause defoliation. Also result agreed with Sherbiny 2012 in that Spectral signature record high readings in the visible region and low in the infrared region under water stress conditions.

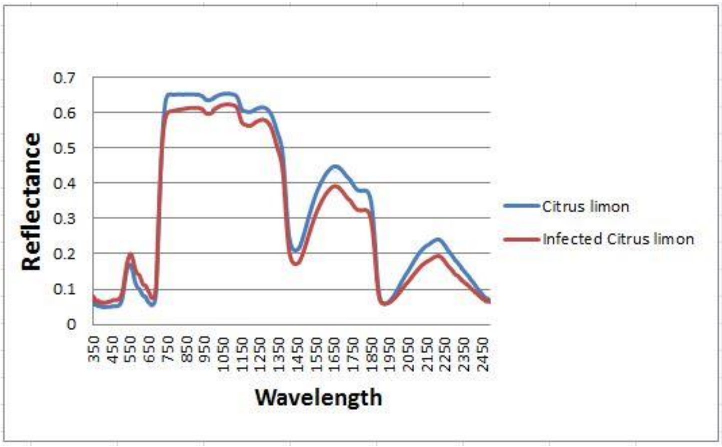

Fig. 5: The Spectral Reflectance manner to Healthy and infected *Citrus limon* by whitefly.

Tukey's HSD test for *C. limon*, show that red and blue spectral zones easily distinguish between healthy and infected *C. limon*, as showed in Figure 6.

Spectral analysis for *O. europaea*, Figure 7 indicates also water stress, this obvious at 950, 1150 and 1450 nm result agreed with Sherbiny 2012 in that Spectral signature record high readings in the visible region and low in the infrared region under water stress conditions. Also, there is an indication for chlorophyll stress found at 550 nm, this result agreed with Del Tio *et al*., 2001; milonas *et al*., 2001 as the emerging larvae of *O. europaea* make mines in the olive leaves Feeding causes direct damage, which is an indication for chlorophyll stress that found at 550 nm.

Finally, Tukey's HSD test for *O. europaea*, illustrate that Red edge is specific to discriminate healthy and infected *O. europaea* as the reflection increase in this wavelength for healthy *O. europaea*and sharply decreased in the infected plant, as showed in Figure 8.
The importance of this research in the point of early warning technology thus necessaryaction is done in time.

Conclusion of that result useful as a guide for the decision maker in timing control programs. As it detects and differentiate healthy and infected plants and determines which pest, infect plants.

Field maps for pest infestation could be created by remote sensing technology for controlling the pest (Willers *et al*., 2005; Voss *et al*., 2010; Karimzadeh *et al*., 2011; Dammer and Adamek, 2012; Mirik *et al*., 2012).

Pest control and pest management procedure could be determined spatially by Integration of spectral and imaging technology with agriculture vehicles (**West et al., 2003**).

Discrimination analysis results appeared in Table 2, and indicated the best wavelength/s to spectrally identify healthy and infected samples

Vegetation indices were evaluated for their suitability to detect differences in vitality between healthy and diseased plants and were used for the purpose of disease identification, Table 3.

The analysis of the reflectance data by the three vegetation indices indicated that there are significant differences between healthy and diseased plants.

MCARI and TCARI, which calculated using R700, R670 and R550, showed the best result for discrimination for the healthy and infected plant in *Prunus dulcis* and *Citrus limon*

In *Olea europaea* there is a significant difference between healthy and infected values when we estimate NPCI which calculated using R680 and R430. Negative result due to the high reflectance at wavelength R430 and the high absorption at R680 and this indicate the destruction of chlorophyll concentration depending on the degrees of nitrogen in infected *Olea europaea*

Differences between healthy and diseased plants were shown for the indices MCARI and TCARI in *Prunus dulcis* and *Citrus limon* and the sensitivity of the indices was not very high, but for NPCI show differences for all three plant types.

So, all used vegetation indices were suitable to detect differences in the reflection between healthy and diseased plants. However, there only NPCI is specific vegetation index for all of the infection. This result agreed with Gröll et al., 2007 (there was no specific vegetation index for only one of the diseases).

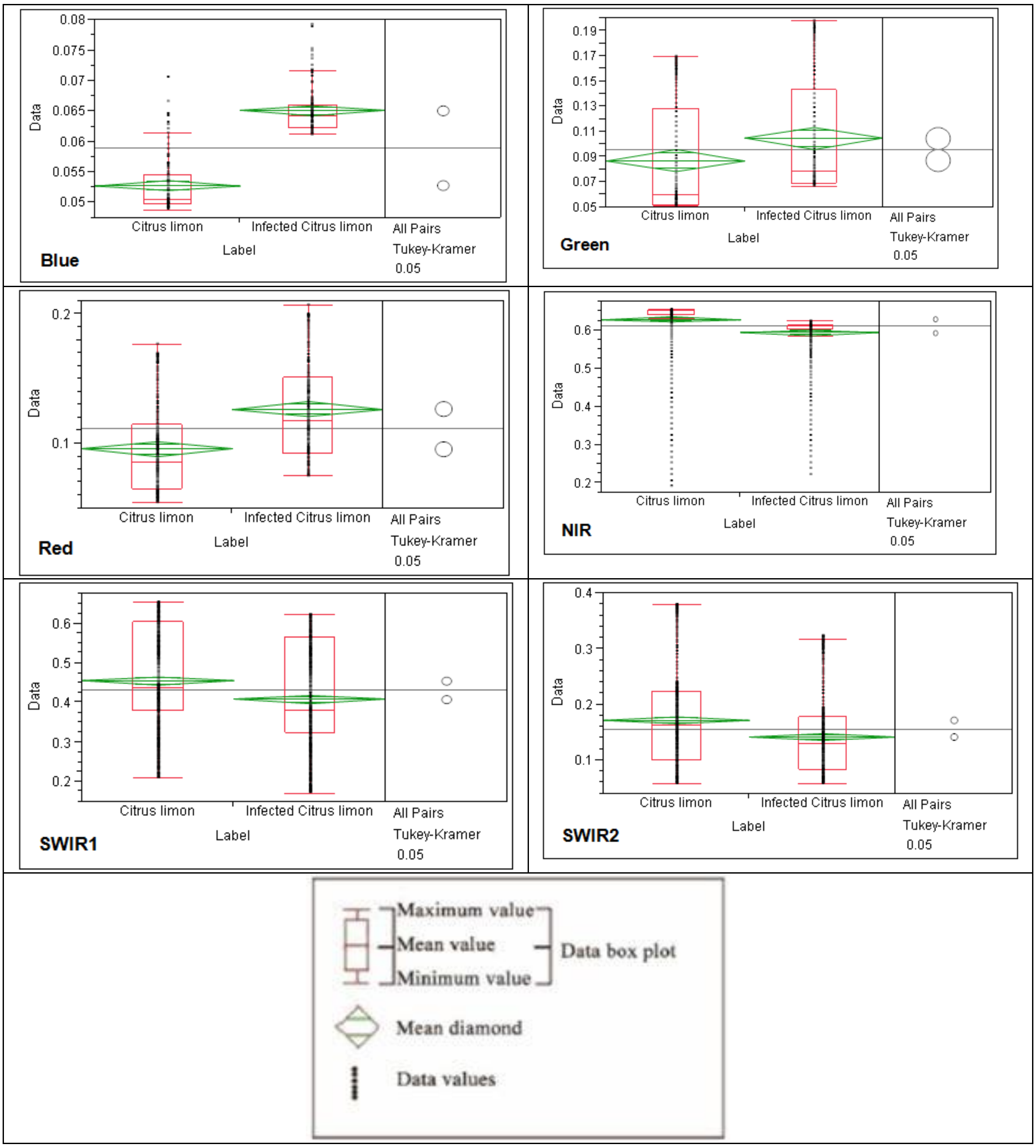

Fig. 6: ANOVA and Tukey's HSD analysis to differentiate between Healthy and infected *Citrus limon* by whitefly.

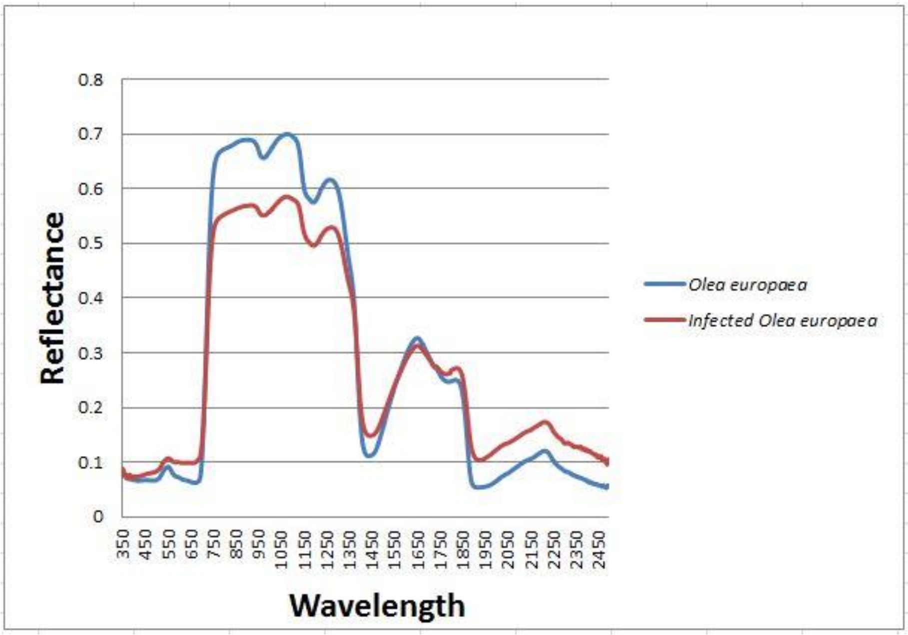

Figure 7: The Spectral Reflectance manner to Healthy and infected *Olea europaea* by *Prays oleae*.

Table 2: The optimal waveband to differentiate between healthy and infected plants.

	Optimal wavelength zones (nm)
Citrus limon	355-363-371-379-387-395-403-411-419-427-435-443-451-459-467-475-483-491-499-507-515-523-531-539-547-555-563-571-579-587-595-603-611-619-627-635-643-651-659-667-675-683-691-699-707-715-723-731-739-747-755-763-771-779-787-795-803
Citrus limon infected	668-676-684-692-700-708-716-724-732-740-748-756-764-772-780-788-796-804
Olea europaea Infected	350-358-366-390-398-422-430-438-462-470-478-494-518-526-574-582-590-598-606-614-622-630-638-646-654-662-670-678-686-694-702-710-718-726-734-742-750-758-766-774-782-790-798-806
Olea europaea	357-365-381-389-397-405-413-421-429-437-445-453
Prunus dulcis	529-537-545-553-561-569-577-585-593
Prunus dulcis infected	530-538-546-554-562-570-578-586-594-602
Zizyphus vulgaris	351-359-367-375-383-391-399-407-415-423-431-439-447-455-463-471-479-487-495-503-511-519-527-535-543-551-559-567-575-583-591-599-607-615-623-631-639-647-655-663-671-679-687-695-703-711-719-727-735-743-751-759-767-775-783-791-799
Zizyphus vulgaris infected	616-624-632-640-648-656-664-672-680-688-696-704-712-720-728-736-744-752-760-768-776-784-792-800-808

Table 3: The different Vegetation Indices to different plants.

Vegetation Indices	Prunus dulcis	Infected Prunus dulcis	Citrus limon	Infected Citrus limon	Olea europaea	Infected Olea europaea
MCARI	0.21	0.11	0.46	0.31	0.023	0.033
TCARI	0.145	0.116	0.22	0.14	0.038	0.053
NPCI	0.070	0.066	0.15	0.04	0.152	-0.027

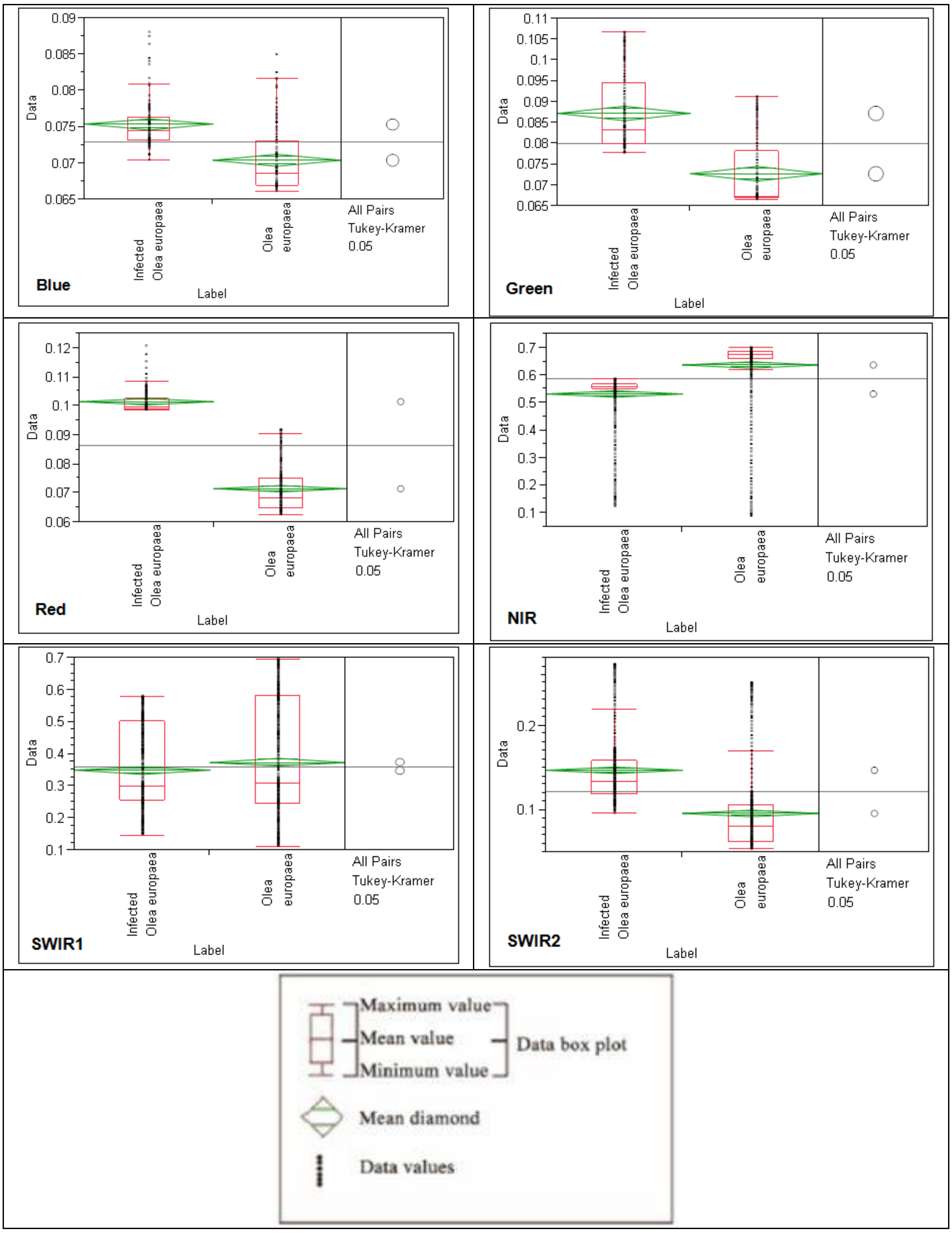

Fig. 8: ANOVA and Tukey's HSD analysis to differentiate between Healthy and infected *Olea europaea* by *Prays oleae*.

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ARABIC SUMMARY

البصمة الطيفية للكشف عن الاصابة بالآفات الحشرية لبعض الانواع النباتية المنزرعة في الساحل الشمالي الغربي لمصر.

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يعد الكشف المبكر عن الإصابة بالآفات أمرًا ضروريًا لتحديد الوقت الأمثل لتطبيق المكافحة. أشارت العديد من الدراسات إلى فعالية تقنية الاستشعار من البعد كأداة لتحديد النباتات التي تتعرض للإصابة بالآفات. في الدراسة الحالية ، تم استخدام بيانات الاستشعار من البعد فائقة التعدد الطيفي للتمييز بين النباتات السليمة والمصابة بالافات. تم اختيار ثلاثة أنواع من نباتات البيئات القاحلة (الصحراوية) وهم: اللوز الحلو ، وأشجار الليمون واشجارالزيتون. كخطوة أولى من التحليل ، تم تحديد نمط الانعكاس الطيفي للنباتات الثلاثة السليم والمصاب كذلك تم تحديد النطاقات الموجية المثلي وكذلك افضل الاطوال الموجية للتمييز بين النباتات السليمة والمصابة. اما بالنسبة لمؤشرات الغطاء النباتي المختلفة: فقد تم حساب مؤشر انعكاس امتصاص الكلوروفيل المعدل (MCARI) ، امتصاص الكلوروفيل المحول في مؤشر الانعكاس (TCARI) ، ومؤشر معدل أصباغ الكلوروفيل (NPCI) . وتم الفحص والمقارنة بين قيم هذه المؤشرات تحت ضغط الإصابة. أظهرت النتائج أن النباتات السليمة تعطي قيم انعكاسية أعلى في الأطياف الطيفية المرئية أكثر من النباتات المصابة لاوراق نبات الزيتون ، ومع ذلك ، أظهرت النباتات السليمة إنعكاسًا أعلى من النباتات المصابة في كامل الطيف مع النباتين الآخرين. أظهرت قيم مؤشرات الغطاء النباتي قيمة أقل مع اوراق النباتات السليمة لنبات اللوز الحلو والليمون ولكن على الجانب الاخر اظهرت النتائج العكس مع نبات الزيتون. كانت المناطق الطيفية الزرقاء والحمراء هي الأمثل للتمييز بين أشجار اللوز الحلوة والليمون السليمة والمصابة بالعدوى بينما كانت جميع المناطق الطيفية بإستثناء SWIRI فعالة للتمييز بين اوراق الزيتون السليم والمصاب.