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Pattern recognition-based optical technique for non-destructive detection of *Ectomyelois ceratoniae* infestation in pomegranates during hidden activity of the larvae

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ABSTRACT

In this research, the feasibility of utilizing visible/near-infrared (Vis/NIR) spectroscopy as an optical non-destructive technique combined with both supervised and unsupervised pattern recognition methods was assessed for detection of *Ectomyelois ceratoniae*, carob moth, infestation in pomegranates during hidden activity of the larvae. To this end, some fruits were artificially contaminated to the carob moth larvae. Vis/NIR spectra of the blank samples and the contaminated pomegranates without and with external visual symptoms of larvae infestation were analyzed one and two weeks after contaminating the samples as three groups of "Healthy", "Unhealthy-A" and "Unhealthy-B", respectively. Principal component analysis (PCA) as unsupervised pattern recognition method was used to verify the possibility of clustering of the pomegranate samples into the three groups. Discriminant analysis (DA) based on PCA was also used as a powerful supervised pattern recognition method to classify the samples. The calibration models of linear, quadratic and Mahalanobis discriminant analyses were developed based on different spectral pre-processing techniques. The best PCA-DA model was obtained using Mahalanobis distance method and first derivative (D1) pre-processing. The total percentage of correctly classified samples with the best calibration model was 97.9%. The developed model could also predict unknown samples with total percentage of correctly classified samples of 90.6%. It was concluded that Vis/NIR spectroscopy combined with pattern recognition method of PCA-DA can be an appropriate and rapid technology for non-destructively screening the pomegranates for detection of carob moth infestation during hidden activity of the larvae.

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1. Introduction

The carob moth, *Ectomyelois ceratonia* Zell. (Lepidoptera: Pyralidae), is a destructive worldwide polyphagous insect and the most important pest of pomegranate (*Punica granatum*) in the Middle East, especially in Iran, attacking the fruits before and after harvest and causing 30–80 present yield losses. Chemical insecticides are not applicable for controlling this pest because of the hidden activity of the larvae. Non-chemical control methods which are currently used, have no sufficient efficiency. This pest normally lays eggs inside the crown, calyx, of pomegranates. Larvae penetrate into the fruit after hatching. The damage caused by larvae, especially from second or third age, on the fruit is due to their feeding from internal parts of pomegranate without external symptoms. This causes penetration of pathogenic fungi such as *Aspergillus* and *Penicillium* which makes the fruits unmarketable and unfit not only for human consumption but also for the food processing industries [1–4]. Sometimes, the appearance of black spots on the pomegranate is the first symptom of carob moth infection and the beginning of fruit decaying process [4]. However, there is mostly no external visual symptom during hidden activity of the larvae inside the fruit to detect infested pomegranates. Thus, the pomegranates with hidden infestation may pass undetected in packing houses and processing lines. They may damage the surrounding healthy fruits during storage. Moreover, the existence of hidden contamination in pomegranates is a vital challenge for the exportation. Therefore, development of a fast and non-destructive detection technique of infested pomegranates is imperative.

Few publications have addressed the use of some non-destructive techniques for the detection of internal insects and insect infestation on pomegranates. The feasibility of using X-ray computed tomography (CT) coupled with image analysis has been investigated by Magwaza and Opara [5] for non-destructive detection internal structure of pomegranates. Arendse et al. [6] investigated the application of micro-focus X-ray CT (μCT) using a density calibration function for non-destructive

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