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Laboratory Innovations for Boosting Crop Productivity: Advanced Approaches and Techniques

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Abstract:-

The article examines state-of-the-art agricultural biotechnology methods meant to increase crop resilience and yields. It explores genetic engineering, showcasing techniques such as CRISPR/Cas9 for accurate genome editing and the development of nutrient- and pest-enhanced crops. The discussion revolves around marker-assisted selection (MAS) and how it can expedite the breeding process by molecularly identifying desirable traits. It is investigated whether high-throughput phenotyping can help choose better crop varieties by quickly measuring and analysing plant traits. The essay also discusses the use of cryopreservation and synthetic seeds in crop conservation and industrial production. Together, these lab techniques improve crop yield, lower the need for chemical inputs, and ensure food security in agriculture.

Introduction

Food is essential to the continued existence of humans on Earth. Harvesting a variety of crops dates back thousands of years. However, employing traditional farming techniques was not going to be able to meet the need for food. New strategies had to be created in order to increase both the yield quantity and quality. New techniques have been devised for higher production, improved nutrient content, and disease-resistant crops as the world's population is growing at an alarming rate. The development of stress-tolerant crops may benefit from developments in the domains of genetics, stress biology, and bioinformatics. There are several strategies in use to adopt improved characteristics of agronomic value, including transformation, mutagenesis, and proteome profiling. Therefore, to enhance crop productivity and proliferation under various environmental several laboratory techniques are used nowadays, some of which are elaborated in this article.

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Plant tissue culture

Plant tissue culture is the aseptic, controlled growth and multiplication of plant cells, tissues, and organs on specified solid or liquid medium in order to generate a large number of true-to-type-plants.

Plant tissue culture of several types depending on the explant used for culturing. These can be broadly classified into the following: Culture of intact plants (Seed orchid culture), Embryo culture (embryo rescue), Shoot tip culture, Root culture, Leaf culture, Anther culture, Callus culture, Single cell culture and Protoplast culture. One amazing example of its use is in preventing the deadly Panama disease from affecting Cavendish bananas.

Microprogation

An in vitro culture method called micropropagation enables the mass replication of plant material from an explant, or part of the plant. Any element of the plant, including an immature embryo, a seed, a section of the leaves, roots, or shoots, an anther, a pollen particle, an ovule, a meristem, or an apex, can be included in the explant. The technique of employing explants and letting them grow into differentiated or undifferentiated cells is known as micropropagation of plants. The explant is cultivated in a sterile culture container that is filled with a synthetic nutritional culture medium. Plant tissue culture technique not only makes it possible to multiply elite plants in large quantities, but it also makes it possible to generate new plants from genetically modified cells (Soumare *et al.*, 2021).

Genetic engineering

The process of genetic engineering entails directly modifying an organism's DNA to change its properties. The first step is to use restriction enzymes to identify and isolate the desired gene. Then, a plasmid vector is created using this gene so that it can be transferred into the host organism. With methods such as CRISPR/Cas9, which modify specific DNA sequences, precise editing is possible. Once within the host, the gene is electroporated into bacteria or plants or transformed into the genome by Agrobacterium-mediated transformation in plants. The effective integration and expression of the genes is next verified by screening the altered organism. To silence particular genes, more sophisticated methods such as RNA interference (RNAi) can also be applied. Crops with improved qualities can be developed thanks to these contemporary methods (Caroll, 2014).

Case study of Cavendish Banana

Saving of Cavendish Banana is classic example of how laboratory techniques like plant tissue culture, micropropagation and genetic engineering can enhance crop productivity and fend of pests and pathogens. With about 99% of the world's banana export market going to the Cavendish type, it is the most consumed cultivar worldwide. However, the pathogen *Fusarium oxysporum* f. sp. *cubense* (Foc), specifically the Tropical Race 4 (TR4) strain, is responsible for a soil-borne fungal disease known as Panama disease, which poses a serious danger to it. There isn't a pharmaceutical therapy for this disease yet, which causes the banana plant to droop and eventually die. As Cavendish bananas are vegetatively propagated, they are particularly susceptible to this disease due to their monoculture status. Scientists employed meristem culture, which involves cultivating meristematic tissues in vitro in sterile conditions, in the case of the Cavendish banana. This approach was especially successful since meristem culture yields plants free from disease and with a high rate of multiplication. To confer resistance to TR4, genetic engineering entailed inserting particular genes into the banana plant. Scientists inserted genes that strengthen the plant's resistance to the pathogen using tissue culture as a platform. For instance, genes encoding enzymes that break down the pathogen's cell walls and antifungal proteins have been introduced by researchers. After screening transgenic plants for resistance, promising candidates are grown via tissue culture techniques. Combining these tissue culture methods has produced encouraging results in the development of Cavendish bananas that are resistant to TR4. These resistant types are being tested in the field in a number of countries, including the Philippines and Australia. In addition to helping to preserve the Cavendish banana, the effective use of these strategies offers a blueprint for resolving comparable issues with other crops (Dita *et al.*, 2018)

Artificial Seeds Cryopreservation

Encapsulated somatic embryos or other plant tissues that may be sown as seeds and grow into full-fledged plants are called artificial seeds, or synthetic seeds. Somatic embryos are encased in a protective gel, usually composed of alginate or other biodegradable materials, to generate these artificial seeds.

Plant tissues are cryopreserved by being kept at extremely low temperatures, usually in liquid nitrogen (-196°C), which stops all biological activity and prolongs the material's shelf life without causing genetic changes. The long-term preservation of plant genetic resources, such as seeds, pollen, embryos, and meristems, depends on this strategy (Benson, 2008).

Marker Assisted Selection (MAS)

Compared to conventional breeding techniques, marker-assisted selection increases precision and speeds up the breeding process by using molecular markers to identify plants with desired features. Russet infections can affect wheat, a major crop. Researchers have created wheat types with increased resilience by using MAS to find markers connected to rust resistance genes. As a result, yields have grown and disease-related losses have decreased.

CRISPR/Cas9

CRISPR/Cas9 is a precise genome editing tool that allows for targeted modifications to an organism's DNA. This technology has revolutionized plant breeding by enabling the introduction of specific traits without the need for foreign DNA. Through focusing on genes related to the regulation of plant growth, they were able to cultivate tomato plants that produced far more and had superior fruit quality (Zaidi *et al.*, 2018).

High Throughput Phenotyping

Advanced imaging and sensor technologies are used in high-throughput phenotyping (HTP) to quickly and precisely quantify plant attributes on a wide scale. This method allows for a thorough examination of phenotypic traits under different circumstances, including growth rate, biomass, and stress reactions. In breeding programmes,

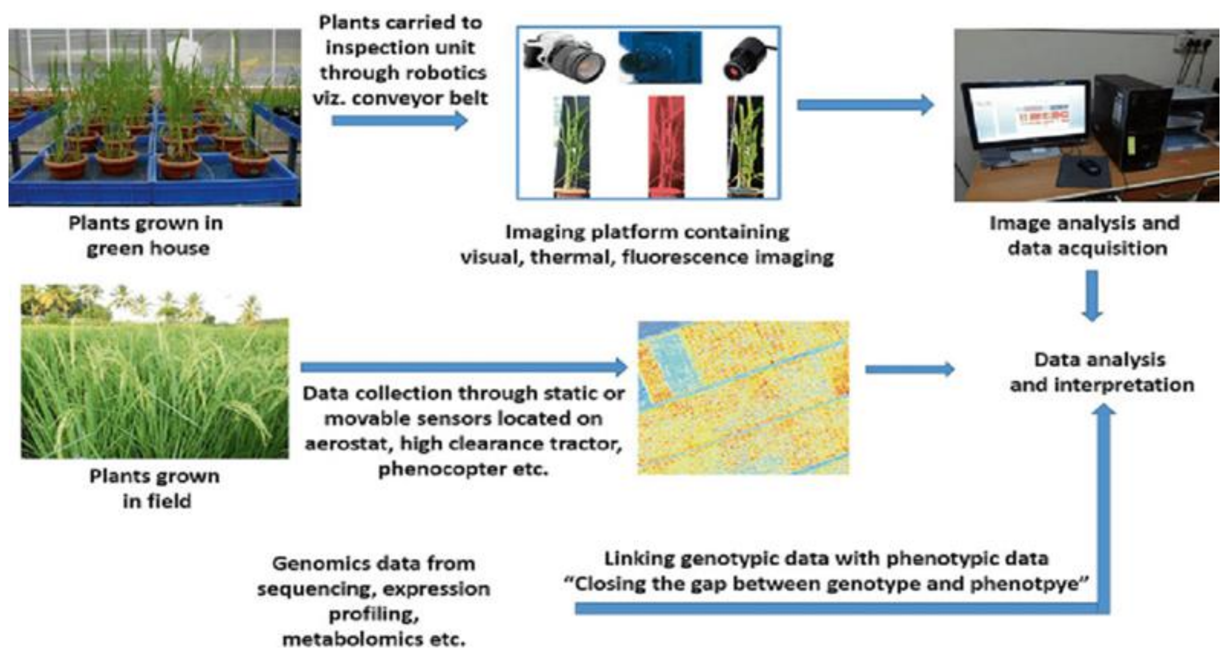

Figure 1: Depiction of high throughput phenotyping (Barh *et al.*, 2015)

It has several applications like trait enhancement and disease resistance. Tomato genes have been edited by researchers using CRISPR/Cas9 to boost fruit yield and size. HTP speeds up the selection process by combining genomic and phenotypic data, resulting in the development of hardy and high-yielding crops. Precision agriculture and crop development are made possible by methods such as multispectral photography, LiDAR, and automated platforms that analyse enormous plant populations swiftly and effectively (Yang *et al.*, 2013).

Conclusion

To sum up, agricultural output is greatly increased by laboratory techniques including cryopreservation, high-throughput phenotyping, genetic engineering, and marker-assisted selection. By increasing crop yields, resilience, and nutritional content, these methods advance sustainable agriculture, which in turn supports environmental sustainability and global food security.

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