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Mini Review

Revolutionizing Vegetable Crop Management with High-Throughput Non-Destructive Phenotyping and Remote Sensing Technologies

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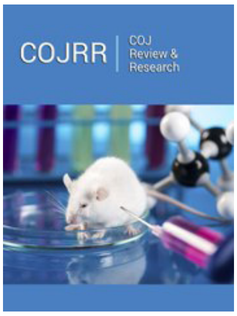

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Abstract

In the coming decades, modern agriculture will face challenges due to population growth, climate change, sustainability demands, and quality expectations. To address these challenges, efficient resource management and innovative crop enhancement methods are essential. Precision phenotyping, aimed at assessing crop traits and selecting superior genotypes, is a primary focus for geneticists and breeders. Despite significant advances in genetics and genomics, a "phenotyping bottleneck" limits the utilization of genetic resources. Comprehensive phenotypic characterization is labor intensive and often inaccessible to many research groups. To overcome this bottleneck, high-throughput, accurate phenotyping is crucial. Remote sensing technologies are gaining interest for characterizing agronomic traits, and it's anticipated that the development of efficient phenotyping strategies will parallel genomics innovation in the next decade, ushering in a new era of digital agriculture.

Keywords: Remote sensing; Imaging techniques; Hyperspectral imaging

Introduction

The field of phenotyping encompasses a wide range of approaches, each with its specific depth scales and processivity levels. This diversity of phenotyping techniques allows for comprehensive analysis of plant traits, from the whole-plant level down to the cellular scale. In this context, High-Throughput Phenotyping (HTP) has gained significant attention as it enables the rapid assessment of numerous plants, particularly in field conditions. High-throughput phenotyping involves non-destructive analysis, making it ideal for field tasks like resource management and crop monitoring. Automated systems can process numerous plants daily, aiding decision-making in agriculture. On the other hand, high-resolution phenotyping offers precision but often requires invasive methods.

Phenotyping platforms can be mobile or stable, suited to open fields or controlled environments. Advanced platforms are available, but their use in vegetable crops is limited. Vegetable production's significance makes innovative phenomic strategies valuable, despite the cost of advanced platforms. This review focuses on non-destructive, high-throughput phenotyping in vegetable crops, aiding plant breeding for growth, quality, and stress resistance. Challenges in handling the generated big data are discussed. In summary, high-throughput phenotyping has the potential to transform plant breeding and crop management in vegetable crops, emphasizing the importance of non-destructive sensing technologies [1].

Remote Sensing Technologies in Horticulture

A. Radiation interception, involving measurements of radiation (e.g., Photosynthetically Active Radiation or PAR) intercepted by plants, is a simple and effective method for assessing plant characteristics.

B. It is commonly used to detect plant organ morphology, characterize canopy architecture, estimate plant biomass and volume, and calculate indices like the Leaf Area Index (LAI) [2]. Simple measurements of light extinction through PAR sensors, or 2D imaging with digital cameras in the visible range, provide valuable information for estimating plant biomass, leaf area, and plant morphology.

C. However, for complex plant structures, 3D imaging using stereo camera rigs and advanced computer programs is preferred.

D. Spectral analysis, particularly in the visible and Near-Infrared (NIR) ranges, provides insights into plant physiology. Reflectance, absorbance, and transmittance measurements can reveal information about plant water and nutrient status, photosynthetic activity, and the presence of biotic and abiotic stress [3].

E. Multispectral and hyperspectral cameras, as well as spectroradiometers, are used for such analyses [4]. Chlorophyll fluorescence analysis offers details about photosynthetic efficiency, and thermal imaging based on plant surface temperature is valuable for studying plant water relations and stress.

F. Plant performance indices, calculated from electromagnetic radiation measurements, are used to assess various plant characteristics, physiological responses, and stresses. These indices, such as the Normalized Difference Vegetation Index (NDVI) and variations like GNDVI, RVI, and GVI, provide insights into plant health, chlorophyll content, and stress levels.

G. However, selecting specific wavelengths relevant to the parameters of interest is crucial for obtaining reliable data. A range of vegetation indices is available, enabling in-depth phenotyping in vegetable crops.

Hyperspectral Sensing Studies

In recent years, hyperspectral sensing studies have demonstrated their significant potential in the field of agriculture, particularly in the Solanaceae family, including crops like tomatoes and eggplants. These studies have focused on early detection of various biotic stresses, quality assessment, and plant phenotype analysis. The use of hyperspectral sensing devices, spectrometers, and predictive models has allowed researchers to gain valuable insights into these agricultural applications.

Disease detection

Hyperspectral sensing devices have been used to detect symptoms related to biotic stresses such as fungal diseases. These devices have identified specific spectral regions, such as the red-edge subregion for chlorophyll-related stress, enabling early disease diagnosis [5].

Insect damage detection

Hyperspectral devices have also aided in identifying damage caused by insects. They have highlighted distinct spectral differences in the near-infrared region due to changes in foliage area and density, helping to quantify the degree and ultimate severity of damage.

Postharvest disease diagnosis

In the case of postharvest of tomatoes, homemade systems combining radiometry and spectrophotometry have been developed to distinguish inoculated from non-inoculated fruits based on spectral differences [6].

Quality assessment

Researchers have employed hyperspectral imaging to assess qualitative defects and ripeness stages in tomatoes. This technology has been successful in detecting surface bruises and classifying ripeness more accurately than traditional RGB imaging.

Chlorophyll content determination

Hyperspectral reflectance studies have been used to estimate chlorophyll content in leafy vegetables with different colors. Spectral indices have shown good correlation with chlorophyll content, indicating the potential for non-destructive assessments.

Bioactive compound quantification

Hyperspectral imaging has been used to quantify bioactive compounds in watermelon. Models based on these measurements have accurately predicted the content of phytochemicals in fruits [7].

Stress response assessment

The combination of hyperspectral and fluorescence imaging has been applied to study phenotypic changes in lettuce that is subjected to extreme temperature and salinity stress treatments. This approach has highlighted relationships between leaf color intensity and chlorophyll and anthocyanin content.

Conclusion

The utilization of high-throughput, non-destructive phenotyping techniques in vegetable crops, particularly through the application of remote sensing technologies like hyperspectral imaging, holds immense promise for addressing the multifaceted challenges faced by modern agriculture. These methods facilitate the rapid and accurate assessment of plant traits, enabling breeders and geneticists to select superior genotypes for enhanced growth, quality and stress resistance. The ability to detect diseases, insect damage, postharvest issues, and even quantify bioactive compounds creates new avenues for crop management and quality improvement. As we move into an era of digital agriculture, non-destructive sensing technologies are poised to revolutionize plant breeding and crop management, offering sustainable solutions to meet the demands of a growing global population.

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