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IoT-Based Techniques for Early Pest and Disease Detection in Crops: A Review

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***Abstract*—Transformative impact of technology has revolutionized how farmers monitor and safeguard their crops. Sensors and other precision farming equipment have indeed made it more efficient and accurate to detect pests and diseases of crops early on, allowing farmers to take timely actions to minimize potential damage because of these pests and diseases. Early detection of pests and diseases plays an important role in maximizing crop yield and quality. By using modern technologies like pest detection sensors, farmers can proactively address issues before they escalate further, ultimately reducing yield loss and ensuring a healthier harvesting of crops. Moreover, the ability to receive real-time data from the field encourages farmers to not only make decisions about crops, such as watering the plants, fertilization, and precautionary measures for pest controlling but also contributes to sustainable agricultural practices by minimal use of resources and inputs. This paper aims to explore four distinct techniques for early detection of crop pests and diseases, which are Thermography, Fluorescence, Hyper Spectral, and Gas Chromatography Disease Detection Method, which are crucial for preventing crop loss because of different diseases and pests. Our approach involves a comprehensive discussion of each technology's capabilities in detecting crop pests and diseases at an early stage. Following this, we will conduct a comparative analysis of these techniques, evaluating them based on various parameters to determine their effectiveness in different scenarios and their accuracy.**

***Index Terms*— Internet of Things (IoT), Disease Detection Method, Agriculture, Early Pest Detection and Accuracy**

I. INTRODUCTION

THE Internet of Things has changed not just how we live, but also our daily activities. IoT is growing rapidly across a lot of industries, such as healthcare, security, and agriculture. Artificial intelligence and robots, along with IoT, will upgrade the farms while reducing the number of manual laborers from 90% to 10%. An advanced farm monitoring system utilizes IoT and sensors to track, improve, and sustain crops. The sensors detect crop development, nutritional levels, soil moisture, and weather to notify farmers. A central server receives data from these sensors. Wireless or cable-based sensors can be used to collect information about crops, soil, and climate.

The Internet of Things enables agriculture to gather, transmit, and analyze data in real time. Monitoring farms remotely boosts productivity and decision-making. Data mining and machine learning can assess and provide recommendations [1]. Crop diseases pose a risk to global food security because they can significantly reduce yield in the absence of timely and effective treatment. Thus, preventing disease is every farmer's most important responsibility. Modern farming techniques are used by farmers to protect their harvest since illness can be efficiently controlled by early detection. These measures include both indirect and direct methods of identifying diseases. [2] Direct detection methods primarily consist of laboratory-based methods for detection of diseases. Some of these methods are immunofluorescence (IF), polymerase chain reaction (PCR), fluorescence in-situ hybridization (FISH), ELISA, flow cytometry etc. While these methods are accurate, they are not adoptable for on-field detection of disease because they require the sample that is tested in the laboratory for further results. In contrast, indirect methods are implemented directly in the field. These methods make use of optical sensors capable of recognizing abiotic and biotic stresses and also diseases present in crops.

Utilizing techniques such as thermo-graph, fluorescence imaging technique, and hyperspectral analysis, these sensors predict plant diseases by analyzing various optical parameters. We are going to discuss indirect methods which are on-field techniques and do not require any supervision for performing their tasks.

A) Early Pest Detecting Methods

Thermography method measure changes in plant surface temperatures at canopy as well as at the leaf. The installed sensors pick up emission of infrared radiation by the plant. In the event of a pathogen infection, the reduced transpiration will cause the plant surface temperature to rise [3]. Temperature fluctuations can be used by the sensor to identify whether a disease is present. Thermography method can detect changes associated with disease even prior to the onset of symptoms. Precision illness control has inherent limitations because of its high sensitivity to changes in the measuring environment. Another problem is that the thermography method cannot identify the specific type of sickness.

Sensors that employ the fluorescence method that measure the Leaf Area Index (LAI) can also be used to monitor insect pest activity. Feeding insects cause damage to leave. This causes plants to lose chlorophyll. The plant's capacity to photosynthesize is subsequently reduced as a result of the reduction in total leaf area. Through the calculation of index of the leaf area, the sensor is able to recognize an attack by insects at early stages and inform farmers, so they are able to take action before further damage.

These sensors are used to measure changes in fluorescence characteristics, incident light, and chlorophyll fluorescence on leaves. By keeping an eye on chlorophyll variations and photosynthesis activity of plants, it can recognize the infections. [4] While this method provides a source of identifying diseases at early stages, its field usefulness is limited.

According to the hyperspectral technique, sensors that use a broad spectrum—from 350 to 2500 nm—are used to measure the health of plants. They identify the changes in reflectance which is produced as a result of the physical and metabolic alterations induced by infection. Hyperspectral cameras gather three-dimensional data i.e. X, Y, and Z axes for more accurate result. [5] Unmanned aerial vehicles (UAVs) are commonly equipped with sensors to observe a broad area of vision.

In order to detect agricultural illnesses, gas chromatography is used, this non-optical sensor detects the volatile chemical compounds that are produced by infected plants. Gas chromatography sensors can accurately determine the kind and severity of disease in this way [6]. The main limitation of this approach is that it severely limits its on-field usability by requiring longer sampling times for pre-collected volatile organic compounds before data analysis. There are five sections in this research.

B) Types of sensors

Sensors are the major thing for detection of pests and infection in crops. Therefore, it's important to discuss the widely used sensors.

Low-power Image Sensors

They function as an autonomous wireless inspection system, utilizing an affordable image sensor. Positioned within individual traps, this wireless sensor efficiently captures images of trap objects, which are then sent remotely to a central control station. [7] These images serve to determine the number of pests present at each trap. By assessing insect population levels, farmers can plan crop protection measures, targeting specific areas within their fields. Farmers use these sensors to monitor vast areas with minimal energy consumption. Low-power image sensors have many benefits like:

- Reduction in pest monitoring cost.
- Humans are not required for monitoring.
- Well-suited for both small and large-scale agricultural tasks.
- Requires low maintenance.
- Real-time pest activity monitoring.

Therefore, use of low-power image sensors is suitable for farmers, as it is cost-effective and provides information about crop diseases at early stages.

Acoustic Sensors

Acoustic sensors are a great tool for detecting insect pests by keeping an eye on the sounds they produce. Wireless sensor nodes are placed in the fields in a strategic manner. The nodes are connected to a central base station. [8] When pest activity above a predetermined noise threshold is produced, the sensors transmit data to a control room server, and the infested area is identified accurately. These sensors play a great role for detecting infestations in very early stages and minimizing damage to crops. They are useful for monitoring large areas and use minimal energy.

There is significant work done on early detection techniques for pests and diseases in plants, but there is a lack of comprehensive review of four popular indirect techniques which are very useful in this regard.

Therefore, our paper aims to provide a thorough and exhaustive review of these techniques. This review will facilitate the exploration of the most suitable technique based on individual requirements and needs.

This research paper comprised of five sections. Section I includes the Introduction of the paper and some techniques and sensors being used in pest detection. Section II includes Literature Review which will throw light on the work of previous authors. The methods employed in this paper are analyzed in Section III Methodology. Section 4 consists of Comparison which contains the analysis of these techniques on the basis of different parameters i.e., Working, advantages, disadvantages, price and practicality of each technique. Finally, the last Section consists of the Conclusion of the research paper which technique is comparatively better.

II. LITERATURE REVIEW

The early detection of pests and diseases is very crucial so that our productivity is optimized, and loss is minimal. These techniques also help us to reduce the use of pesticides by identifying the infested area, so we spray on this area only and healthy crops are not affected. In the last few years, very popular techniques have been used for detections of swarms and diseases at early stages including infrared thermography, hyperspectral imaging, fluorescence imaging and gas chromatography. This detailed literature review will provide recent research into these methods.

A) Infrared Thermography

Thermography is a gentle effective method of identifying problems in plant health. Infrared thermography is utilized to identify life phases of a pest and difficulties in young trees and to detect CLB infected plants according to a study conducted by Pico and others using three different types of thermographic cameras. This method is illustrated in Fig. 2.

Moreover, Hoffman and Nills showed how good infrared thermal imaging method works to find stored product insect infestations in grains. The researchers successfully detected insect infestations by using thermographic sensors, signifying the usefulness of infrared thermography in monitoring the quality of stored grain. All of these studies show the effectiveness of infrared thermography as a non-destructive methodology for early detection of pests. By capturing infrared radiation, thermography offers timely management of pests in crops.

B) Hyperspectral Imaging

Machine learning algorithms combined with hyperspectral imaging has become a valuable method for early detection of plant diseases. Hyperspectral sensors were used in research to identify illnesses and pests that affect soybeans early on. The researchers effectively located disease marks on soybean

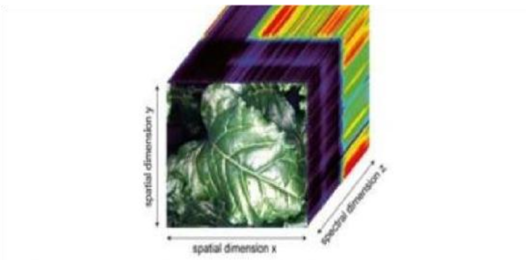

Fig. 1: Hyperspectral sensor image of a sugar beet leaf in a cube scheme

plants by analyzing spectrum in hyperspectral images, allowing for efficient pest management methods.

Furthermore, Liu and Guishan suggested a method for detecting pesticides in fruits and vegetables using a combination of hyperspectral imaging and deep learning strategies. The researchers formed an excellent method that can detect pests early on.

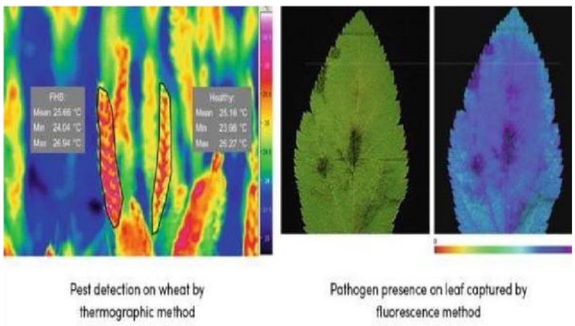

Fig. 2: Thermographic and Fluorescence Method

C) Fluorescence Imaging Method

Fluorescence method is used to identify changes in fluorescence characteristics, incident light, and chlorophyll fluorescence on leaves. By keeping an eye on changes in chlorophyll level and photosynthesis mechanism, it can identify the infections. its field applicability is limited, this method is illustrated in Fig. 2.

D) Gas Chromatography

A very important method for detecting pesticides in crops is gas chromatography.

Pico, Yolanda et., al. highlighted growths in gas chromatography methods for detection of crop pesticide residue. They improved the accuracy and dependability of pesticide residue analysis by creating techniques for preparation of sample and other optimizations.

In short, the literature review stresses the advancement made in strategies and tools for early recognition of plant diseases and pests. Data processing advanced techniques, in combination with infrared thermography, hyperspectral imaging technique, and gas chromatography, provide useful tools for successfully monitoring and controlling agricultural threats. Farmers may guarantee justifiable food production, improve monitoring of crop health, and enhance pest management policies by implementing these techniques into agricultural systems.

Table I: Technologies overview

Year	Sensors/Technique /Models	Problem	Solution
2016	Thermography sensors	To detect CLB infected plants [9]	Three types of thermographic cameras are used to detect these plants
2013	Thermographic sensors	To detect stages of insects in young trees [10]	Successful detection using thermograph sensors
2021	Hyperspectral sensors	To detect soya bean pests and diseases at early stage [11]	Hyperspectral sensors are used to detect disease spots on soya bean
2024	Hyperspectral sensors	To detect pest growing in fruit or vegetable at early stages [12]	Using hyperspectral sensors for detecting the disease
2022	Hyperspectral imaging and deep learning	Disease detection in plants and crops at early stages [13]	Automatically identification of digital images of diseases along with healthy crop images
2022	Gas chromatography sensors	To detect pests [14]	Gas chromatography sensors are utilized efficiently

III. METHODOLOGY

The goal of literature review is to assess new developments for the identification of plant diseases and pests at very early stages before too much harm. The goal of the review is to explore how infections in agricultural crops can be identified and treated by utilizing deep learning, gas chromatography, infrared thermography, hyperspectral imaging etc. After thorough literature review was done by using many academic databases, such as PubMed, IEEE Xplore, Web of Science, Scopus, and Google Scholar. Search terms included keyword combinations including "deep learning," "hyperspectral imaging method," "infrared thermography strategy," "plant pests' detection," "early disease diagnosis, "disease detection" etc. The scope of search was limited to publications in English between the years 2010-2023 to ensure relevancy and regency. Included studies in this research paper are related to techniques for early disease and pest detection like gas chromatography, thermography, hyperspectral imaging, fluorescence imaging. Excluded studies were those published in languages but English or those not directly related to the research topic.

First, the retrieved studies were evaluated to analyze their relevancy to the presented research topic by investigating their titles and abstracts. Full text screening was then carried out to ascertain worthiness for inclusion in accordance with determined criteria. A selection of appropriate studies was made for in-depth examination and data extraction. Data including author(s), publication year, title, approach, dataset/technique/models utilized, and problem addressed, and suggested solution by the authors, were methodically gathered from a few chosen publications. As indicated in Table I, important discoveries, insights, and conclusions were compiled to identify patterns and gaps in literature.

Table II: Literature Survey

2020	Gas chromatography sensors	Detection of pesticide residue [9]	Great accuracy by using these sensors
2016	Recapture technique	To develop a reliable method for the long-term monitoring of abundance of coypu in agricultural land [10]	An index was calibrated based on surveys for coypu paths against density estimates obtained via a standardized mark
2018	Wireless sensor network technology	Pest monitoring and detection using wireless sensor networking technologies: A review [11]	Existing techniques are analyzed based on some key parameters like sensor types used, their cost, etc.
2022	Spectroscopic and imaging techniques	Non-invasive techniques used to detect crop diseases [12]	Spectroscopic and imaging technology is used for reliable, real-time detection of crop diseases.

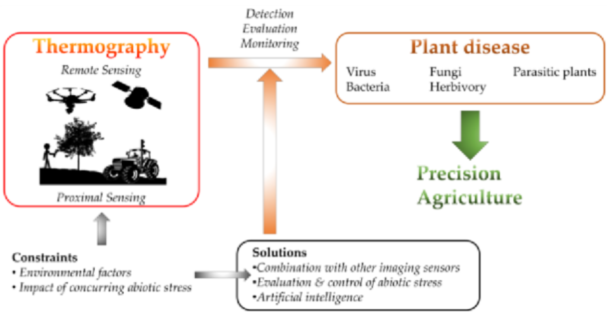

Fig. 3: Thermographic Remote Sensing

IV. ANALYSIS AND DISCUSSION

In this review paper, we will discuss four popular indirect methods that are utilized for identifying the pests and crop diseases at early stages. These methods are used according to one's needs and requirements.

A) Thermography Method

Sensors in thermography can detect changes in leaves' surface temperature by detecting emission of infrared radiation from the plants. When a pathogen infects a plant then its surface temperature rises due to reduced transpiration. By analyzing temperature changes, the sensor can detect disease presence before visible symptoms appear.

The imaging setup typically comprises two visible light cameras and a camera which can produce thermal images. Components of this camera include: an optical system, a detector, an amplifier, signal processing technology, and a clear display [19].

Thermal cameras capture and generate images of objects using the infrared radiation emitted by the objects, a process known as thermal imaging. These images represent the object's temperature. In conjunction with visual cameras, infrared cameras provide precise surface temperatures and their distribution on leaves. This capability allows for insights into leaf health, resilience, and plant growth

This method offers several advantages: it's simple, efficient, and discreet in surveillance. It operates effectively both day and night and requires minimal maintenance, resulting in reduced total cost of ownership. Its exceptional performance extends across various weather and air conditions, including rain, fog, snow, and smoke. However, there are limitations. It cannot distinguish between different types of infections, and thermal images cannot penetrate certain materials like water and glass. Additionally, precise disease control proves challenging due to the sensor's sensitivity to environmental fluctuations during measurements. The initial cost is high, but it's highly practical in practice.

Fluorescence Imaging Method Fluorescence sensors are used in measuring chlorophyll present on leaves, assessing variations in chlorophyll and photosynthetic activity to detect pathogens. Despite its sensitivity in detecting photosynthesis abnormalities, practical implementation of fluorescence measurement in field settings is limited.
Different parameters are used to detect the changes in plant photosynthesis mechanism. The setup for fluorescence method involves the installation of active sensors which have LED used for evaluating photosynthetic transfer of electrons. The fluorescence emitted by an object is typically determined after it is excited by a beam of light commonly in ultraviolet range.

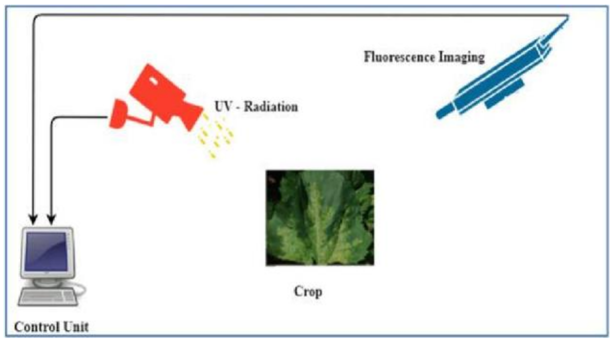

Fig. 4: Fluorescence Imaging

Fluorescence imaging when combined with image analysis technology has proven valuable for discriminating against and quantifying fungal infections.

The main advantages include monitoring of nutrient deficiencies, environmental stress levels, and plant diseases. High sensitivity, selectivity, and low background noise [20]. Ability to determine fluorescence intensity, decay time, and component concentration. Potential insensitivity to light scatter. The limitations include strict protocol required for plant preparation, making implementation challenging in agricultural greenhouses or field environments. The susceptibility to interference stemming from variations in sample pH and oxygen levels, as well as potential toxicity concerns arising from foreign substances present in biological media, are areas of consideration.

Price range is slightly higher compared to the thermographic disease detecting method. Practical implementation of fluorescence measurement in field settings is limited.

Hyperspectral Disease Detection Method Hyperspectral sensors utilize a wide spectrum ranging from 350 to 2500 nanometer to assess health by detecting reflectance changes because of biophysical and biochemical alterations caused by infection. These sensors gather data in three dimensions, integrating spatial details along the X and Y axes and spectral information along the Z axis, offering comprehensive understandings of plant health. To cover extensive field areas, they are typically mounted on unmanned aerial vehicles (UAVs). [21]

Various hardware techniques are utilized in hyperspectral imaging spectrometers, including push broom, filter wheel, and liquid crystal tunable filters. In a push broom configuration, incoming light is directed through either a convex grating or prism, dispersing it into narrow wavelengths. These wavelengths are then detected by a light-sensitive chip. This system records both a single spatial line of the image and the entire color spectrum concurrently. Following this, the camera or object is adjusted to capture the next line, essentially acting as a line scanner. The final image is compiled once the entire scanning process is finished.

The main advantages include enhanced disease detection, identification, and monitoring in precision agriculture applications. Provides detailed information about objects due to narrowband information acquisition and fine spectral resolution. Utilizes spatial relationships among different spectra for more accurate segmentation and classification of images. Differentiates between crops and weeds based on their spectral characteristics, guiding targeted weed control strategies and optimizing resource allocation [22].

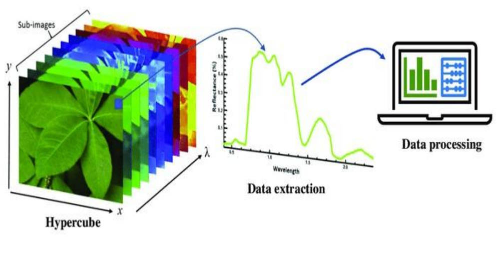

Fig. 5: Hyperspectral Disease Detection Method

Limitations include hyperspectral data of plants may suffer from variations in illumination due to light scattering, shadowing of plant parts, and complex combinations of scattering and shadowing. High initial cost and complexity. Price range is very high compared to all the other methods. Practically it is despite the limitations, hyperspectral imaging remains highly practical for various applications.

Gas Chromatography Disease Detection Method An alternative strategy for detecting plant diseases involves analyzing the volatile chemical signature emitted by infected plants, offering a non-optical indirect approach. When plants are infected by pathogens like Phytophthora cactorum, they emit specific volatile organic compounds (VOCs) that serve as strong indicators of the stress experienced by the plants. For example, infections in strawberries caused by Phytophthora cactorum lead to the release of distinct VOCs such as p-ethyl guaiacol and methylphenyl from the affected areas. Similarly, both pathogenic and mechanical damage to green leaf plants triggers the production of VOCs, including green leaf volatiles (GLVs) like cis-3-hexenol, cis-hexenyl acetate, and hexyl acetate. Profiling these VOCs offers a method to determine the type and nature of infection, aiding in disease diagnosis and confirmation. [23]

Gas chromatography (GC) is commonly utilized to analyze the volatile signature of plants, identifying specific VOCs linked to particular diseases. To enhance compound separation and analysis, gas chromatography is often combined with mass spectrometry (GC-MS), which aids in identifying unknown compounds in the volatile sample. This approach presents numerous benefits. Relative to optical imaging-based detection methods, GC/GC-MS provides heightened specificity and delivers more accurate insights into plant diseases. Moreover, it allows for disease detection at different stages.

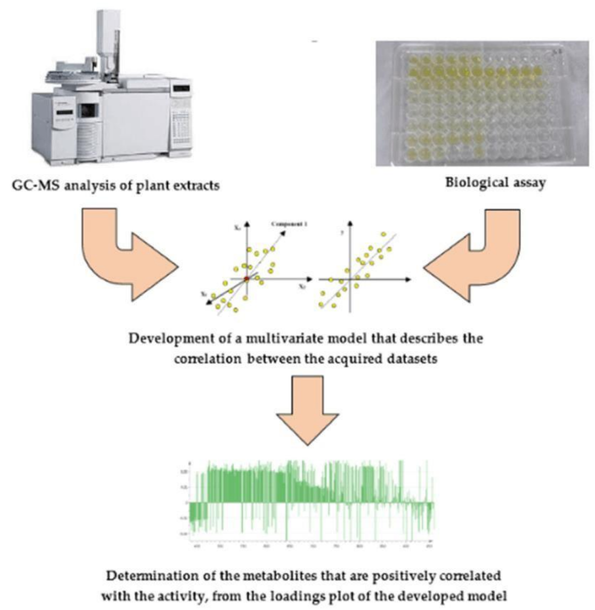

Fig. 6: Gas Chromatography Disease Detection Method

One limitation is that, unlike imaging systems that can collect data directly in the field, GC/GC-MS requires the sampling of pre-collected VOCs over an extended period before data analysis, which limits its on-field usability. Moreover, the price range depends on the setup, with additional maintenance costs, further restricting its practical application [24].

Table III: Comparison Table for Disease Detection Methods

Methods	Advantages/ Limitation	Price & Practicality
Thermography Disease Detection Method	Advantages: - Simple, competent, and inconspicuous monitoring. - Effective both during the day and at night. - Low maintenance requirements for reduced total cost of ownership. - High performance in various weather and air conditions (rain, fog, snow, smoke). Limitations: - Unable to distinguish between different types of infections. - Thermal images cannot penetrate certain materials like water and glass. - precise disease control is challenging due to the sensor's sensitivity to environmental fluctuations during measurements	Initial cost is high. & Highly practical
Fluorescence Disease Detection Method	Advantages: - Monitoring of nutrient deficiencies, environmental stress levels, and plant diseases. - High sensitivity, selectivity, and low background noise. - Ability to determine fluorescence intensity, decay time, and component concentration. - Potential insensitivity to light scatter. Limitations: - Potential risks of toxicity arising from foreign substances - Sensitivity to disturbances resulting from fluctuations in sample pH and oxygen levels - Strict protocol required for plant preparation, making implementation challenging in agricultural greenhouses or field environments.	High. & Implementation of fluorescence measurement in field settings is limited.
Hyperspectral Disease Detection Method	Advantages: - Enhances disease detection, identification, and monitoring in precision agriculture applications. - Provides detailed information about objects due to narrowband information acquisition and fine spectral resolution. - Utilizes spatial relationships among different spectra for more accurate segmentation and classification of images. - Differentiates between crops and weeds based on their spectral characteristics, guiding targeted weed control strategies and optimizing resource allocation. Limitations: - Hyperspectral data of plants may suffer from variations in illumination due to light scattering, shadowing of plant parts, and complex combinations of scattering and shadowing. - High initial cost and complexity.	Very high price. & Despite the limitations, hyperspectral imaging remains highly practical for various applications.
Gas Chromatography Disease Detection Method	Advantages: - Compared to optical imaging-based detection methods, GC/GC-MS provides higher specificity and more accurate information about plant diseases. - It also allows for disease detection at different stages based on quantitative information collected from the VOC sample. Limitations - GC/GC-MS requires the sampling of pre-collected VOCs over an extended period before data analysis, which limits its on-field usability. - Maintenance cost is too high.	Depends upon setup Maintenance cost is additional & Limited

V. CONCLUSION

Hyperspectral imaging is positioned as the most promising indirect imaging technique for plant disease detection, thanks to its robustness, accurate targeting, and rapid data analysis abilities. Its technique involves using a camera mounted on an unmanned aerial vehicle (UAV) to gather data over a broader area of agricultural fields. It not only detects infected plants but also clearly differentiates between weeds and plants to help the former to spray only those areas which consist of weeds so that healthy plants are not affected. Also, it is not affected by the environmental changes that make it highly reliable and accurate. In contrast, thermography and fluorescence imaging, while also indirect methods, are not well suited for on-field crop disease detection. They lack specificity and are vulnerable to the influence of ambient environmental conditions, diminishing their effectiveness in accurately identifying and diagnosing plant diseases in real-time field conditions.

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