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Exploring The Potential of Thermal Imaging for Pre-Symptomatic Diagnosis of Fall Armyworm Infestation In Maize: A Case Study From Ismailia Governorate, Egypt

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ABSTRACT

Early detection of Fall Armyworm (FAW), *Spodoptera frugiperda* infestation in maize is crucial for minimizing crop losses. This study investigated the potential of thermal imaging as a non-destructive technique for differentiating between healthy and FAW-infected maize plants. Maize samples were collected from Ismailia Governorate, Egypt, during the 2023 growing season. Result succeeded to identify crop monitoring data with the highest priorities for maize in Egypt, Maize cultivation covered approximately 3,096 feddans of the study area, with an average productivity 20 ton / Faddan. So, the total Maize product in the study area is 61,920 ton. Using a Testo IR camera, captured thermal images revealing a significant temperature difference between healthy and diseased maize plants, with infected maize exhibiting an average 3.3°C increase compared to healthy ones. This suggests that FAW infection alters maize structure, potentially impacting temperature. Thermal imaging offers a promising tool for pre-symptomatic diagnosis of FAW infestation in maize, enabling early intervention and improved pest management strategies. These findings highlight the promise of thermal imaging as a non-destructive technique for early detection of FAW infestation. Early and targeted interventions can significantly reduce crop losses and minimize reliance on broad-spectrum pesticides.

KEYWORDS: Remote sensing, *Spodoptera frugiperda*, Monitoring, Predictions, productivity.

1. INTRODUCTION

Maize is Egypt's main strategic crop grown in the summer (Metwally, et al. 2019). Maize (*Zea mays* L.), a versatile crop valued for its role as a staple food, animal feed, biofuel, and even construction material, is a global agricultural powerhouse. (Abebe & Feyisa, 2017).

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), a highly damaging polyphagous lepidopteran pest native to tropical and subtropical America (Sarmento, et al. 2002), has emerged as a new invasive threat to maize crops in Egypt, likely arriving from South Africa. Notably, its genus, Spodoptera, is recognized as a major culprit for global agricultural losses within the Noctuidae family (Gamil, 2020).

The fall armyworm (FAW) poses a significant threat due to its polyphagous nature, (Huesing, et al. 2018). This means FAW can infest a variety of crops, causing widespread damage. This is especially concerning for maize, the dominant cereal crop in Africa (Devi, 2018). As a preferred target for FAW, maize crops face a heightened risk of significant yield losses, were some of the factors that aided in its rapid spread across the continent. Africa is predicted to lose between US$ 9.4 and US$ 13.3 billion annually due to FAW losses in maize alone (Day R, et al. and Eschen R, et al.). Aswan Governorate, Upper Egypt was where it was first discovered in May 2019 (Dahi, et al. 2020). From there, it quickly expanded to Luxor, Qena, and Sohag until arriving in Assiut Governorate in 2021 (Mohamed, et al. 2022). By the end of 2021, the pest had spread to every governorate in Egypt, based on its current rate of invasion.

The agricultural sector's long-term success hinges on the ability to detect plant infections early. Non-destructive monitoring techniques offer a powerful and practical solution for real-time tracking of plant health. While spraying pesticides remains the most common pest control method, it often involves uniform application across entire fields, regardless of infestation patterns. In reality, insect populations tend to be localized, making targeted interventions more effective. Early detection empowers farmers to strategically deploy pesticides only where needed, minimizing unnecessary spraying and reducing the risk of severe outbreaks. (Yones, et al. 2012). As soon as the target stage appears, it is imperative to modify the pest's generations and the timing of insecticidal treatment. Remote sensing technologies can be used to monitor the detection of larval populations in bolls and determine this parameter. (Yones, et al. 2019).

Plant diseases can be identified and diagnosed with the use of remote sensing technologies. Theoretically, Pathogens responsible for crop diseases trigger physiological changes within the plant, leading to extensive damage at the tissue level, which is the basis for the use of remote sensing technology in agricultural disease assessment. (Abdel Wahab, et al. 2017).

Thermography, also known as thermal remote sensing technology, is a non-destructive method for figuring out an object's thermal characteristics. The idea underlying thermal remote sensing is the conversion of an object's invisible radiation patterns into visible pictures, or what are known as thermal images. Thermal remote sensing has the potential to be used in agriculture for plant disease identification and greenhouse monitoring. However, because of recent equipment cost reductions and straightforward operating procedures, thermal imaging has become more and more popular in pest detection (Al-doski, et al. 2016). Thermography has recently been utilized to identify pest infestations (Grossman, 2006). This work presents thermal imaging, which is becoming a popular method of insect detection.

In the agro-ecosystem, insect pest forecasting helps farmers be aware of impending disruptions. This information enables them to plan ahead and employ mechanical methods, pesticides, and biocontrol agents appropriately, reducing production costs and aiding in precision farming.

The trick to managing fall armyworm infestations is to identify them before they lead in commercial harm. It is advised to implement an efficient management measure on maize to stop additional damage if 5% of seedlings are removed or 20% of whorls of tiny plants (during the first 30 days) are infested with FAW (Fernández, 2002).

The primary objective of this study is to explore the application of thermal imaging for the observation and monitoring of FAW infestation in Maize. This research seeks to develop a new, non-destructive method for detecting FAW-infected Maize plants based on thermal signature differences. This approach has the potential to revolutionize early detection of FAW, ultimately minimizing crop losses.

2. MATERIAL AND METHODS

Acquiring Sentenal 2 satellite data sets and readings from ground observations as well. Data like those related to the climate, agriculture, integrated data (such base maps), or additional items that are generated from models and other deliverables. Among these resources are fundamental geographic data sets that are dependable, trustworthy, and adaptable to a variety of agricultural applications.

Crop yield and total acreage grown are the two factors that determine total crop production. By combining the proportion of a specific crop within the cultivated land with an estimate of the total cultivated land derived from remote sensing, we can calculate the approximate acreage of that crop. Sentenal 2 satellite data and collected field data are used in this crop planting and type proportion (CPTP) technique (Wu and Li, 2004). Data from Sentinel 2 satellite with a spatial resolution of 10 meters were used. Thirteen (13) vegetation indies were estimated based on the spectral bands of Sentinel-2 imagery. All input bands were used in crops monitoring and classification. A machine learning system using Google Earth Engine and object BASED Classification were used in the supervised classification of satellite images.

A certain crop's acreage can be calculated by multiplying the crop's planting percentage, crop type proportion, and farmland acreage.

To estimate global and national maize yields with reduced uncertainty, a three-pronged approach is employed. The first approach employs an agro-meteorological model as its foundation that considers both long-term trends in agricultural practices and management (yield trend) and the impact of weather patterns during the growing season (meteorological yield) (Meng, et al. 2004). The other approach utilizes remote sensing data and a statistical model built on the relationship between specific remote sensing indicators and actual crop yield (Li et al., 1990). Finally, a recently developed method (Du, et al. 2009) estimates crop biomass based on plant health during the growing season and then translates that information into yield using a harvest index derived from growth parameters. This novel approach doesn't rely on historical data and can be applied globally after regional calibration.

Once crop yield figures are available, they are integrated with estimated crop areas to determine overall crop production. These production forecasts are generated one month prior to harvest and subsequently adjusted for accuracy after the harvest.

Land cover and crop type maps were generated using imagery from Sentinel satellites. Ground control points (GCPs) were collected to aid the classification process.

The initial step of this study involved identifying the spatial distribution and total area occupied by different crops within the study area. This information is crucial for developing specific models to estimate biophysical parameters (like plant health) and to determine locations for field measurements. The current study was conducted at a 33,186 feddan area within the 23,763 feddan 6th October farm located in the Ismailia governorate.

2.1. Thermal measurement

Maize specimens were collected (Twelve samples were collected) at the 6th October farm in Ismailia Governorate in September 2023, which is the Maize cultivation season, and processed in a lab within 30 minutes.

Thermal images of the Maize samples were obtained using a Testo 890 Thermal Imaging Camera equipped with a standard lens (0.1 mm, 42° x 32° field of view). This camera's autofocus ensures sharp images and allows for one-handed operation. It has a minimum focus distance of 10 cm and offers a resolution of 640 x 480 pixels with 307,200 measurement points. Super Resolution technology can enhance the resolution to 1280 x 960 pixels. The camera, with a thermal sensitivity of 40 mK, captured JPEG images of both healthy and diseased Maize samples from 1.1 meters away. Emissivity was set to 0.95.

Maize temperature data was measured in offline mode. The captured thermal images were processed and analyzed using Testo IR software. This software allows users to select specific areas on the image and provides statistical data on the temperature distribution within that region. It can also calculate minimum and maximum temperatures and generate histograms, and Plant stress can be accurately assessed by measuring leaf temperature (Costa et al., 2013; Martynenko et al., 2016).

Afterward, each Maize sample was inspected for Fall Armyworm (FAW) infestation.

3. RESULTS AND DISCUSSION

The study succeeded to identify crop monitoring data with the highest priorities for maize in Egypt, Maize cultivation covered approximately 3,096 feddans of the study area, with an average productivity 20 ton / Faddan. So, the total Maize product in the study area is 61,920 ton.

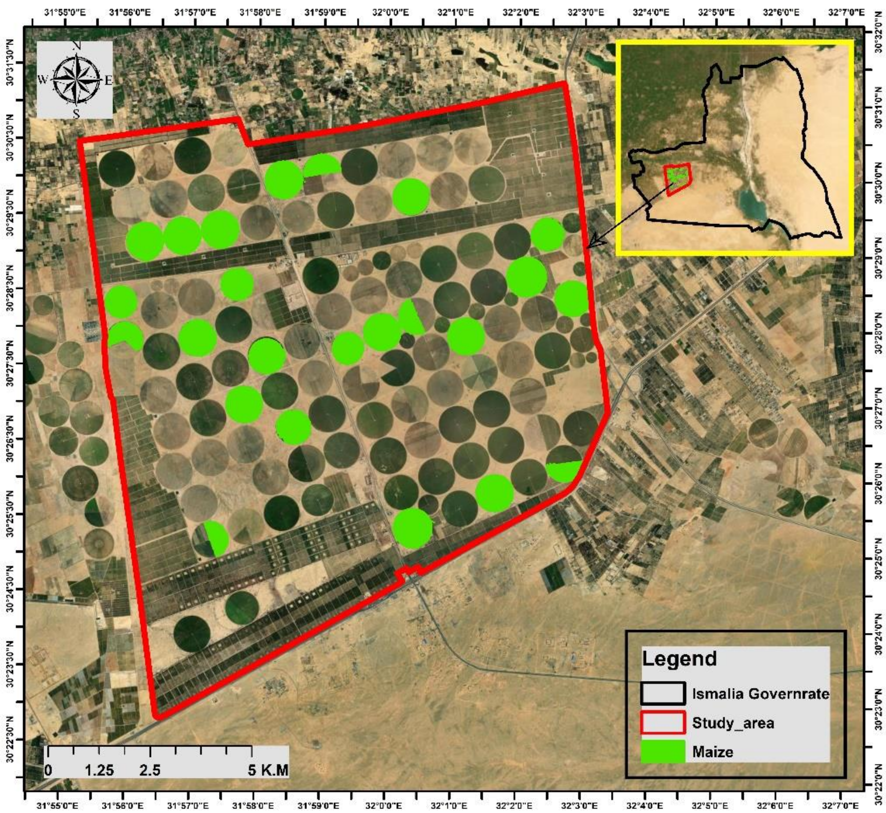


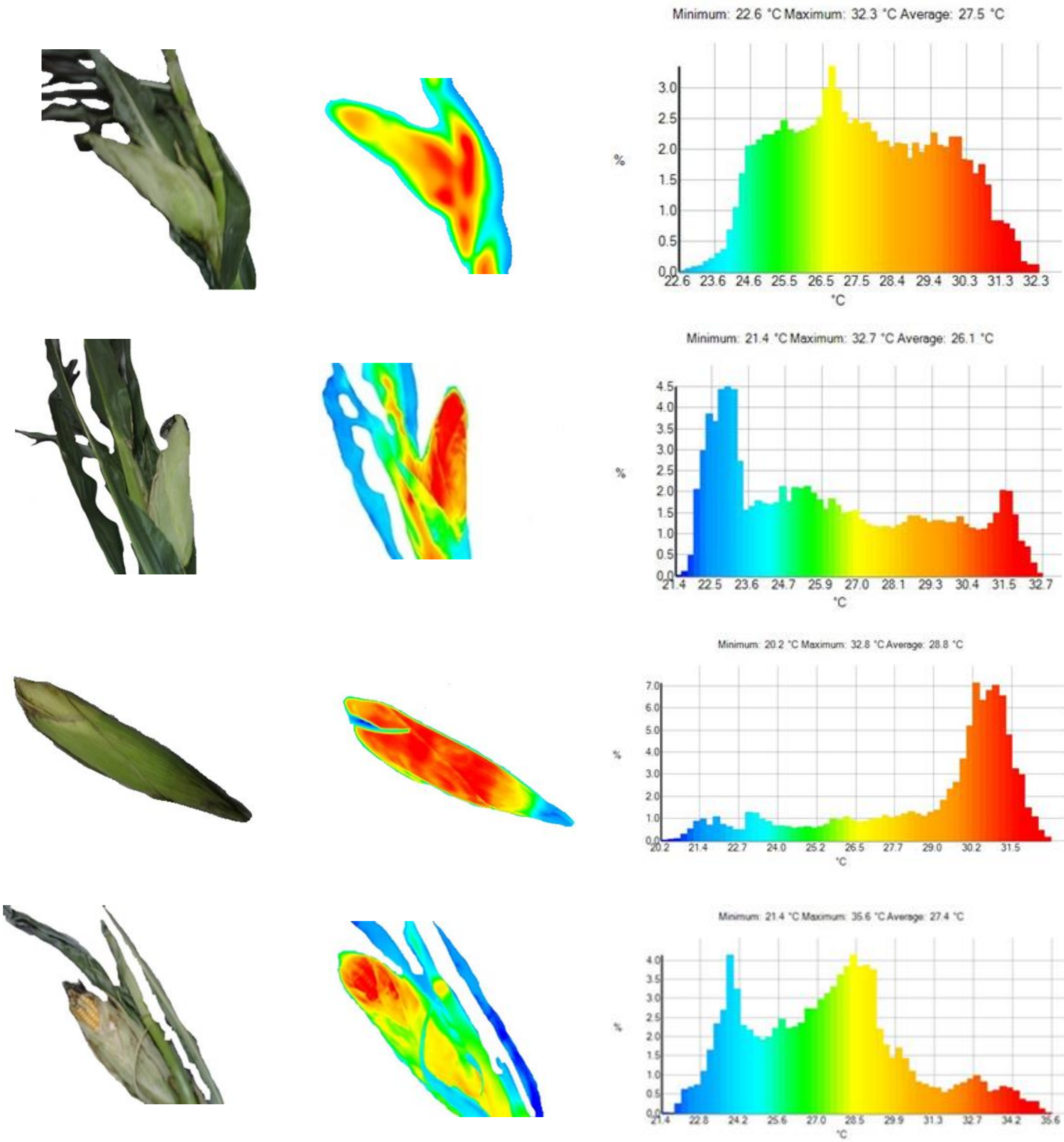
Figure 1. Maize map for Winter Agricultural season (6th October farm)

3.1. Thermal Imaging

Thermal imaging of the Maize samples revealed abnormal warmth and wetness in infected areas. Our findings revealed a maximum temperature difference of 3.3°C between healthy and diseased maize, with healthy plants ranging from 32.3°C to 35.6°C. Thermal imaging provides a detailed map of surface temperature distribution. This allowed us to observe a significant temperature increase in infected maize compared to healthy plants. As shown in Table 1 using histogram adjustments, diseased Maize exhibited an average temperature 3.3°C higher than healthy Maize. This temperature difference suggests that pest infection might alter the Maize's structure. Overall, thermal imaging appears to be a promising technique for differentiating infected from non-infected tissue with high precision.

Table 1. Comparison of photo and Thermal camera images with histogram analysis of healthy and infected Maize (Generated with Testo IR Software)

Photo image | Thermal camera image | Histogram adjustment of thermal image



A wide range of agricultural applications, including plant disease identification, yield estimation, maturity assessment, and fruit and vegetable damage detection, have benefited greatly from the use of thermal imaging. The increased temporal and geographical resolution of the images produced by this method makes it more and more popular in agriculture. By analyzing the temperature variations between infected and healthy maize plants, thermal imaging offers a reliable method for early detection of biotic stresses. The high spatial resolution of digital infrared thermography allows for precise identification and quantification of management zones associated with pests and diseases. Furthermore, plant transpiration was frequently impacted by any maize sample illness.

Previous studies by Oerke et al. (2006) and Moshou et al. (2004) demonstrated the effectiveness of thermal imaging in identifying plant diseases such as powdery mildew, cucumber leaf damage, and wheat yellow rust. To investigate if thermal imaging could similarly detect early signs of water and pest stress in cotton boll plants, as suggested by Martynenko et al. (2016) and El Hoseny et al. (2022), we collected temperature data on both healthy and diseased plants under controlled conditions.

The insect management industry has only recently recognized the potential of IR thermography, by identifying signs of stored moisture within structures, might assist in the detection of pest infestations. Grossman (2005) discusses the use of thermal imaging to identify thermal patterns linked to insect infestation, data verification, and specific issues with the inspection procedure.

4. CONCLUSION

Thermal imaging has the potential to revolutionize maize pest management in Egypt. This study demonstrated a clear distinction in temperature between healthy and FAW-infected maize plants. The observed temperature increase in infected plants suggests an alteration in plant structure, potentially affecting Temperature. These findings highlight the promise of thermal imaging as a non-destructive technique for early detection of FAW infestation. Early and targeted interventions can significantly reduce crop losses and minimize reliance on broad-spectrum pesticides. Further research is recommended to optimize image acquisition parameters, explore the link between FAW infection and thermal variations, and validate the effectiveness of thermal imaging for large-scale field applications.

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الملخص العربي

إستكشاف إمكانات التصوير الحراري للتشخيص المبكر لإصابة دودة الحشد الخريفية في الذرة :دراسة حالة من محافظة الإسماعيلية، مصر

د مني سيد احمد يونس[1]، غاده خضري[1]، طاهر محمد سعيد قدح[2] و محمد امين ابو الغار[1]

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الكشف المبكر عن إصابة دودة الحشد الخريفية، *Spodoptera frugiperda* (FAW)، في الذرة ضروري لتقليل خسائر المحاصيل. بحثت هذه الدراسة إمكانية التصوير الحراري كتقنية غير تدميرية للتفريق بين نباتات الذرة السليمة والمصابة بدودة الحشد الخريفية. تم جمع عينات الذرة من محافظة الإسماعيلية بمصر خلال موسم الزراعة ٢٠٢٣. تم التقاط الصور الحرارية وتحليلها باستخدام برنامج Testo IR. أظهرت نتائجنا اختلافًا كبيرًا في درجة الحرارة بين الذرة السليمة والمصابة، حيث أظهرت الذرة المصابة زيادة متوسطه قدرها ٣,٣ درجة مئوية مقارنة بالذرة السليمة. يوحي هذا بأن إصابة دودة الحشد الخريفية تغير بنية الذرة، مما يؤثر على درجة الحرارة. يقدم التصوير الحراري أداة واعدة للتشخيص المبكر لإصابة دودة الحشد الجيشي في الذرة، مما يتيح التدخل المبكر وتحسين استراتيجيات مكافحة الآفات.

الكلمات المفتاحية: الاستشعار من البعد، التصوير الحراري، دوده الحشد الخريفية، الذرة، التتبع، التنبؤ.