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Advances in Nanopore Sequencing Technology and Its Role in Plant Pathogen Diagnostics

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Plant diseases lead to substantial yield losses worldwide and pose a considerable threat to food security and agricultural sustainability. Traditional Diagnosis methods (microscopy, ELISA, PCR) have been critical, although they lack the agility, portability and coverage to address a modern problem. Nanopore sequencing is a recent, groundbreaking, and disruptive approach to third-generation sequencing, in which the in situ real-time sequencing and portable capabilities are changing the way we define plant pathology. This article talks about the technological development of nanopore sequencing, comparing it with conventional techniques to diagnose diseases, its regulatory impact, and its future outlook. By connecting laboratory precision with real-world practicality, nanopore sequencing can revolutionize the management of plant health and contribute to global food production.

Keywords: Nanopore sequencing; plant pathology; diagnostics; metagenomics; agricultural biotechnology; detection of pathogens; food security.

Introduction

Plant agents — fungi, bacteria, viruses and oomycetes — continue to serve as a persistent threat to agriculture, reducing crop yields by as much as 40% each year. Conventional diagnostic methods are of benefit but demand enhanced comprehension of the pathogen, laboratory apparatus, and long time-to-return-period. On the other hand, nanopore sequencing affords real-time and portable, highly detailed analyses of nucleic acids and suggests its possible use in plant pathology.

Advances in Nanopores

Nanopore sequencing is used to transpose DNA or RNA molecules into protein nanopores that are deposited in membranes. As nucleotides pass through the pore, they disrupt ionic currents forming electrical signals associated to the bases involved. Such advantages consist of amplification free real-time sequencing, long-read, portable and direct RNA sequencing. There are scalable solutions like MinION, GridION, PromethION, and Flongle which can meet any throughput needs. Basecalling algorithms, pore chemistry and machine learning can increase that accuracy rate enormously as it has been recently.

Diagnostic potentials of nanopore sequencing in plant pathology

The potential diagnostic applications of new sequencing in plant pathology have emerged. Nanopores allow for real-time detection of plant pathogens, fungi, bacteria and viruses. Nanopore sequencing can identify novel or unexpected pathogens, which PCR does not, requiring special primers. This portable device eliminates any transport delays in sample shipment for on-site sequencing. Metagenomic profiling yields detailed information on diverse microbial communities of plants which can be categorized into microbial communities present in it to distinguish pathogenic communities as well as beneficial microorganisms. Nanopore technology offers potential tools for revealing resistance genes and monitoring responses to emerging pathogenic communities.

Comparative advantages over traditional approaches

Historically, plant virus detection has relied on morphological observation, PCR assay, and immunological approaches. Nonetheless, these strategies have significant limitations, including long detection times, complex preprocessing requirements, and low efficiency. They are also more likely to depend on prior genomic or immunological data, which renders them less applicable for novel or emergent virus detection (Zhang, Y., Singh, R., Singh, P., Li, H., and Mishra, B. (2022)).

Table 1 Comparison of performance of sequencing platforms.

Feature	PCR/ELISA	Illumina	Nanopore
Speed	Hours to days	Days to weeks	Real-time
Portability	Lab-based	Lab-based	Field-ready
Pathogen Knowledge	Requires prior primers	Requires reference genomes	Detects novel pathogens
Read Length	Short	Short	Long
Cost	Moderate	High	Scalable, flexible

Regulatory and Policy Context

The real-time sharing of data acts as an early warning system for outbreaks. Validation must continue to be carried out in order to gain widespread acceptance of nanopore-based diagnostics over gold-standard techniques. In this regard, regulatory authorities are beginning to accept nanopore sequencing as a clinically acceptable diagnostic strategy but country-level harmonization is ongoing.

Difficulties and limitations

Nanopore sequencing is an enhanced version of Illumina's analysis. Nevertheless, it suffers from larger errors as well. Here the hybrid methods of nanopore and short-read sequencing can help. Research with bioinformatics expertise is necessary. Devices are cheap, but consumables and computational resources are likely to be limited in resource-poor regions. Standardized protocols are required for official diagnostics.

Future Directions

Basecalling, pathogen identification and predictive modeling of disease outbreaks can be enhanced by advanced algorithms. Possible alternatives merge nanopore sequencing with lab-on-a-chip processes to offer thorough diagnostic capabilities in hand-held formats. Not only does nano-sequencing allow preventive and personalized treatment, but it also enables precision diagnostics, reduced pesticide use and better crop recovery. Nanopore data-empowered open-access archives can help facilitate global cooperation in mitigating plant diseases.

Conclusion

Nanopore sequencing is new for diagnostics of plant diseases and is so promising that it is emerging an innovation among medical professionals in plant health sciences. Rapid and portable nanopore sequencing has very much potential use-cases in disease control. Its convenient, rapid and innovative pathogen detection capabilities lend themselves nicely to the challenges of our current agricultural environment. Whilst the risks and associated inaccurate and additional charges and regulatory implications persist, the global cooperation and continued technological progress will contribute to nanopore sequencing for routine plant health applications.

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