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Use of spectral information for red scale pest control

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Abstract

Decreasing the use of pesticides is one of the main goals of current agriculture, which requires fast, precise and continuous assessments of crop pests. Citrus pests cause a lot of damage worldwide and the techniques to evaluate them are mainly based on manual, time-consuming readings of insects stuck on traps spread over the crops. This is the case of red scale insects, whose control is notably challenging due to their small size and high reproduction rate. Hence, in this work, we carry out a spectral characterization of this insect in the visible range through spectrometric devices, microscopy and hyperspectral imaging technology to analyze the feasibility of using this information as a means of automatically identifying specimens belonging to this species in this era of precision agriculture. The results obtained show that spectral reflectance differences between red scales and other insects can be recorded at long (red) wavelengths and that red scales are morphologically different, i.e., smaller and more rounded. A reflectance ratio computed from spectral images taken at 774 nm and 410 nm is proposed as a new approach for automated discrimination of red scales from other insects.

Introduction

In the 21st century, agriculture faces multiple challenges since it has to produce more food to feed a growing population with a smaller rural labor force, adopt more efficient and sustainable production methods and adapt to climate change. In particular, preventing the development of pests in crops is an essential and difficult task in agricultural production, even more since regulations in many countries worldwide aim to achieve a sustainable use of pesticides by reducing their impact on human health and the environment through alternative non-chemical approaches.

Precision agriculture, which is nothing more than the consequence of the landing of new technologies in agriculture, promotes the use of photonic-based sensors allowing data acquisition, processing and conversion into information useful for decision making. However, current pest control systems are based on periodic manual readings of chromotropic traps spread over the crops, which are adhesive sheets that often include female pheromones to attract males from certain species of insects. A magnifying glass is later used to manually recognize and count the insects, allowing the farmer to decide the optimized pesticide application.

Only for some large insects, few automated counting systems based on color imaging devices are already commercially available [1-3], which are mostly focused on the analysis of morphologic features. In general, the target insects identified belong to the Lepidoptera, Coleoptera and Arthropoda orders which have a size of some centimeters. However, some of the most notorious pests in fruit involve very small insects, such as red scales (*Aonidiella Aurantii*) for citrus, which still cannot be automatically detected neither classified.

Male red scale (Fig. 1) has an orangish appearance with a transversal dark brown band on the back and transparent wings, a size from 0.6 mm to 0.8 mm and a wingspan of 1.5 mm, approximately [4]. It has a short life cycle of 8 h on average, with the only purpose of fertilizing the female, leading to a high reproduction rate and from two to six generations per year [5,6]; for this reason, the fast and accurate control of this pest is crucial. This is the most important pest in most citrus-growing areas of the world, which are distributed in almost 90 countries from Europe over North, Central and South America, Africa, Central and South Asia to Oceania [7].

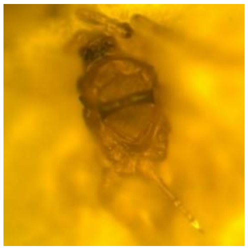

Figure 1. *Male red scale on a chromotropic trap. Image captured with an uEye UI-1460-C camera coupled to a Nikon ECLIPSE L150 microscope (magnification: 20x). The wings were out of focus.*

As for other insects, the small size of red scales makes difficult to extract morphological features from them in an easy, fast and economically affordable way. In order to overcome this limitation, several authors have applied spectroscopic techniques for feature extraction from different insect species. Near-infrared spectroscopy (NIRS) has been one of the most widespread approaches since low energy wavelengths allow non-destructive inspection of pests even in crops or grains, no sample preparation is needed and can be implemented as an automatic process [8-10]. Aldrich *et al.* [8] evaluated termite species and subspecies genus *Zootermopsis* by means of a visible (VIS) and near-infrared (NIR) spectrometer. The most relevant signatures obtained from the reflectance spectra were found between 1200 nm to 1700 nm. The different species and subspecies were classified using either a partial least squares regression or a neural network, leading to minimum accuracies of 85% and 99%, respectively. Zhao *et al.* [9] developed a method to distinguish between dead and live insects, such as *Oryzaephilus surinamensis*, in stored grain by quantifying their moisture content through the water absorption peaks in the NIR with an accuracy above 97%. Jamshidi [10] reviewed different studies of VIS and NIR spectroscopy for internal insect detection in fruits such as jujubes, pomegranates or chestnuts where insects like moths, flies or weevils can be found inside. In most the studies reviewed, NIRS (>1100nm) offered the best detection rates.

However, the high cost of NIR image sensors promoted the use of other spectral ranges such as the VIS and the ultraviolet (UV) when deploying multispectral imaging (MSI) systems [11,12]. To reduce the cost, smaller sensors in size are selected in the NIR, providing lower spatial resolution. Despite this fact, MSI allows useful spatial information to be obtained rather than only spectral data, which can help during insect detection and classification. Grieve *et al.* [11] developed a MSI device for identifying and discriminating species of the *Bemisia tabaci* whitefly. It consisted of 63 narrow-band light-emitting diodes (LEDs) covering from 380 nm to 940 nm, a modified color CMOS sensor with the spectral range extended to the NIR (<1125 nm) and a macro lens to image the small whiteflies. A classification accuracy above 85% was reached for the four species when applying a partial least squares discriminative analysis and using only 11 out of the 63 LEDs; however, the selection of the insects over the image was performed manually. Liu *et al.* [12] built a MSI system to identify different types of snails, slugs, moths and worms on green leaves. The device included a UV camera and a filter with peak wavelength of 330 nm and 85 nm bandwidth, and a CCD camera to capture color and NIR images, leading to a 5-channel system. The UV image offered an enhanced contrast between green leaves (dark) and some of the camouflaged specimens (bright). The developed technique was particularly efficient when detecting regions in the image that did not correspond to the insects of interest. Other studies also employed spectral imaging techniques but for evaluating the changes in fruits or leaves caused by a pest instead of the pest (insects) itself [13-15].

In this work, a spectral and spatial analysis of red scale insects is carried out using spectrometric devices, microscopy and hyperspectral imaging technology to study the feasibility of using this information for their automated detection and identification. The analyzed range was restricted to the VIS since the target insects present remarkable color traits that are already useful to differentiate them from other insects in this spectral region.

Materials and Methods

Samples

Eight chromotropic traps, hereafter referred to as traps (Fig. 2) and which had been spread over citrus crops for the preceding three months in farms located in Southern Catalonia (Spain), were spectrally and spatially analyzed. They consisted of white cardboards with a sticky surface and three holes, two for introducing the pheromones and the other to hang them from a branch. From these traps, 50 red scales and 50 other insects were randomly selected and measured; all of them were already dead.

***Figure 2**. Chromotropic traps for red scale. The small holes in each trap (red circles) is where the female pheromone is located to attract male red scales.*

Spectral characterization

The spectral properties of red scales and other insects in the traps were studied by means of their reflectance spectra. To do this, a tele-spectroradiometer PR-655 SpectraScan® (Photo Research, Inc., United States) with spectral sensitivity from 380 nm to 780 nm and a spectral step of 4 nm was attached to a Nikon ECLIPSE L150 microscope (Fig. 3 left). As a reference for reflectance computation, a white standard SRS-99-020 Spectralon® (Labsphere, Inc., United States) was used. Four different magnifications (5x, 10x, 20x and 50x) were set to precisely measure the spectral reflectance of different parts of the red scales as well as parts of others insects. The instrumentation used was that available in the laboratory.

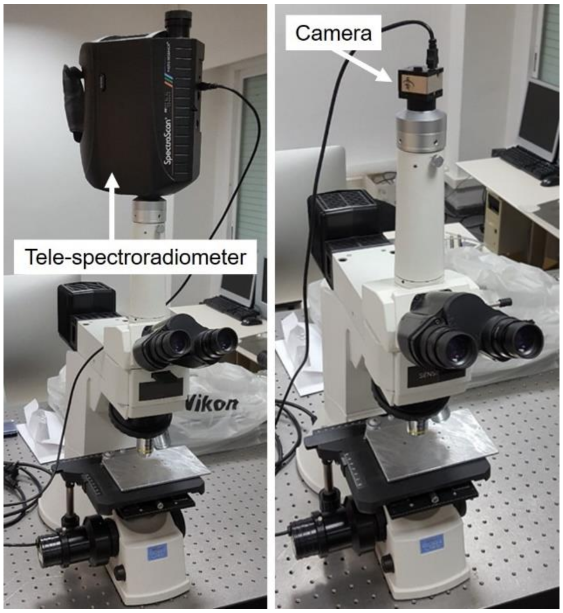

***Figure 3.** Tele-spectroradiometer PR-655 SpectraScan® (left) and uEye UI-1460-C camera (right) attached to a Nikon ECLIPSE L150 microscope.*

The spectral reflectance was computed for each wavelength as follows:

$$I_R = k \cdot \frac{I - I_D}{I_W - I_D} \qquad (1)$$

where I_R is the reflectance value and I, I_D, and I_W are the raw, the dark and the reference white standard signals. The dark one was acquired without using any light source. The calibration of the reference white standard provided by the manufacturer was in *k*.

Spatial evaluation

The morphology of red scales was also assessed to extract differential traits when compared to other insects also available in the traps. For this task, an uEye UI-1460-C color camera coupled to the Nikon ECLIPSE L150 microscope was used (Fig. 3 right). From the four magnifications (5x, 10x, 20x and 50x), the largest ones were especially useful when visualizing red scales since they were the smallest insects on the traps.

Spectral imaging assessment

As a first approach to obtain a joint spectral and spatial characterization of red scales, the traps were also studied by means of spectral imaging technology. To do so, a hyperspectral imaging system based on LEDs previously developed at the Centre for Sensors, Instruments and Systems Development (CD6) of the Universitat Politècnica de Catalunya (UPC) was used [16]. The traps were imaged through 20 spectral bands from 410 nm to 774 nm, and the spectral reflectance was computed at every pixel as in Eq. (1) .

Results and Discussion

Reflectance curves

Fig. 4 shows the mean reflectance curves ± standard deviation for red scales and other insects from 380 nm to 780 nm; NIR evaluations up to 1700 nm were also performed and showed that the reflectance spectra of red scales and the other insects were flat and very similar beyond 850 nm. It is to be noted that the characteristic dark brown band of red scales could not be measured in isolation because, even using the highest magnification (50x), the measurement area of the tele-spectroradiometer was larger. It should be also considered that for some positions of the specimens on the trap, this band was not visible; then, it could not be used as a clear identifying trait. Additionally, those recordings at 50x were rejected because focusing at this high magnification was very critical and the results could be affected.

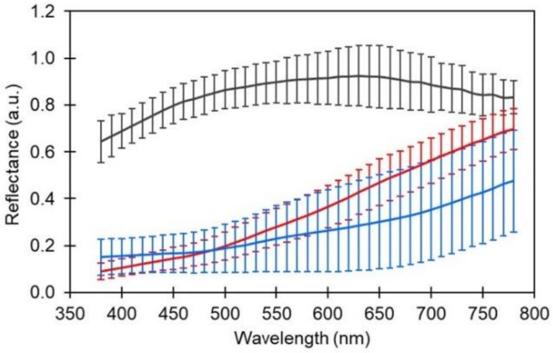

Figure 4. *Mean reflectance curves ± standard deviation of all the 50 red scales (red), 50 other insects (blue) and 40 measurements at the white regions of the traps (gray) at 5x, 10x and 20x.*

It can be seen how red scales showed higher reflectance values than the other insects at longer (red) wavelengths while at shorter (blue) ones, reflectance values were slightly smaller; on the contrary, the trap (i.e. the white parts) is very bright at all wavelengths as shown in Fig. 4. The enhanced contrast (larger reflectance differences) between the trap and the insects at short wavelengths was similar to that found by Liu *et al.* [12] in the UV, although in that study the background was dark (green leaves) and the insects were bright.

Morphological features

Red scales were the smallest insects on the traps as the spatial evaluation performed through the camera attached to the microscope later confirmed. From the literature, it was found that the red scale is the smallest insect along with the whiteflies (1mm – 2 mm length) studied by Grieve *et al.* [11], which had a green appearance, very different from red scales. The other insects were bigger, even with a size of some centimeters. In Fig. 5, two perspectives of a red scale are shown: one from the back, where the dark brown band can be perfectly seen, and the other from the side of the thorax, which did not reveal the band. A magnification of 20x was needed for the red scale to fill almost the whole field of view of the camera whereas for other insects (Fig. 6) the lowest magnifications (5x and 10x) were enough. Apart from the bigger size of the rest of insects, their shapes were remarkably different from that of the red scale, being more elongated. Images taken at 50x-magnification revealed that they are useful for visual inspection but not for precise data retrieval as focusing non-uniformities appear over the measurement area due to the high magnification. This preliminary spatial assessment will be the basis for future detection of red scales by means of quantitative morphological methods.

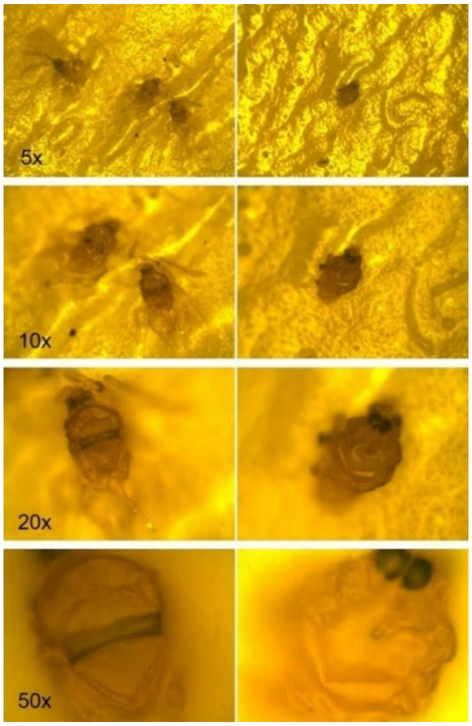

Figure 5. *Red scales seen from the back (left) and the thorax (right) at different magnifications. They were captured with an uEye UI-1460-C camera coupled to a Nikon ECLIPSE L150 microscope.*

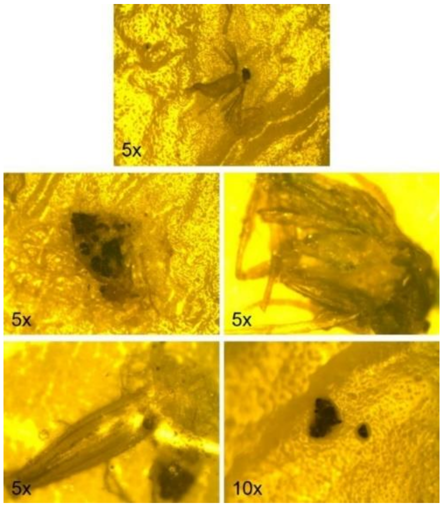

Figure 6. *Insects imaged at different magnifications. They were captured with an uEye UI-1460-C camera coupled to a Nikon ECLIPSE L150 microscope.*

Spectral images

From the spectral analysis, it was found that reflectance values of red scales at long wavelengths are slightly larger than those from other insects whereas at short (blue) wavelengths they were more similar. Fig. 7 depicts the spectral images captured with the hyperspectral imaging system when illuminating the traps with LEDs emitting at 410 nm and 774 nm (Fig. 7).

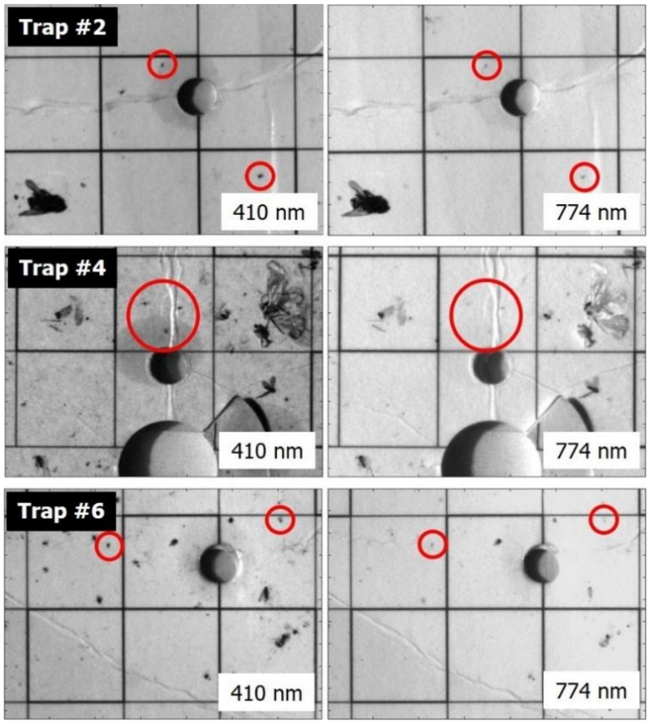

Figure 7. *Images at 410 nm and 774 nm for the three traps (#2, #4 and #6). Red circles indicate the location of red scales.*

It can be noticed that all insects are very dark at 410 nm images, while at 774 nm, red scales appear brighter, with a reflectance similar to the background (trap); for this reason, some of them are hardly visible when looking at the images of this wavelength (Fig. 7, right images). Although the reflectance was also higher at 774 nm for the other insects, it did not increase as notably as for red scales.

In order to quantify the reflectance difference amongst insects from the spectral images, the mean reflectances at 774 nm were divided by those registered at 410 nm. After a proper segmentation, red scales and the other insects were analyzed leading to mean reflectance ratio ± standard deviation values of 6.68 ± 2.03 and 3.30 ± 1.66 for red scales and other insects, respectively. In terms of sensitivity and specificity, values of 83.33% and 64.10% were obtained respectively, which means that the proposed method detects the 83.33% of the red scales in a trap. Therefore, these results revealed that the discrimination between red scales and others insects could be done with remarkable accuracy from spectral records. Nevertheless, in those cases where spectral information is not enough, additional morphological information (e.g., the size) could help differentiating red scales from other species, as they are the smallest on the traps.

In this sense, it should be noted that the spatial resolution achieved is a critical issue that must be carefully considered. In the spectral images taken with the hyperspectral imaging system the details of red scales are hardly observable, such as the characteristic dark brown band. If images closer to the trap are taken in order to achieve more accurate spatial information, a smaller field of view is seen; this means that for a whole evaluation of one trap, a vertical and horizontal spatial scanning would be needed, thus involving a more complex mechanical arrangement.

Alternatively, a similar procedure was followed to test the performance of the method on RGB images, and the ratio between the red (R) and blue (B) channels was computed; the camera used was the same than for the spatial evaluation. In this case, the discrimination between red scales and other insects was very poor, with mean R/B ratio ± standard deviation values of 6.30 ± 2.58 and 6.10 ± 2.17 for red scales and other insects, respectively. These results can be justified by the broader spectral bandwidths of R and B channels, which integrate tens of wavelengths, and the closeness between R and B channel peak wavelengths. These limitations were not found when using LEDs with narrow-band spectral bandwidths (< 25 nm) and with peak wavelengths at the outermost wavelengths of the VIS as done in the reflectance ratio.

Conclusions

In this study, spectral assessments of red scales, the pest that mostly affects citrus crops worldwide, were performed. An increased reflectance at long (red) wavelengths was found for red scales in comparison to other insects. The reflectance ratio computed between long (red, e.g., 774 nm) and short (blue, e.g., 410 nm) was found to be useful to discriminate red scales from other insects. Since red scales are also linked to small sizes, spatial information provided by an imaging system was found to be useful to improve even more the detection of this pest.

Future work will focus on setting a hyperspectral imaging prototype for the specific evaluation of red scales considering the spectroscopic and morphological information retrieved from this preliminary study. From these features, an algorithm will also be developed for the automatic identification of red scales. The final goal is to monitor and control red scale pests with higher accuracy than current methods to further decrease the use of pesticides in the current era of precision agriculture, where imaging technologies will play a key role.

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Author Biography

Carlos E. Garcia-Guerra obtained his BSc degree in Telecommunications Engineering from National Autonomous University of Mexico. In 2010, he completed the joint MSc program on Information and Communication Technologies MERIT at Catholic University of Louvain and UPC. In 2016, Carlos obtained his joint PhD degree in Optical Engineering from UPC and Karlsruhe Institute of Technology. He is currently working as a researcher at CD6-UPC in the development of optical instrumentation for different applications.

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