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The role of biotechnology in ensuring the long-term viability of banana and plantain harvests

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Abstract

Food security and economic stability in rely on the steady supply of bananas, and plantains. However, these crops face significant danger from pathogens, pests, and environmental limitations. The banana and plantain sector are an essential source of revenue and ensures the continued availability of food for millions of people throughout the continent. However, it confronts some problems, such as those posed by pests, diseases, and the effects of climate change, all of which undermine agricultural yield and resilience. Small-scale farmers cultivate the vast majority of bananas. Still, they typically need more resources to invest in the long-term sustainability provided by chemical fertilizers, fungicides, and pesticides. Biotechnology offers a way to make plants more suitable for long-term cultivation. Tissue culture, molecular marker creation, and genetic engineering are all examples of biotechnology that are put to use. The challenges with banana and plantain production cannot be solved by using biotechnology in isolation; rather, it must be included in integrated disease and pest control systems.

Keywords: Biotechnology, bananas and plantains, harvested, Andhra Pradesh, diseases, pests

1. Introduction

Millions of people throughout rely on bananas and plantains as their primary source of sustenance and money. Diseases, pests, and environmental pressures are only some of the obstacles that farmers of these crops must overcome. Some of these problems, including ensuring the long-term viability of banana and plantain production, may have answers that might be found via biotechnology (Fufa *et al.,*2021). The fungus Fusarium oxysporum f. sp. cubense causes Panama disease, devastating banana, and plantain crops throughout. Banana plantations may be wiped out by this illness, making the area unusable for years (Oladimeji *et al.,* 2022). Bananas and plantains may be made more resistant to pests and illnesses by using biotechnology methods like genetic engineering. Crops more resistant to Panama disease and other common illnesses may be developed via biotechnology by transferring genes from resistant species or strengthening the plants' natural defensive systems (Pua *et al.,* 2019). Bananas and plantain crops are vulnerable to insect pests, including nematodes and weevils, which may cause substantial damage and significant productivity losses.

Creating genetically engineered types resistant to certain pests is one way in which biotechnology might aid in pest management tactics (Giwa *et al.,* 2023). Scientists can increase banana and plantain pest resistance by, for instance, introducing genes from naturally pest-resistant plants. Using less toxic pesticides makes farming safer for humans, animals, and the environment (Karienye and Kamiri 2020). Climate change and environmental pressures, including drought and salt, threaten the cultivation of bananas and plantains. Improved tolerance to these pressures is a goal that can be achieved with the help of biotechnology (Bisheko and Rejikumar (2023)). Genes that increase resistance to drought, salt, and other environmental stresses may be introduced using genetic engineering (Ciceri and Allanore 2019). By doing so, biotechnology may help make banana and plantain harvests more consistent and less susceptible to climate change (Palanivel and Shah (2021)). Biotechnology helps protect the variety of banana and plantain germplasm. Gene banks and tissue culture methods preserve and spread these precious genes. These measures protect uncommon and wild banana types that may have desirable features for future breeding efforts (Satekge and Magwaza (2022)). The application of biotechnology in agriculture, such as the cultivation of genetically modified crops, is contingent upon legal frameworks and public support. To empower the dependable and secure rollout of biotechnological answers for banana and plantain creation, scientists in biotechnology, rural organizations, and legislators must cooperate (Afiukwa *et al.,* 2021). Millions of people throughout rely on the continued success of their banana and plantain crops for their survival, economic growth, and income. Many factors, including disease, pests, climate change, and a lack of genetic variety, threaten the viability of these crops. Plantain and banana production is dangerous from pathogens like Panama disease and banana bunchy top virus (Sehgal and Khan 2020). Using disease-resistant cultivars, crop rotation, sanitation practices, and biosecurity measures are all part of an integrated disease management strategy that may help reduce the severity and frequency of disease outbreaks. Biotechnology, including genetic engineering and marker-assisted breeding, may contribute to creating disease-resistant strains Pathirana and Carimi (2022). Increased temperatures, shifting rainfall patterns, and severe weather events all offer problems for banana and plantain cultivation exacerbated by climate change. It is important to develop climate resilient cultivars using traditional breeding or biotechnological techniques to ensure these crops can endure and adapt to shifting climatic circumstances. Improved drought resistance, heat tolerance, and water efficiency may be achieved by selective breeding Listman *et al.,* 2019). The long-term survival of bananas and plantains depends on our capacity to diversify their genetic resources. Traditional landraces and their wild cousins should be prioritized in conservation efforts because they frequently include useful features that may help agricultural development. Cryopreservation, tissue culture, and seed banks are all examples of biotech tools that may be used to preserve and spread genetic variety Jones (2019). Seaweed aquaculture is fundamentally behind terrestrial agriculture's progress in biosecurity and technology production techniques, despite rising demands for seaweed biomass and major economic advantages for low and middle-income workers (Ndawala*et al.,* 2021). To create long-term solutions to climate change, it is necessary to have sufficient data on the relationship between sector policies and the causes, consequences, and responses to climate change. Chia *et al.,* 2019) used agriculture to investigate this relationship in the Cameroonian Humid Forest Zone (HFZ). Research on forest cover shifts, Climate susceptibility, and agricultural systems within the harmonic field were used as secondary sources.

Considering current food safety and security dilemma, Gbashi*et al*., (2021) provided an overview of the current situation and strives to reconcile different opinions on GMOs research. Kraithong and Issara (2021) compile data on banana chemical makeup to illustrate the strategic route for creating new food items via the comprehensive usage of agricultural waste and by-products. Mabusela *et al.,* (2021) described the benefits and drawbacks of several methods for removing ethylene during postharvest processing. Photolysis, photocatalytic oxidation, and ozone-assisted catalytic oxidation are just a few of the newer methods that are being explored as potential replacements for traditional methods of ethylene management in post-harvest value chains. To increase the carrying capacity of the resource base and ensure the agricultural production system can continue to fulfill the requirements of the population in the foreseeable future, it must be dynamically stable and continuous. Producing food is a complicated bioeconomic activity that involves many different facets of science, technology, management, and society (Okigbo 2020). Agriculture has several issues, including food and nutrition security, environmental protection, soil fertility, and crop adaptability to changing climatic circumstances, however these problems may be mitigated with the use of plant biotechnology and breeding (Travella*et al.,* 2019). Armengot*et al.,* (2020) provided a historical context for fertilizer usage then make recommendations for future study by the materials science community. To become self-sufficient in food and make significant progress toward objectives of food and nutrition security, the continent must develop a new generation of indigenous and economical fertilizers. To effectively and efficiently manage Fusarium wilt mitigation, they offer research priorities and complementing techniques and difficulties. Our methods include increasing crop resilience via agrosystem diversification, and developing stable and comprehensive Foc resistance in commercial banana cultivars through the use of precision breeding technologies that allow for the quick assessment and introduction of disease resistant genes. The goal of increasing the output of bananas and plantains cannot be achieved by using biotechnology on its own; rather, it must be included into disease and pest management systems that are integrated.

2. Methods and materials

Produces Bananas and Plantains

Around 100 million people in rely heavily on bananas and plantains for their daily carbohydrate intake, making them a crucial food crop. Andhra Pradesh is a good example, since their annual per capita intake of bananas is roughly 223 kilograms, demonstrating the fruit's major role as a main food source.Andhra Pradesh also produces more bananas than any other state and is second only to Maharashtra. Andhra Pradesh, Maharashtraaccount for the vast majority of the 1% of the region's 20 million metric tonnes (MMT) of banana output that is exported. However, many farmers make living selling bananas to middlemen dealers, who then carry the bananas on trucks to commercial centers to meet rising urban demand. Bananas have been planted on more land in recent years, although production per hectare has been about the same or decreased somewhat during the last decade. There are concerns about food security since this modest rise is not keeping up with the expanding human population. Banana production restrictions may be better understood because to extensive research into the drop in Andhra Pradesh. Banana production is hampered by a number of factors, some of which may be mitigated with the use of biotechnology.

Banana production constraints

Biological and environmental limitations provide significant challenges to banana and plantain cultivation. Infested soil and plants have spread several illnesses and pests over the continent. Since the banana business has expanded, new regions have become susceptible to these pests and illnesses. Pathogen populations have grown to epidemic levels in several parts of the world. Banana production is very hard to maintain in regions severely impacted by these diseases and pests due to the high expenses associated with their management. (**Figure 1**) displays, according to the Andhra Pradesh Census of Agriculture, the percentages of production and harvested area from the various sub regions of Andhra Pradesh during the 2008/09 season.

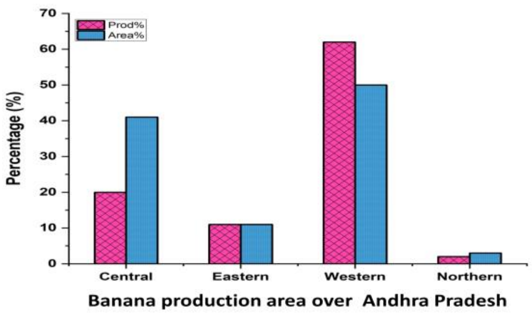

Figure 1: *AndhraPradesh Central, Eastern, Western, and Northern banana harvests*

Diseases

Dark Sigatoka, welcomed on by the leaf parasite MycosphaerellafijiensisMorelet, is the most destroying illness of bananas and plantains. Bananas in most of tropical regions have been plagued by the black Sigatoka leaf disease caused by Mycosphaerellamusicola Leach over the last 13 years. In the subtropics, the yellow Sigatoka still reigns supreme and may do significant damage at certain times of the year. Gujarata nd Karnataka are now home to a third Sigatoka disease, eumusae leaf spot, which was previously only known from Uttar Pradesh. Banana and plantain leaf death, lower yields, and early ripening are all consequences of these three diseases. Black Sigatoka, in particular, may cut yields by as much as 75 percent, which has devastating effects on the food supply for those with little material resources. Bananas are susceptible to Fusarium wilt, a severe disease that may be prevented by planting disease-resistant types. Banana Streak Virus (BSV) and Banana Bunchy Top Virus (BBTV) are the two most prevalent viruses that cause damage to bananas and plantains. The effects of the disease known as "bunchy top" on crops may be severe. Banana syncytial virus (BSV) may be introduced to new places through inoculated planting material because it can integrate into the banana plant's DNA. Aphids and mealybugs, respectively, may spread BBTV and BSV from infected plants to healthy ones after being transferred to new areas.

Pests

Planting nematode-free material is one cultural management method that may help reduce their populations. The banana weevil causes enormous losses of bananas and plantains throughout the continent and is the most destructive insect pest of these crops. These methods include plant resistance, cultural control, and biological control. Banana weevil resistance has not been a focus of any existing conventional breeding effort for Musa anywhere in the globe. Only a small number of researches have used germplasm screening to select banana weevil-resistant cultivars and determine their underlying resistance mechanisms. Since there has been so little done to better understand the banana weevil, Research center A has made it a priority to include weevil research into its genetic enhancement activities. In response, PROMUSA has organized a weevil-working group.

Abiotic stress

Environmental hazards such as drought, wind, cold, and a lack of nutrients pose serious risks to banana farms. Damage might be confined to certain places and time frames, and environmental factors may exacerbate disease and pest outbreaks. Bananas are a tropical crop; therefore they thrive in warm, wet climates. However, environmental degradation often happens in marginal regions when bananas are cultivated in less ideal subtropical climates or in locations where soil quality is low owing to factors like erosion.

Solutions to the problems plaguing banana farms

Traditional breeding methods, along with first- and second-generation biotechnological techniques, are all available for enhancing bananas and plantains' biotic and abiotic resistance. Banana disease diagnosis and selection might be aided by biotechnological methods such plant tissue culture, plant manufacturing, and the creation of molecular protein markers. Because there is so little seed available, even within breeding lines, conventional breeding techniques are laborious and time-consuming. Growing and maintaining plant populations takes a lot of room, which has slowed down efforts to enhance their genetics. Across the globe, there are now five significant banana breeding programs. (**Figure 2**) shows that the region's banana output has increased dramatically over the previous decade. In 2012, Côte d'Ivoire exported 339,357 metric tons of bananas, making it the region's highest exporter.

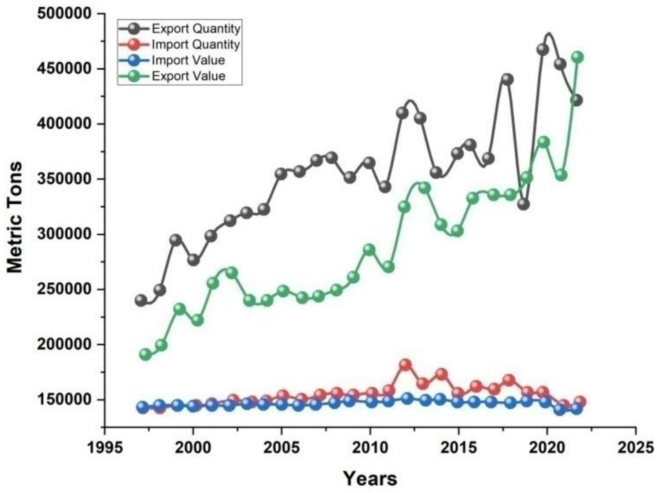

Figure 2: The region's strong banana output growth

Disease- and pest-resistant breeding

Bananas and plantains have a small genetic pool because they are propagated by vegetative regeneration rather than seed. Improved diploid males are created in these breeding programs so that they may be bred with the appropriate triploid female. At CARBAP, doubling the chromosomal number of targeted diploids using colchicine is another breeding approach. To produce triploids, the resultant tetraploids are crossed with diploids. Several new plantain-type hybrids have been registered as a consequence of IITA breeding efforts, in addition to the innovative highland banana selections undergoing early evaluation trials in Andhra Pradesh. The effectiveness of Musa breeding is now being enhanced by the use of molecular methods. The low frequency of detectable variants in restriction fragment length polymorphisms (RFLPs) makes their usage seem restricted; Technology for breeding bananas using molecular biology, such as molecular marker-assisted (MAS) breeding, has lagged behind those of other major food crops. Despite MAS breeding's promise to significantly increase the rate and efficiency of genetic improvement in Musa, this remains the case.

Tissue culture

The introduction of sick plant material into fresh banana fields is a key contributor to the development of pests and diseases. Roots and rhizomes of suckers collected from infected areas may conceal fungal and bacterial wilt pathogens without displaying any signs, in addition to spreading nematodes, the banana weevil, and Sigatoka disease. Tissue culture, a technique of first-generation biotechnology, was crucial in the development of bananas with a high degree of genetic uniformity and resistance to disease. Viruses may still infect tissue culture plants even if they are devoid of fungus, bacteria, insects, and nematodes. Bananas are susceptible to a number of viruses, thus commercial labs that engage in vitro propagation should first check for the absence of viruses in the mother plant material they utilize. Despite this success with other viruses, further study is needed since banana syringe virus is present in most banana and plantain germplasms and it is difficult to create BSV-free plantlets by tissue culture. Since the advent of simple tissue culture methods like shoot-tip and embryo culture, Musa germplasm management and breeding have advanced tremendously. Several industrial tissue culture facilities are either in operation or have been opened throughout the continent. In particular for subsistence farmers in remote regions, tissue culture plants remain expensive and elusive.

Methods of detection

Using DNA/protein-based markers for pest/disease detection is a relatively new use of biotechnology in the banana industry. In the not-too-distant future, genetic markers that may be utilized to identify pathogen and pest prevalence in asymptomatic plant material, irrigation water, and soil will be in high demand. Molecular or genetic markers may be used to learn about the demographics of a disease or pest population, which is vital information for designing an effective control strategy. Many studies have been conducted to learn more about the population genetics of different diseases for this same reason, including banana viruses, and nematodes.

Genetic modification (GM)

Banana has been the subject of cutting-edge biotechnological genetic modification due to recent advances in plant transformation and the generation of beneficial genes for disease and pest resistance. New and better banana types may be possible with the aid of these technologies in the future. Finding appropriate resistance genes to convert into susceptible banana plants is a significant difficulty in banana transformation. Genes for proteinase inhibitors and antifungal peptides are among those being studied in both for-profit and non-profit research institutions at the moment. By maintaining stable banana output in environmentally responsible cropping systems aimed at satisfying local and export market needs, these advancements in banana via contemporary biotechnology can eventually help assure food security in many regions. Since the sterility of edible cultivars eliminates the possibility of the transplanted foreign genes escaping from GM banana plants, this factor may also provide support to the manufacture of GM banana plants.

Scientists are investigating banana biotechnology

Banana biotechnology has been pushed forward by consumer demand, with an emphasis on cultivar development in the face of biotic and abiotic barriers. Tissue culture methods, molecular marker creation, and the isolation of resistance genes are all examples of biotechnology used in banana breeding programs (**Figure 3**). Moreover, corporations engage in vitro propagation of banana plants for commercial purposes.

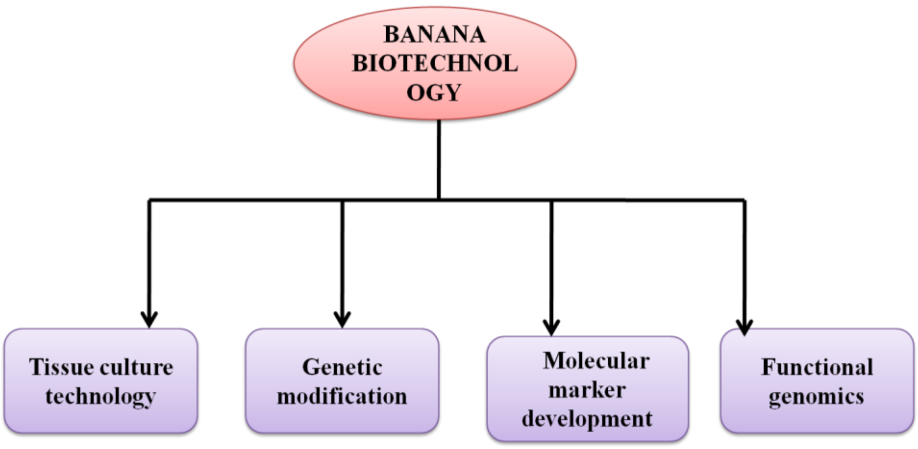

Figure 3: *Explanation of Recent Banana Biotechnology Initiatives*

Management of infectious diseases and pests together

Banana biotechnology research at Institution A takes a multi-disciplinary approach (**Figure 4**), and institution A also trains post-graduates. Banana types are tested for their susceptibility to Fusarium wilt and their ability to resist the disease when exposed to systemically acquired resistance (SAR) chemicals. Banana leaf nematode investigations have been conducted recently as part of Institution A'sactivities. The Institution B in Research Center B has done extensive research in the past on these topics. The Institution C specializes in studying plant viruses and identifying their species.

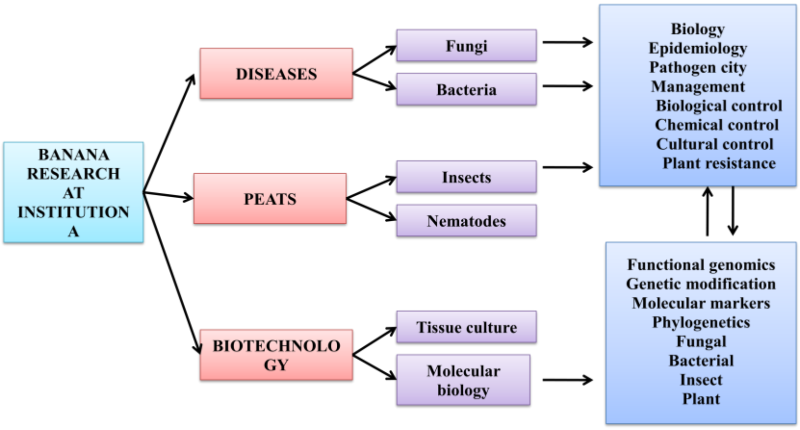

Figure 4: Summary Institution A at the University of Karnataka

Cultured tissue technique

Methods for identifying Somaclonal variation in vitro propagated banana plants are being developed by Institution A researchers using markers like Random Amplified Polymorphic DNA (RAPD) and Amplified Fragment Length Polymorphism (AFLP). However, these approaches have not been successful as predictors of the extent of chromosomal diversity that has occurred. Another strategy for spotting banana variants is presently in development, and it makes use of representational difference analysis (RDA). Its purpose is to distinguish between two groups of plant tissue culture/transformation-derived normal and possibly variant banana plants in terms of their genomes. Characterizing the differences between the two plant kinds will allow researchers to create a panel of indicators for detecting early genetic alterations. Somaclonal varieties of Cavendish bananas resistant to Fusarium wilt were developed by mutation breeding at the ARC-ITSC. As a result of poor fruit quality and unfavorable agronomic qualities, large investments in this area were halted.

3. Detection and Isolation of Resistance Genes

Concealment Subtractive Hybridization (SSH) and turn around quality articulation examination are two DNA deduction strategies being utilized by Institution A to reveal differentially communicated qualities in light of microorganism or bug pervasion, including those answerable for protection from Foc and the banana weevil. Genes that are differently expressed between tolerant or resistant plants and vulnerable plants have been identified, and we are in the process of characterizing and investigating them to gain insight into the impacts of Foc infestation on Cavendish bananas. The ability quickly screens germplasm for resistance to Fusarium wilt might be greatly aided by knowledge of gene expression for resistance. Creating resistant cultivars would be a great long-term solution for weevil management. To increase resistance against weevils, researchers are testing the effectiveness of phytocystatins, which are cysteine proteinase inhibitors found in both wild and cultivated plants. We also compare the expression of cysteine proteinase inhibitors in banana varieties that are resistant to and vulnerable to attack by weevils, and we investigate metabolic changes in transformed plants brought on by the synthesis of an exogenous inhibitor gene.

Molecular reprogramming

Isolates from the 'subtropical' race 4 of Foc were transformed with the green fluorescent protein (GFP). To study the relationships between fungal pathotypes and host genotypes, the infection process, and host defensive responses, green fluorescence protein (GFP) has been introduced into isolates resembling' subtropical' race 4 of Foc. Additionally, Institution A is establishing a facility to modify Cavendish bananas for resistance to disease and pests. Embriogenic callus development has been produced from immature male flowers that have been successfully isolated. To prepare cell suspensions for later use in genetic engineering, this callus is now being cultured. Institution A will be pivotal in the future when it comes to teaching students about banana genetic transformation and conducting greenhouse and field tests to determine the level of pest and disease resistance in transgenic banana plants.

4. Conclusion

Agriculture across the globe is become a high-input, low-profit industry. In the future, excellent quality and high yielding crops will need the careful breeding of new enhanced varieties, the implementation of effective disease and pest control techniques, and the careful management of agricultural fields. Diseases and pests threaten the livelihood and food security of small-scale farmers, yet they often lack the resources to learn about and control these problems. There is little question that plant biotechnology play a significant role in the long-term sustainability of this essential crop on the continent. A comprehensive strategy is needed to enhance Musa in order to breed superior banana and plantain varieties. Plant enhancement should be seen as a low-cost alternative for protecting plants, increasing yields, and maintaining a satisfactory quality of fruit for small-scale producers. The use of molecular marker systems has several potential uses in Musa breeding. Indirect genotypic selection for determining heritability of phenotypes, thorough genetic linkage mapping, map-based gene cloning, and helping find a resistant genotype in the lab are all examples. The launch of expensive biotechnology-derived goods will be hampered by their prohibitive cost. Banana farmers on a smaller scale aren't in a financial position to invest in expensive new technology or costly pesticides to combat pests and illnesses.

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