DOI: https://doi.org/10.54083/978-81-980121-1-1-1

CHAPTER : 01

Plant Disease Detection: Current Scenario, Emerging Challenges and Technology Advancement

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Abstract

Plant diseases are the driving force for substantial losses to the agricultural industry all around the globe. There is sufficient information available regarding most of these pathogens and their nature of damage. But effective management of all these biotic stresses is still a great challenge to plant pathologists and farming community as accurate identification and diagnosis of plant diseases are not possible with the available conventional methods. Serological techniques like enzyme-linked immunosorbent assay (ELISA) and molecular methods such as polymerase chain reaction (PCR) brought a revolution in disease diagnosis and detection but it takes long time in terms of sample harvesting, processing, and analysis. Simultaneously, it is not very reliable at the asymptomatic stage, especially in case of the pathogen with systemic infection. Keeping pace with these emerging challenges and requirement of advanced, reliable, sensitive and specific diagnosis tool, there is a strong need of innovative technology which may enable detection of early stage of disease development. Detection of plant disease through some automatic technique will be beneficial as it will reduce a work of monitoring in big farms. To meet the requirements, the technology like application of novel sensors based on host response, biosensors and remote sensing techniques coupled with spectroscopy-based methods, Image segmentation for detection in plant leaf diseases should be adapted. These techniques may produce successful and efficient detection of disease in primary infection stage. The biosensors and remote sensing technologies make the monitoring and forecasting more effective and easy. Hence, the application of these innovations may become an unbeatable tool for timely detection and diagnosis of the devastating pathogen and helps to generate effective management practices which are economical, ecofriendly and farmer-friendly crop protection tools.

Keywords Biosensors, Disease diagnosis, Internet of things, Remote sensing, Spectroscopy

Introduction

Diseases are important constraints in agricultural field which leads to excessive crop loss. Every year, large area of crop field is destroyed due to diseases which severely affect the economy of country. Accelerated development of global trade and the distributions system also impacted by

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In: Current Trends in the Diagnosis and Management of Plant Diseases. (Eds.) Dutta, P., Upamanya, G.K., Pandey, A.K., 2024. Biotica Publications, Tripura, India.

plant diseases. It causes stress in plants, social issues or political issues. In the past 45 years, 20% and 40% of global crops have been lost annually to pests and diseases respectively. The average worldwide yield losses caused by pests and diseases in wheat, rice, maize, potatoes, and soybeans are estimated to be 21.5%, 30.0%, 22.6%, 17.2%, and 21.4%, respectively. In addition to this, many new diseases are emerging now a day due to climate change and shift in host range. To mitigate this problem, a huge amount of pesticides are applied blindly without proper detection and diagnosis which leads to improper management of diseases, ecological imbalance and also increase in cost of production. According to FAO statistics, the consumption of pesticides increased from 3.05 million tonnes in 2000 to 4.09 million tonnes in 2016. In the era of precision farming, need based application of chemical is mandatory. The detection, quantification, diagnosis, and identification of plant diseases is particularly crucial for precision agriculture. Recently, traditional visual assessment technology has not been able to meet the needs of precision agriculture. Therefore, the early and accurate detection, monitoring, and assessment of plant diseases is important and necessary for farmers, managers, and decision makers and accordingly management practices should be undertaken. Proper diagnosis of disease is the first step towards management of disease in economical way. There are different methods of disease detection which are gradually upgraded with time, need and technological advancement.

Conventional method of disease detection

Diseases are more or less present in the crop field since time immemorial causing loss to the crop. People treated it as curse of god those days. Later on, they realized, it is a disease and treat them accordingly with their available resources. Conventionally diseases were identified by visual observation basing on their traditional knowledge and skill. It may be diagnosed by observing the symptoms or presence unusual things on plant parts. But this technique required trained person with in depth knowledge on different symptoms and sometimes it is very confusing. With the advancement of technology and plant pathology, microscopes are made and upgraded with time. Diseased samples were cut, scrapped or teased and slides were prepared. This is an effective method to detect the causal pathogen, but again it requires trained person and small laboratory set up with a microscope. Still it is widely used techniques in field condition. Ooze test is another very common method to confirm bacterial infection of plant. The release of white thread like ooze from the infected part, when cut and dipped in a clean glass of water confirms the positive association of bacterial infection. It does not specify the type of bacteria responsible for disease but it is still widely used technique as it does not require any laboratory set up nor requires any trained person. Looking into the constraints in conventional techniques, many new techniques of disease diagnosis and detection have been designed.

Current technologies for disease detection and challenges

With advancement of technology many techniques were developed which are commonly used in many laboratories in current situation. It is broadly divided into two main groups i.e. direct method and indirect method. Direct methods identify pathogen directly and detect the disease with maximum accuracy e.g. molecular and serological methods. Indirect methods are based on changes in morphology, temperature, transpiration rate etc in infected plant as compared to healthy plants. Measurements of volatile organic compound released by infected plants are also important parameter to detect plant disease e.g. Thermography, Fluorescence imaging, hyperspectral techniques etc.

Polymerase chain reaction (PCR)

It is a molecular method of disease detection which amplifies the nucleic acid of the pathogen. It is a primer mediated enzymatic amplification of a DNA segment lying between two regions of known sequences using DNA polymerase. The reaction has three phases such as denaturation, annealing and extension. This cycle is repeated 25-40 times to amplify the target sequence to more than a million fold which can be detected in electrophoresis. PCR has been put to various uses after suitable modification. Reverse transcription PCR (RT-PCR) used in detection due to its high sensitivity. Multiplex PCR is another type of PCR which enable simultaneous detection of different DNA or RNA by running single reaction. Real time PCR used for on site, rapid diagnosis of plant diseases based on nucleic acid of pathogens.

It is a portable method which is easy to operate providing greater accuracy with highly sensitive and specific due to the fidelity of DNA amplification. It is faster and cheaper and can detect lower pathogen amounts because antibodies are not required. Very small amount of sample are needed in this technique. Dry, fresh or frozen or even partially degraded sample can be used. But, it is confined to laboratory only which requires expensive instruments, advanced set up, skilled persons for conducting experiments. It needs 1-2 days for sample harvest, processing and analysis. There is need of primer designing to initiate replication which limits its applicability in field. It is not very reliable at asymptomatic stage especially in systematic diffusion rate. The result may be affected by inhibitors present in the sample assay. Different factors like concentration of PCR buffer, dNTP may bring faulty results and it requires skilled person in each and every steps.

Enzyme Linked Immuno Sorbent Assay (ELISA)

It is a serological method of detection based on antigen and antibody where substrate changes the colour due to presence of enzymes; hence a low concentration of pathogen can be detected i.e. 1-10ng/ml. Precipitation and agglutination test which were commonly used conventionally require more amount of antibody and less sensitive. It is an extremely sensitive, rapid testing using small sap sample and antibodies. The pathogen concentration can also be quantified by measuring intensity of colour. There are many variations of ELISA like Double antibody sandwich assay (DAS/ Direct ELISA) and Indirect ELISA (I-ELISA). Large number of samples can be tested simultaneously. The procedure for conducting such test can be semi automated and result is quantitative. It is only useful only for confirmation after appearance of visual symptoms. It is not applicable for early detection. It is more widely used for detection of viral diseases due to its poor sensitiveness towards bacteria.

Fluorescence *in situ* hybridization (FISH)

It is a molecular disease detection technique which combines microscopy and hybridization of DNA probes and target gene from plant samples. It is used to detect pathogen infection in plants by recognizing pathogen specific ribosomal RNA(rRNA). It is use to detect bacteria, fungi, virus and other endosymbiotic bacteria in plants. High affinity and specificity of DNA probes provides high single cell sensitivity in FISH because the probe will bind to each other of ribosomes in the samples. It can detect culturable microorganism as well as unculturable organism in order to investigate complex microbial community. The major drawback in this technique is it can give false positive results with autofluorescence material. Accuracy and reliability of FISH is highly dependent on the specificity of nucleotide probes. False negative can be caused by insufficient penetration, higher order structure of target or probe (3D rRNA, loop and hair pin formation and rRNA protein interactions), low rRNA content, Photobleaching. Apart from these, it requires complex sample preparation. This technique is confined to laboratory condition and required skilled person to conduct experiments and professional data analysis for interpretation.

Immunofluorescence (IF)

It is a fluorescence microscopy based optical technique used for analysis of microbial samples to detect infections in plant tissues. In this technique, plant sample fixed to microscope slides with thin section along with fluorescent dye with specific antibody to visualize distribution of target molecule throughout the sample. The important limitation in this case is photobleaching which results into false negative result. It can be controlled by reducing intensity and duration of light exposure, increasing the concentration of fluorophores and employing more robust fluorophores that are less sensitive to photobleaching. It is also laboratory based technique requiring skilled person and not applicable for field condition.

These techniques required sophisticated laboratory, skilled technician, display low specificity and takes long time. It does not provide real time monitoring. It is not applicable for large field. It cannot detect early stage of crop. It only confirms presence of pathogen after symptom expression. Growers generally demand for a handy technology which can be used in field level, detect the pathogen rapidly, real time, inexpensive, non destructive technology.

Flow cytometry

It is a laser based optical technique used for cell counting and sorting, bio marker detection and protein engineering. It is used for rapid identification of cells while cells pass through an electronic detection apparatus in liquid stream. It uses an incident laser beam and measures scattering and fluorescence of the laser beam reflected from the sample. It is efficient for detection of soil borne bacteria such *Bacillus subtilis*, useful for viability evaluation. It can detect 10^4 CFU/ml accurately within 30 minutes. It is also used in study of antibiotic susceptibility, enumeration of bacteria, differentiate viable and non- viable bacteria and characterize bacterial DNA and fungal spore. Apart from its wide advantages, it has many drawbacks also. It produces unnecessary data which complicates the data analysis. It requires professional and experienced technicians for interpreting the results of data analysis. Involvement of expensive instruments makes it less likely for use in the field.

Modern innovative approaches for disease detection

These modern innovative approaches offer pathogen detection easy, rapid, inexpensive, and reliable at pre symptomatic to early spread stages. Few of the technology listed are novel sensor based on the analysis of host responses, biosensors based on phage display and biophotonics can also detect instantaneously infections although they can be integrated with other systems, Remote sensing techniques coupled with spectroscopy based methods, analysis of volatile compounds and genes as biomarkers of diseases. Some modern technology used in disease diagnosis are listed below

Thermography

It is an indirect method of disease detection based on plant stress profiling. It allows imaging the differences in surface temperature of plant leaves and canopies. The emitted infra red radiation can be captured by thermographic cameras and the difference in colour can be analysed. It is a promising tool to monitor the heterogenicity in the infection of soil borne pathogens. It is highly sensitive to changing environmental condition during measurement. It lacks specificity towards disease. So, it is difficult to identify type of infection as similar thermographic patterns created by many diseases.

Hyperspectral techniques

Hyperspectral imaging technique is used for plant phenotyping and crop disease identification over a large area. Hyperspectral cameras facilitate data collection in 3D with X and Y axes for spatial and Z for spectral. It is used in disease detection by measuring the changes in reflectance resulting from biophysical and biochemical characteristics changes upon the infection using over a wide range of spectrum between 350-2500nm. It is a robust technique which provides rapid analysis of imaging data. It is highly specific and widely used technology. Images can be taken by drone i.e. unmanned aerial vehicle from a large area. Different diseases such as blast of rice, apple scab, late blight of tomato can be successfully identified by this technique.

Fluorescence imaging

The chlorophyll fluorescence is measured on leaves as a function of incident of light. The changes in fluorescence parameter can be treated as infection of pathogen basing on changes in photosynthetic apparatus and photosynthetic electron transport chain. The temporal and spatial variation of chlorophyll fluorescence were analysed for precise detection of leaf rust and powdery mildew infection on wheat leaves at 470 nm. This technique is not specific and susceptible to ambient environment. Hence, it is less useful for on field disease detection.

Gas chromatography

It is a non optical, indirect method which involves the profiling of the volatile chemical signature of the infected plants. Infected plants release specific volatile compounds (VOCs) that are highly indicative of the type of stress experienced by plants. VOC are low molecular weight bio-molecules with high vapour pressure and low boiling point that exist in gaseous phase under standard temperature and pressure. VOCs emitted from plants, indicates its physiological health status. VOCs are released from green leaf plants when they are damaged mechanically or pathogenically that may be during herbivore invasion. Profiling of such volatile organic compounds can be used to identify the type and nature of infection and accordingly be used for disease diagnostics and confirmation. Gas Chromatography (GC) is used to analyze the presence of specific VOC that is indicative of a particular disease. It is often combined with mass spectrometry (GC-MC) to identify unknown volatile compounds. It provides accurate information about the plant disease due to its high specificity. It can detect disease at different stages based on quantitative information collected from volatile organic compound samples. It is a laboratory based technique, which involve complex procedures. Hence, skilled person is required for conducting experiment and professional analysis of data. It requires sampling of pre-collected volatile organic compound for longer time before data analysis, which limits its field application. Novel methods of data analysis are also required for interpretation of experimental results which needs hardware and software tool are the major obstacle for bringing this technique to the field.

Disease detection based on use of VOC marker

There are several VOC markers which are associated with host response, independent of plant species and disease type. One commonly used VOC marker is ethylene, which plays important role in fruit ripening. Miniature ethylene sensors are portable but low in accuracy and sensitivity. The advanced detectors are too large to be used in crates or shipping containers and are bit expensive also. Ethylene sensor only provide single targeted molecule. The untargeted VOC profiling is more effective as it provides information regarding presence and quantification of multiple VOCs. GC-MS is the best option for VOC profiling as it uses a gas phase separation and detection of individual component for VOC mixture by providing comprehensive structural and chemical information. Other spectrometric based techniques include proton transfer reaction mass spectrometry (PTR-MS) and selected ion flow tube mass spectrometry (SIFT-MS). Both above methods provides near real time profiling and measurement of volatile organic compound samples. Current MS based are bulky and not likely for direct and on field analysis, but can be practiced if it is miniaturized.

Currently VOCs are collected and sent to lab for chemical analysis and characterization. It can be collected by active sampling and passive sampling. Passive sampling uses small, functionalized polymer traps like solid phase micro-extraction (SPME) or stir bar sorptive extraction (SBSE). In SPME, different functionalized surface and film thickness are used for enhanced trapping of particular VOCs classes such as volatile, semi-volatile, polar or non polar compounds. In active sampling, VOCs can be sampled by collecting directly surrounding the plant several times and passing through high capacity sorbent traps followed by chemical detection and analysis. Active sampling requires thermal desorption introduction system to transfer and focus the samples into the GC/MS system.

Differential mobility spectrometry (DMS) are the alternative portable chemical detection system for VOC profiling which can be attached to MS system (Krebs *et al.,* 2006).They can be used as standard alone separation and detection devices (Aksenov *et al.,* 2012). It can be easily employed in field for VOC analysis as there is low power requirement less support infrastructure and portable. It offers higher throughput near real time measurement but lower resolution than MS. GC can also used to analyse complex bacterial samples (Shhaydeman *et al.,* 2005, Cheung *et al.,* 2009) and diagnose citrus disease (Aksenov *et al.,* 2014).

Lateral flow microarrays

It allows rapid, hybridization based nucleic acid detection using easily visualized colorimetric signals (Carter and Carry, 2007). These arrays are built on miniaturized lateral flow chromatography microcellulose membrane, hybridize in minutes, have detection limits similar to microarrays and can reduce the need for expensive lab instruments. It depends on availability of storage and reliable host and pathogen biomarkers discovered through transcriptomic approaches (Martinelli *et al.*, 2012 a, 2013 a). Metabolomics is widely used to identify key primary metabolites of primary and secondary metabolism usable as biomarkers for different environmental stressed or pathogen infections.

Biosensors

Sensors are commonly in use these days in various fields. It can detect different stimulus basing on its principles using electrical, chemical, electro-chemical, optical, magnetic or vibration signals. The efficiency of these sensors can be enhanced by use of nano material matrics as transducers and specificity could be enhanced by the use of bio-recognition elements such as DNA, antibody and enzymes etc. These biosensors can be a great technique for diagnosis of diseases.

a. Biosensors based on nano materials

Nanoparticles, due to its high surface area, high electronic conductivity, plasmonic properties, assembly of bio recognition elements, it can be exploited well for development of biosensors for disease detection. The immobilization of the bio-reorganization elements such as DNA, antibody and enzymes can be achieved by various approaches like biomolecule adsorption, covalent attachment, encapsulation or sophisticated combination of these methods.

Metal and metal oxide, nano particles, quantum dots, carbon nano materials such as carbon nanotubes and grapheme as well as polymeric nanomaterials are commonly used nanomaterials for biosensors. Quantum dots can also be used as biosensor for disease detection. Using this technique disease can be detected by fluorescence resonance energy transfer (FRET) mechanism which describes energy transfer between two light reactive molecules. Gold nanoparticles are widely used due to its high electroactivity and electronic conductivity for electron transfer. AuNp modified electrode can be used for detection of methyl salicylate, a key Volatile organic compounds released by plants during infection (Umasankar and Ramasamy, 2013). Semi-conductive metal oxide nanoparticles have also used for detection of VoC due to its low cost, suitability for electron conduction for amperometric signal and ease to obtain desired shape and size. SnO2 and Tio2 can be used to detect p-ethyl guaiacol produced by infected strawberry (Fang *et al.,* 2014). In addition to detection of VoC, nanoparticle based sensors can also used for detection of compound released by pathogens.

b. Affinity biosensors

There are different non specific nano particle based biosensors, but the affinity biosensors which are achieved based on reaction of the bio recognition elements and target analyte. These affinity biosensors are developed by using antibody and DNA as recognition elements which greatly increase the specificity of sensors.

c. Antibody based affinity biosensors

Antibodies are widely used in diverse immunosensing applications. It is helpful in fast detection, improved sensitivity, real time analysis and has potential to analysis (Skottrup *et al.,* 2008). It can detect pathogen from air, water and seed in various areas like green house, field and post harvest stores and distributors.

A specific antibody coupled with a transducer, which converts binding event to a signal that can be analysed. This tech has been tremendous progress upon implementation of nano technological approaches for the sensor fabrication. For rapid diagnosis of viral infection, gold nano rods functionalized by antibodies has been widely used.

Antibodies are vulnerable and easy to get denatured which require specific pH and temperature etc for storage. It may deteriorate over time. Exposure of bacterial strain to environmental stress such as pH, temperature could cause errors in measurement. These are the important limitations which restricts its use for disease detection.

d. DNA/RNA based affinity biosensor

This technique involves use of specific nucleic acid fragment for pathogen detection. It is applicable for detection of disease before appearance of any visual symptoms. It is based on a specific nucleic acid hybridization of the immobilized DNA probe as a sensor and analyzes DNA sequence. It allows rapid, simple and economical testing of genetic and infectious diseases. In this case, a single stranded DNA on electrodes with electroactive indicators is use to measure hybridization between probe DNA and complementary DNA in the analyte (Eun and Wong, 2000). For which, it requires synthesis of specific DNA probe, amplification of DNA which is important drawback of the technology. It involves high cost and unsuitability for real time detection.

e. Enzymatic electrochemical biosensors

The use of enzyme as a bio-recognition elements provide a high level of selective detection of target pathogen due to its high specificity. An enzyme specific for the analysis of interest is immobilized on the nano-material modified electrode. The reaction between the target analyte and electrode results into electrical signal which can be used for quantitative detection of the analyte. It can be used, if the target volatile organic compounds can be collected in the form of liquid samples. Many of the volatile organic compounds produced by infected plants are alcohol and aldehyde which can be catalyzed by alcohol dehydrogen enzymes. Accordingly these enzymes can be used for the development of biosensors for detection of alcohol or aldehyde based VoCs which are specific to the infection. It is highly sensitive and specific for disease detection but are not stable. Enzyme catalysis affected by various factors like temperature and pH.

f. Bacteriophage based biosensors

It is a virus which infects bacteria, replicate inside it and finally lyses the bacterial host to propagate. It is a noble organism which is widely used phage therapy not only in human but also in plant disease. Due to its high selectivity, high sensitivity, low cost and high thermostability, it can be a great alternative for detection of bacterial plant pathogen. During the interaction between bacteriophage and target analyte, a change in charge transfer occur at the interface which is used as signal for detection. It can be used as recognition element for biosensor due to its thermostability, low cost, high specificity and sensivity. It can works well at different range of temperature unlike other antibody based biosensor. It can easily differentiate between live and dead pathogen which reduces the confusion and false positive signals during observations. Apart from all these boons, it takes long time due to its complex sample preparation process (Tlili *et al.,* 2013). One important drawback for developing such biosensors is it only restricted to detection of bacterial plant diseases and not applicable for fungal or viral disease which contributes more to overall diseases and cause maximum loss to the crop.

Internet of things

Internet of thing collects tons of data by smart sensors. It provides better control over the internal processes. It also produces cost management, waste reduction, process automation and enhanced product quality and volume. It may replace the need of manual identification method in large field in future without entering the field. It can cover a large area and allows farmer to monitor the field by working at their own places without physically entering into the field.

Internet of things system includes sensors and cameras which capture images of leaf which divided into 80 and 20 ratio for training and testing of image. The colour, texture, shape, sizes are the various attributes used in this techniques. Several steps are involved in this technique such as Acquisition of image, processing of image to remove noise and normalize data followed by image analysis which separates healthy and diseased region based region based on colour. It includes feature extraction and feature selection like colour feature contains information about boundary, spot and broken areas. The shape attributes includes percentage of lesion and its type. Texture feature contains uniformity, contrast, probability, variance and correlation. After identification of features, the data base divided into images for training and testing. Training images used to build deep convolutional neural network to extract macro information about image. There are various CNN architecture which are available that can be used in this approach concerning the identification of plant leaf disease which were Alex Net, Google Net, VGG. It is based on image processing techniques. It is easy to detect disease but require great set up and trained person to operate and analyse the data for interpretation.

Remote sensing

Remote sensing is a technology of obtaining information of an object without actually being in contact with it. This is done by sensing and recording reflected or emitted energy followed by analysis and application.

Remote sensing methods can be divided into non imaging or imaging sensor based applications. Non imaging sensors includes radiometers i.e. spectroradiometers (hand held or mounted on elevated platform or tractors) and fluorescence radiometers. Imaging sensors includes RGB camera (visible or infra red), multispectral (broad band) sensors and hyperspectral (narrow band) sensors, thermal infrared sensors and fluorescence imaging sensors. Less frequently used sensors include passive microwave radiometry in THz bands, nuclear magnetic resonance (NMR) and X-ray imaging. There are different issues such as atmospheric effect, pixel herogenicity and acquisition geometry should be taken into account when analyzing the signal while measuring in high altitude.

It is used to detect different stress such as biotic and abiotic stress in plants basing on its canopy characters and physiological processes. Canopy structures such as leaf area and orientation, spatial arrangement and roughness and optical, di-electric or thermal characteristics of the vegetation elements influence the spectral signature. A stressed plant shows changes in variables such as leaf area index (LAI), chlorophyll content or surface temperature which produces different spectral signature than healthy, unstressed vegetation. These differences in stressed plant can be monitored by remote sensing by analyzing changes in radiation harvesting and use by the plant. The total energy absorbed by plant (Absorbed Photosynthetic

Active Radiation (APAR)) is determined by plant's total leaf area and by the concentration of pigments (Chlorophyll). A healthy plant uses APAR primarily for photochemical reactions (0-20%) and dissipates the rest as heat (75-90%) and fluorescence (2-5%) (Meroni *et al.,* 2010). When a plant is infected by a pathogen, it activates numerous defense responses. The methods can be improved by integrating different remote sensing technologies such as fusing spectroscopy and fluorescence data (Moshou *et al.*, 2005, Blasco *et al.,* 2007, Sighicelli *et al.,* 2009).

In early stage of infection, before appearance of prominent visual symptoms, pathogen reacts with plant and affects the physiological mechanism such as decrease in photosynthesis rate which increase fluorescence and heat emission (west *et al.,* 2003). The presence of stress factors changes the thermal properties of plant, which in turn influence the radiation emitted and also changes of the water content of leaves which can be detected at the early stage of the diseases (Costa *et al.*, 2013). In later stage of infection, there is reduction of chlorophyll content due to necrotic or chlorotic lesions that increase reflectance in the VIS and cause shift of the edge position in the spectrum. The browning effect due to senescence of infected spots on leaves can influence the VIS and NIR regions due to dryness. At the canopy scale, infection can change canopy density and leaf area which can be observed in the NIR (Franke and Menz, 2007).

Remote sensing can provide information on both physical processes on going under stress conditions, such as passive fluorescence effects or thermal energy dissipation and plant parameters like leaf pigments, water content and chlorophyll content. It can detect (deviation from healthy), Identify (diagnosis of specific symptoms among others and differentiation of various diseases) and quantify (measurement of disease severity e.g. per cent leaf area affected) disease (Mahlein *et al.,* 2012 a). Different sensors and techniques are required for detecting plant response to various diseases and disease severity. Joint monitoring of leaf temperature, chlorophyll fluorescence and hyperspectral vegetation indices (VIs) has provided good capabilities in identifying and distinguishing cucumber diseases like mosaic virus, green mottle mosaic virus and powdery mildew (Berdugo *et al.,* 2014).

The data acquired from different UAV can be processed and interpreted accordingly. Remote sensing offers good perspective for disease monitoring. It enhances the spatial resolution of recent satellite sensors and decrease in cost of data acquisition. Increase in availability of small, inexpensive, high resolution spatial and spectral sensors has enhanced the operational capabilities of remote sensing through UAV mounting spectral sensors for crop disease monitoring at the farm scale. Different statistical softwares such as MATLAB, R, Weka are commonly in use by researcher and target users of products covering plant disease assessment.

It is a great technology to detect in its early stages of infection and can be recorded from long distance in large scale. But the measurements can be taken at a distance from which single leaves cannot be observed. Often the imaging sensors are mounted on air craft, drones or satellites. It involves high cost in installation of *in situ* spectro-radiometry and air borne platforms.

Specialized and experienced workers are needed to gather and process data. Currently developed protocols are only confined to few diseases only not universally adapted for all the crops. These points makes it unfit for on field diagnosis of disease.

Conclusion

The development of disease diagnostic tools is quite advanced with advancement of technology. As new diseases emerging day by day due to changing climatic conditions and cropping patterns, the tools should be designed accordingly. The availability of UAV mounted hyperspectral sensors and integration of spectroscopy fluorescence and potentiality thermal imaging tech used in combination with data from non remote sensing based methods can be an interesting and fruitful approach for studying plant diseases in future. Despite the challenges, the modern tools have shown tremendous potentials in improving plant disease diagnosis and crop health monitoring in long run. The future of these advanced technologies is indeed very bright in the coming era of digital farming and precision agriculture.

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