Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 04, Issue: 05 (SEP-OCT, 2024)
Available online at http://www.agriarticles.com

Future Perspectives of Plant Biotechnology

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Biotechnology today empowers an organism to produce a totally different product which an organism cannot or does not produce normally through the incorporation of the technology of "Genetic engineering". Biotechnology shows its technical merits and developments in breeding of new plant varieties, with high yield, good quality, and more importantly stress resistance. Some of the most prevailing problems faced in agricultural ecosystem could be solved by introducing transgenic crops incorporated with the characters of insect-pest resistance , herbicide tolerance etc. Plant biotechnology has achieved importance in the recent past for increasing the quality and quantity of agricultural, horticultural plants and in exploiting the plants for agronomic performance.

Keywords: Genetic engineering, molecular breeding, plant genomics, phytoremediation

Introduction

Plant biotechnology is based on the proven ability of plant cells to regenerate entire plants (totipotency), which is merged with the introduction, stable incorporation, and expression of foreign genes, the regeneration of genetically modified plants, and the inheritance of these modifications in subsequent generations through Mendelian genetics. Since the Mendels discovery of the laws of heredity in 1865, controlled breeding has transformed agriculture and significantly boosted crop yields. Plant biotechnology is just one of several technological strategies for solving specific agricultural challenges. E g., A particular pest issue could be tackled equally through conventional plant breeding, a transgenic approach, or through an integrated crop management (ICM) approach, or by combining any of these methods.

Plant biotechnology serves an effective and versatile tool for creating novel plant traits and cultivating new plant varieties. Such new varieties must be produced on a large scale to achieve commercial success and to fulfil demand from the growers. In the past, new plant varieties were produced through seed propagation method. Modern plant biotechnology has ushered in a new era of science and technology, focusing on producing secondary metabolites, enhancing genetic traits, conserving germplasm, and generating large numbers of disease-free and novel plant varieties.

Plant Genetic Engineering: The insertion of genes into plants to develop new commercially viable varieties might appear to be a worthwhile endeavour today. However, in the early 1980s, this was one of the primary obstacle hindering the process of the agricultural revolution, which began with the use of restriction enzymes and was later advanced by the genetic modification of bacteria for industrial and medical applications. Plant biotechnology has been technology-driven since it's introduction and the successful establishment of gene transfer technologies for major crops was a significant breakthrough for small biotech companies, fueling advancements in the field during the early 1980s (Gordonn-kamm et al., 1990). The early innovators in plant genetic engineering recognized the potential of the technology and it's capacity to boost crop yields and tackle some of the most pressing societal challenges.

Biotic stress resistance: Biotic stresses refer to the damage inflicted on plants by living organisms such as bacteria, fungi, virus, viroids and nematodes. Several biotic stresses have had significant historical impacts including the Irish potato blight, maize leaf blight caused by Cochliobolus heterostrophus in the U.S., and the Bengal femine of 1943 (Hussain, 2015). Pathogens account for 15% reduction in global food production, posing a major challenge for breeding disease-resistant crops (Onaga and Wydra, 2016). Over the past four decades the widespread and often excessive use of pesticides to manage these stresses has lead to negative environmental impacts and health risks. Hence there is a need of reducing the pesticide usage by applying biotechnological tools to develop the crops resistant to diseases and pests.

Insect pest resistance: Globally, it is estimated that 14% of crop productivity is lost due to insect pests (Krattiger, 1996). Insect-resistant transgenic crops were first introduced commercially in the mid 1990s with the release of genetically modified corn (maize) potato, and cotton plants that express genes encoding entomocidal endotoxins from bacillus thuringiensis (Bt), commonly known as cry proteins (Gatehouse et al., 2011). Resistance to insect-pests can be effectively engineered by utilising insecticidal proteins found in bacteria, plants and animals (Kumar, 2001). obal scale it is estimated that 14% of crop productivity is lost to insect pest (Krattiger, 1996). Insect resistant transgenic crops were first commercialized in the mid 1990s with the introduction of genetically modified corn (maize), potato, and cotton plants which are expressing genes encoding the entomocidal endotoxin from bacillus thurengenesis Bt; also known as cry proteins (Gatehouse *et al*, 2011). Resistance to insect-pests can be effectively engineered by utilising insecticidal proteins found in bacteria, plants and animals (Kumar, 2001). The bacterium B. thuringiensis (Bt) was first discovered in Japan in 1902 in a silkworm rearing facility, and was later isolated from flour moth population in the year 1911 with Berliner characterizing it in Thuringia (Germany). Most of the bt strains produce multiple crystalline proteins (cry proteins) each with a relatively narrow host range (Bravo *et al.*, 2013). In the coming years the next generation of trangenic crops is expected to carry a multiple insecticidal protein genes for enhanced pest resistance.

Viral resistance: Viral diseases significantly impact crop yields, leading to substantial losses in productivity. Subsistence crops such as cassava, sweet potato, papaya, banana, rice and maize are frequently infected by RNA and or DNA viruses, which are resistant to pesticide control. (Kreuze and Valkonen, 2017). In many cases, sources of natural resistance are absent or the complexity of genetics and difficulties in incorporating resistance genes into cultivars through traditional breeding methods hinder crop improvement efforts. As a result, biotechnological approaches to developing and transferring resistance into crops presents a promising alternative. For instance, in potatoes, Potato Virus Y (PVY), a member of the genus potyvirus; (family potyviridae) Potato Leaf Roll Virus (PLRV) from the genus polerovirus ; (family Luteoviridae) and Potato Virus X (PVX) of the genus potexvirus; (family Alphaflexiviridae), are among the most prevalent and destructive viruses globally (Kreuze and valkonen, 2017). To address this issue virus- derived resistance was successfully engineered in the potato cultivar Russet Burbank against both PVY and PVX. Utilizing virus-resistant plants remains the most effective and economical method for minimizing losses caused by plant viruses. However, one drawback of the resistant cultivar is the inevitable breakdown of resistance due to the emergence of new viral strains or species. (Kumar *et al.*, 2017). On the other hand, the use of pesticides to control insect vectors is costly and causes harmful environmental consequences. Thus exploiting strategies that provide durable and broad-spectrum resistance is important in future.

Fungal resistance: Several important crop diseases are attributed to fungal pathogens, and for a long time fungicide application was the primary method for controlling these diseases. However, advances in molecular biology and biotechnology have led to significant progress in understanding plant defense mechanisms. Numerous antifungal proteins and peptides have been identified and tested through invitro bioassays (Culture and Islam, 2014). RNA interference (RNAi) has emerged as a promising approach to combat fungi and oomycetes with initial patent applications for RNAi-based fungal control methods dating back to 2006 (Esse *et al*., 2020). Notable results have been achieved against Fusarium species by silencing the cytochrome P450, family 51 (Cyp 51) genes which encode sterol 14 alpha demethylase, the target of azole fungicides through host-induced gene silencing (HIGS) (Koch *et al*., 2013).

Bacterial resistance: The wide range of interactions between bacteria and the numerous bacterial types with different pathogenic modes suggests that plants have multiple resistance mechanisms against bacterial infections. Studies have been spurred by the presence and release of phenolic compounds and their oxidation products in diseases plants, aiming to demonstrate that specific phenolics play a key role in resistance to bacterial pathogens and other diseases(Farkas and kiraaly, 1962). The hydrolysis or oxidation of arbutin, for example, has been identified as a biochemical defense against the fire-blight pathogen, Erwinia amylovora. Recent discoveries that specific proteins from bacterial cells trigger general resistance reactions in plants hold promising potential for advancing the understanding of bacterial disease resistance.

Herbicide tolerant: For many years, both scientists and farmers have been aware that herbicide tolerance can be passed from one plant to another through crossbreeding, occuring in both cultivated crops and in wild plants. The transfer of herbicide tolerance has been studied and managed long before modern biotechnology techniques were used to genetically modify the plants for these traits. The genetically engineered (GE) trait for glyphosate tolerance was first introduced into soybean and canola in 1996, and in cotton in 1997, marking a major shift in farming practices for these crops (Azhakanandam *et al*.,2015). The development of transgenic glyphostae-tolerant (GT) soybean, commonly known as Roundup Ready soybean, in 1996 transformed agriculture by enabling widespread adoption of glyphosate-based herbicide applications. Thus, glyphosate can be applied “in crop” as a post-emergent herbicide to control weeds without crop injury.

In regions, where atrazine has been extensively applied, numerous weed species have developed atrazine- resistant biotypes. Glyphosate-tolerant cell cultures of Corydalis sempervirens and petunia hybrida were produced through selection on the herbicide ,(Amrhein *et al*., 1983). Various crop species has been genetically modified to confer resistance to herbicides, like glyphosate, bromoxynil, and others expanding options for weed management in agriculture. Herbicide-tolerant crops are under cultivation in countries such as USA and Canada (Kumar, 2001).

Abiotic stress resistant: Over the past fifty years it has become clear that abiotic stresses significantly affect plant growth and crop productivity, leading to stagnation in yields for many economically vital crops. Only high input levels can sustain high yields under these conditions. Drought stress triggers fluctuations in calcium ion levels which in turn activate calcium-dependent protein kinases (CDPKs) via calmodulin-like domains. These activated CDPKs regulates various components of calcium signaling pathways. For instance, rice plants overexpressing OsCPK4 show enhanced water retention under drought or salt stress (Campo *et al.,* 2014). Transcriptional factors like HSFs, WRKY, zat and MBF1c which regulates DREB genes are key players in the expression of heat shock proteins (HSPs) and other heat stress responsive genes (Suzuki *et al.*,2011). Additionally, during cold stress, several metabolism- related proteins including enzymes involved in carbohydrate metabolism such as----- phosphogluconate dehydrogenase, NADP-specific isocitrate dehydrogenase, fructokinase, cytoplasmic malate dehydrogenase, aconitate hydratase, glycine dehydrogenase, and anolase -- are activated (Lee *et al.*, 2009). The need for crop resistance to these environmental stresses is expected to rise as agriculture expands into diverse environments and the frequency of extreme weather events increases.

Quality improvement: The nutritional quality of the foods we consume is a crucial concern, especially in developing countries. Plant biotechnology offers vast potential to enhance food quality by improving the levels of proteins, amino acids, vitamins, oils, which are essential for human health and well being. When it comes to plant proteins there are two primary strategies to boost their nutritional value: I) modifiying the amino acid profile of the plant proteins and ii) introduction of transgenes that encodes highly nutritious proteins. For example, the gene encoding the human milk protein beta-casein has been expressed in transgenic potatoes under the control of an auxin-inducible promoter (Chong *et al.*, 1997). The nutritional health and well-being of human beings are dependent on plant foods containing vitamins, minerals and phytochemicals. Human nutrition depends heavily on plant- based foods rich in vitamins, minerals and phytochemicals. Iron for instance, plays a vital role in cellular processes, and iron deficiency remains a serious health issue in many parts of the developing world (Kumar, 2001). To address this a gene encoding soybean ferritin (iron-storage protein), has been introduced into rice driven by the glutelin promoter to ensure seed-specific protein expression (Goto *et al.*, 1999). Moreover, rice, a staple food for much of the world, naturally lacks both beta-carotene (pro-vitamin A) and its C40 carotenoid precursor. Advances in transgenic oil crops that produce high levels of stearic acid in seeds offers an alternative method for the industrial production of saturated fatty acids.

Post-harvest trait: Characters that determine the viability and storage life of plant products (fruits, vegetables, flowers and tubers) after harvest are of high economic importance. For extending the post harvest life of leafy vegetables, there is a high need of focus on the minute observation of these events that occur in regular leaves during senescence. It has been reported that cytokinins can delay leaf senescence and at that time there is a drop in endogenous ethylene levels (Van staden, 1989). In fact, tomatoes manipulated for delayed ripening are the first genetically modified plant products to be marketed in USA (flavrsavr), 1994 (Kumar, 2001). Delaying ripening in fruits and extending flower longevity can also be achieved by suppressing the genes involved in pectin breakdown or ethylene production through antisense technology (Kumar, 2001). Studies have shown that transgenic fruits can maintain their firmness and color for upto 60 days at room temperature (Fry, 2004). Looking ahead, the in-depth exploration of crop metabolic pathways through transcriptomic analyses could lead to the development of plant varieties or species with enhanced tolerance to environmental challenges (Shukla *et al.*, 2015). The genetic modification of the ripening processes in tropical fruits like mangoes and bananas shows significant potential for future advancements.

Phytoremediation: Phytoremediation refers to the use of plants to restore polluted environment. Over the past hundred years activities such as mining, industrial production and urbanization have significantly contributed to extensive soil and water contamination. In response transgenic Arabidopsis plants have been engineered to express the bacterial merB gene, which encodes organomercurial lyase (MerB), with the goal of breaking down highly toxic organomercurial compounds. (e.g methylmercury) (Cai, 1997). A number of transgenic plants have been engineered for increased arsenic (As) tolerance and accumulation.

Molecular Breeding: Improving even the most basic plant traits requires the manipulation of numerous genes, the reorganization of key alleles, and precise identification of their chromosomal positions. Molecular tools now enable the tracking of valuable alleles in segregating populations through the use of genetically linked markers. Comprehensive sets of molecular markers including restriction fragment length polymorphism (RFLP), randomly amplified polymorphic DNA (RAPD), micro-satellites and amplified fragment length polymorphism (AFLP) have been developed for various species (Kumar, 2001). Efforts to create agricultural crops with enhanced traits, such as improved nutritional value, are constantly underway.

Plant Genomics: Plant biology research has hit a major milestone with the development of whole-genome sequencing for various plant species. This breakthrough in genome sequencing paves the way for deeper exploration of plant biology, especially in understanding the intricate cellular, physiological and developmental processes. (Kumar, 2001). A significant early use of plant genomics has been large-scale analysis of gene expression patterns. One of the key methods enabling this advancement is RNA profiling which involves the hybridization of transcripts to DNA molecules affixed to solid surfaces. It is widely known as DNA chip technology, this approach has been instrumental in linking sequence data to functional genomics (Baldwin *et al.*, 1999). In general, the advantage of arrays is that they provide hundreds or thousands of specific genes simultaneously. Thus, two general types of DNA chips or micro-arrays have been developed.

Problems in Biotechnology

1. **Regulatory and ethical challenges:** One of the major hurdles for plant biotechnology is the complex and often restrictive regulatory environment governing the approval of genetically modified organisms (GMOs). Many countries have stringent regulations that slow down the process of developing and commercializing genetically engineered crops. This discourages smaller companies and institutions from investing in biotechnological research. Additionally, ethical concerns around GMOs persist.
2. **Public perception and acceptance:** Public skepticism about plant biotechnology remains a significant barrier. In many parts of the world consumers are wary of GM crops, often due to a lack of understanding. Negative portrayals in media and the absence of transparent communication have contributed to the perception that genetically engineered crops are harmful. This opposition has led to slow adoption rates, even in regions where biotechnological impacts could have a profound significant impact on sustainability.
3. **Technological limitations:** while gene -editing technologies such as CRISPR/cas9 have revolutionized plant biotechnology, the field still faces technological challenges. Achieving precise gene modifications in complex, polyploid plants like wheat remains difficult. Moreover, unintended genetic changes can occur during modification leading to changes in nutritional content or new allergens.
4. **Economic barriers and access:** The commercialization of genetically modified crops is often dominated by large multinational corporations, raising concerns about access and equity. Small farmers in developing countries, may find it difficult to afford patented seeds. This could exacerbate existing inequalities in global agriculture, as wealthier farmers and countries are at better position to avail the benefits of recent biotechnological advances. The high cost of research and development also means that, certain regions particularly low-income countries, lack the resources to invest in biotechnology which is needed to address local agricultural challenge. As a result some of the vulnerable populations may not get the benefit from biotechnological innovations.
5. **Environmental Risks:** The potential environment risk associated with GM crops cannot be overlooked. One of the main concerns is the loss of agricultural biodiversity as genetically modified varieties replace traditional crop species. This could lead to the vulnerability of crops to insects-pests especially in change of environment.

Future Perspectives of Plant Biotechnology

1. **CRISPR and advanced gene editing:** The future of plant biotechnology lies in more refined and efficient gene-editing technologies. Tools like CRISPR/cas9 and it's newer iterations, such as base editing and prime editing allow scientists to make highly specific changes to a plant's genome. As the precision of gene editing improves, it will become easier to engineer crops that can withstand extreme weather conditions, pests and diseases.
2. **Climate-Resilient crops:** One of the most important applications of plant biotechnology is developing of climate- resilient crops. By engineering plants that can tolerate drought, heat and salinity. Scientists can help ensure food production in regions affected by environmental stress. As global temperature are rising and rainfall patterns shift, such climate resilient crops will be essential for maintaining global food security.
3. **Nutritional Enhancement and food security:** plant biotechnology also offers the potential to address malnutrition by biofortifying crops with essential vitamins and minerals. For instance, genetically modified crops like Golden Rice which is rich in beta-carotene can help combat vitamin A deficiency in developing countries. Looking forward, more crops could be engineered to contain higher levels of providing healthier diet to the populations which are in need.
4. **Synthetic Biology and New Crop Traits:** Synthetic biology is another exciting frontier in plant biotechnology. By designing new metabolic pathways, scientists could create crops that produce valuable compounds such as pharmaceuticals, biofuels or biodegradable materials. These innovations could diversify the role of crops in society, turning plants into factories for producing a wide range of products while reducing reliance on fossil fuels.
5. **Sustainable Agriculture and Microbiome Engineering:** Sustainable agriculture is increasingly reliant on biotechnological innovations. Future advancements in plant biotechnology could enable crops to require fewer chemical inputs such as fertilizers and pesticides, reducing the environmental footprint of farming. One promising area is the engineering of plant- associated microbiomes. By modifying the communities of microorganisms that live in and around plants. Scientists hope to enhance nutrient uptake, improve growth and increase resistance to pests and diseases – all that without the need of harmful chemicals.
6. **Public Engagement and Policy Development:** For plant biotechnology to reach its full potential, public engagement and education will be crucial. Transparent communication between scientists, policymakers and the public can help dispel misconceptions about GM crops and foster greater acceptance of biotechnological innovations. Additionally, international collaboration on regulatory frameworks can help create an environment where plant biotechnology can thrive or survive while ensuring that ethical concerns and environmental risks are addressed.

Conclusion

The dynamic time always offers an opportunity to reflect on human activity in a particular discipline and to formulate a future strategy. Researchers constantly test the past occurrences in order to learn lessons that could help in the acquisition of new knowledge or for the further development of appropriate technology ensuring from it. Science and Technology cannot be isolated in the world, so researchers are expected to act according to the changing global scenario in which they live. Applications of biotechnology in the genetic enhancement of crops have been a great task in plant biotechnology to be conducted in coming decades. Few decades earlier, plant biotechnology was relied upon few applications only such as, tissue culture, recombinat DNA technology and monoclonal antibodies. Today, transformation, and marker-aided selection and breeding are just a few of the examples of applications of biotechnology which are discovered as per needed by the crop improvement program. Plant biotechnology is surrounded by a multitude of scientific tools and techniques for screening and genetic manipulation of plants to develop beneficial or useful plant or plant products. Use of nani-materials as vehicles for gene or proteins and nani-crystals for high-resolution imaging of the plant cell and organs could be another field to explore by the researchers for creating better novelty in food crops. We can conclude by plant biotechnology is a powerful tool for the development of new plant traits and varieties and such new varieties must be produced on a large scale to achieve commercial success and to satisfy the demand from growers and consumers as a whole.

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