relationship between spectra information, chlorophyll content, and disease severity assessment. After that, the leaves with angular spot diseases were mapped with the healthy cucumber leaves to know the ratio of chlorophyll and carotenoid contents. The mapping was done by employing an optimal pixelwise model [165].

The limitations of the above studies include the image resolutions and illumination level. Image resolution plays an important factor in performing the disease severity analysis. This is because diseases may look very similar, and if a higher resolution camera is employed, the detection of details of tiny pores and lesions can be obtained. Also, the lighting level and weather conditions should be consistent, while data are collected for disease severity analysis. A variation in the light and weather conditions can capture a poor-quality image, which might result in a wrong disease severity analysis [300].

4) Genetic Resistance of Diseases: Diagnosing pathogen–host interaction is very important to know the genotype's resistance to a particular disease. This assessment is critical for the breeder to establish a sound breeding system. Generally, the genotype phenotyping of plants is manually performed by experts by using costly visual examination techniques. Hyperspectral images can be used to automate the phenotyping process for the breeders [17] to reduce the burden on the human experts and the cost.

Downy mildew is one of the most common types of diseases in the grapevines. Spectral reflectance methods were used to identify the discoloration of the grape leaves. The leaves' color usually starts to change to brown before the downy mildew symptoms appear, and reflectance values of the hyperspectral images also change accordingly. The spectral indices provide much information, such as relative water content in tissue, chlorophyll pigments, and biochemical activity. The hyperspectral images captured at the 750–900 nm range could provide the phenotype to resist the diseases in grapevines [171]. A study regarding powdery mildew resistance in barley cultivars was conducted by Kuska et al. [311]. Every day, the reflection of healthy and infected leaves was recorded using the hyperspectral camera at 400–700 nm in the visible range and 700–1000 nm in the infrared range for two weeks. The study shows that resistant leaves increased the reflection level compared to the other healthy leaves in the visible wavelength range. However, no significant changes could be observed in the infrared spectrum of wavelengths [311].

A study regarding the genotype resistance of Cercospora leaf spot disease for sugar beet was conducted by Leucker et al. [312] in a laboratory setting. Using the traditional quantitative and qualitative techniques, the lesions of Cercospora leaf spots were ranked. The spectral information of hyperspectral images shows that the spatial distribution of the pathogens in the leaf can estimate the intensity of the pathogen invasion on the leaves. Therefore, the resistant plants had a lower spatial distribution of pathogens in the leaves. The investigation of this study shows that lesion phenotyping can play an essential role in knowing the genotype of plants for disease resistant [312]. Table V presents the models used for the applications of hyperspectral imaging in plant disease detection.

The aforementioned studies mainly depended on spectral reflectance methods and their sensitivity to the slight changes in plant phenotypes and spectral reflectance patterns. However, the spectral reflectance methods may be highly sensitive to factors other than disease presence, such as water content, chlorophyll pigments, and biochemical activities. This sensitivity could affect the accuracy of disease detection [171]. Hence, it is essential to calibrate the hyperspectral imaging systems under consistent environmental/weather conditions and conduct extensive testing under various conditions to understand how factors like water content, chlorophyll pigments, and biochemical activities might affect the reflectance values. The studies above also show that they are limited to the effectiveness of the infrared spectrum [311]. To overcome this problem, multiple wavelength ranges in the visible and NIR spectra can be explored to know which wavelengths are most informative for disease detection.

C. Limitations and Potential Solutions

Over the years, remarkable progress in monitoring plant diseases by hyperspectral images has been achieved. However, some pressing issues must be resolved to ensure a reliable application and interpretation. The challenges and the potential solutions can set future research trends. The current limitations and possible solutions are listed as follows.

1) Most hyperspectral image analyses are performed when the diseases are fully displayed on the plants/crops. Therefore, there is a need to develop reliable plant disease and pest monitoring remote sensing platforms so that the spread of the diseases can be prevented in the early stage [16], [17].

2) Accurate detection of different types of pathogens and stress (abiotic/biotic) levels remains one of the unresolved issues for plant disease detection [16]. This is because the biochemical analysis is not taken into account. The hyperspectral images can potentially find the active pathogen and stress components because they can operate within limited wavelength bands [313]. To combat these issues, higher spatial resolution can be used to detect pathogens more accurately. In addition, auxiliary data such as soil information, meteorological, and field management data can be used to detect the abiotic and biotic stress levels in the plants [16].

3) Most of the experiments are conducted in laboratory-based settings. In other words, illumination levels are also controlled or manually positioned in controlled environmental conditions to ensure that the hyperspectral images can capture the leaves or plants. However, the illumination level can vary for a large field of crops/plants. Due to the variation in illumination level, the tissue colors can also appear different. Therefore, the results obtained through the laboratory setup cannot guarantee the same results in a large field as they are subjective to the angle of incidence. Hence, more studies should be conducted at the canopy level and the larger field areas [17], [314], [315].