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Original Article

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An Overview on the Ramification of Biotechnological Trends in Indian Agricultural and Food Sectors

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Article Information

Received 7 Mar 2026

Accepted 13 Jun 2026

Available online 30 Jun 2026

Keywords: Agriculture, Biotechnology, Beet, Crops, Disease, Food, Genetically modified, Pesticides, Tools, Trends

Abstract

As we approach the next millennium, numerous challenges confront not just agriculture but society as a whole. Today, the industrialized world is undergoing a transformation due to the implementation of modern technology, such as biotechnology. This progressive science is expected to significantly contribute to disease relief, improve food security, and aid in environmental preservation due to the technical and economic advantages of biotechnology. In India, the goal for the agriculture and food sector should be to persistently enhance efficiency through both conventional and innovative technology. So far, plant genetic engineering has predominantly concentrated on altering agronomic traits that lead to improved production efficiency. These characteristics mainly involve herbicide, insect, or disease resistance and are transforming numerous crop production systems in the India and beyond. A shift in emphasis towards altering traits that provide distinctive quality characteristics to food products is expected to have an even greater influence in the future. A strategy to alter the quality of food items includes the rerouting or adjustment of internal metabolic pathways to reach distinctive outcomes.

Introduction

As we developed, agriculture and food production have seen the implementation of new technologies. During the latter part of the 20th century, significant enhancements in agricultural productivity were predominantly dependent on selective breeding initiatives for both plants and animals, extensive application of chemical fertilizers, pesticides, and herbicides, along with advancements in mechanization. This model has effectively enhanced productivity; however, these gains have resulted in issues such as greater uniformity in the genetic diversity of crops and livestock, pests that are resistant to chemical pesticides, effects on environmental quality, and production requiring significant capital investment. There is currently and will continue to be a heightened focus on creating improved and more sustainable methods to enhance production efficiency while simultaneously minimizing the environmental effects linked to agricultural practices. In this context, the instruments and offerings of biotechnology and genetic engineering will hold significant importance, and the developing biotechnology revolution is fostering optimism that it will establish a foundation for more sustainable agricultural practices.

The innovative features of biotechnology contrast with earlier agricultural technologies in several ways that are likely to be important. Biotechnology can improve efficiency and quality of products while slightly raising production costs by offering tools to better create and integrate desired traits in plants and animals. By utilizing genetic engineering, it will be feasible to improve the nutritional value, taste, growing period, and harvest amount, resistance to diseases, along with additional characteristics vital for the cultivation of crops. Engineered microorganisms and enzymes created through recombinant DNA techniques are now utilized in various areas of food production. Biotechnology can help preserve natural resources and enhance environmental quality by decreasing reliance on chemical inputs through the creation of natural fertilizers and pest-resistant crops, as well as by supporting the operation of biocontrol systems. Biotechnology can offer altered organisms to break down waste and contaminants and for converting biomass to lessen reliance on non-renewable resources.

The impact of biotechnology on India's agricultural and food industry will most likely bring significant benefits. In this

https://doi.org/10.63954/spnxy683

paper the areas of most relevance will be discussed under three headings: Crops, Animals, and Food.

Arable Crops

The innovative features of biotechnology distinguish themselves from earlier agricultural technologies in several respects. While most past research has concentrated on herbicide resistance, other significant traits are presently in advanced development stages, such as insect protection, virus resistance, and crops with improved quality attributes. In the future, there may be potential for plants to serve as mini-factories for producing different pharmaceutical compounds. The initial experiments of genetically modified crops in India were performed at Maharashtra's Crop Research Centre at Mahyco, in partnership with Monsanto, utilizing Bt cotton developed by Monsanto, followed by herbicide-resistant beet sugar. Herbicide-resistant sugar beet enabled the application of relatively inexpensive herbicides on sugar beet that effectively manage a broad spectrum of weeds, are eco-friendly, and offer substantial potential savings compared to existing weed management systems. This idea has been assessed in eight Indian states since 1990, and no issues of any kind have arisen. Different types of sugar beet have been modified to tolerate a different herbicide called Glufosinate. Wheat varieties have been altered to be resistant to imidazolinone herbicides. These herbicide groups offer enhanced flexibility, are eco-friendly, and deliver excellent contact and residual weed control. Since effective weed management is crucial for maximizing yield potential, having a variety of weed control options is essential to easily tackle problematic weeds. The primary breeding objectives for cereals are disease resistance, yield, and various traits, which are crop-specific, such as enhanced brewing or baking qualities.

Diseases and pests

In India, the impact of fungal diseases is severe, and resistant varieties currently play an essential role in reducing the negative effects of diseases and pests. Input programs related to cultivars are currently implemented in conventional agriculture, and with emerging decision support systems and molecular diagnostic methods, this strategy could be further utilized in future cost-effective production systems. Resistance to diseases based on the 'gene-for-gene' interaction in fungal infections (the idea that for every gene that regulates resistance or susceptibility in the plant, there exists a matching gene for avirulence or virulence in the pathogen) has been shown to be the most successful. Nevertheless, resistance to disease in modern varieties is predominantly [2,3]

Monogenic, hypersensitive in nature, and thus these cultivars possess a relatively brief lifespan unless safeguarded by more frequent applications of fungicides. This form of resistance is frequently unstable, failing as the pathogen adjusts to the altered selection pressure caused by the emergence of a new variety. Consequently, new varieties are continuously substituted mainly because of their failure in disease resistance.

Conventional plant breeding has significantly enhanced the resistance of numerous crops to key diseases. A significant drawback is the duration needed to perform crosses and back-crosses, as well as to identify the desired resistant offspring, which hampers the ability to quickly respond to the emergence of new fungal races. Furthermore, for numerous significant fungal diseases, these plant-breeding methods will not offer a remedy since there are no natural sources of resistance accessible to the breeder. Research in biotechnology related to disease resistance is behind that for herbicide and insecticide resistance, with initial introductions anticipated in 3 to 7 years. Creating varieties with wide-ranging multigenic disease resistance (field resistance) may significantly address this issue, and advancements in breeding and biotechnology could greatly facilitate their introduction.

The primary disease focuses for wheat breeding worldwide include Septoria leaf spots (S. tritici) and Septoria nodorum, along with Fusarium ear diseases, while various other diseases, such as powdery mildew (Erysiphe graminis), are also significant. Conditions that have efficient seed treatments are typically not primary focuses, such as smuts and bunts (Ustilago spp. and Tilletia spp.) as well as Cochliobolus sativus [9,12]

Septoria tritici, responsible for Septoria leaf blotch, is estimated to cause global wheat yield and quality losses of 15%, with numerous Teagasc trials indicating that losses can reach 50% of the potential harvestable grain in Ireland when fungicides are not applied. Recent studies conducted at universities in the US have verified that transgenic expression of genes or specific peptide inhibitors can hinder pathogens such as S. tritici. Advancements in this field may result in the establishment of novel disease management approaches that hold significant potential to be both environmentally friendly and efficient against a wide range of bacterial and fungal pathogens affecting cereal crops. This type of multi-genic resistance could help Irish cereal farmers save around 10 million each year just in fungicide expenses. The advantages for both growers and nature are clear. With the advancement of genomics and bioinformatics, alternative methods for activating the defense mechanisms in plants are also being investigated. One method involves assessing fungal avirulence genes, which are activated solely when the plant generates a disease resistance protein due to infection. Incorporating these genes into plants is anticipated to provide improved resistance to fungal pathogens. Recently, several field trial outcomes have been released for experimental lines, featuring a wheat variety that demonstrates resistance to Fusarium. Although the occurrence of Fusarium is infrequent, even a mild infection can lead to yield losses. In Ireland, the illness may lead to a 25% decrease in yield, and mycotoxin contamination can be considerable. Just a limited number of

https://doi.org/10.63954/spnxy683

fungicides provide protection, making new wheat varieties with inherent defense mechanisms highly beneficial [9,12].

Other viral diseases pose considerable challenges for tillage farmers, and once the plant is infected, no pesticide can safeguard the plant. Viruses have evolved various innovative methods to transfer from one infected plant to others using carriers like aphids, nematodes, and fungi. Although resistant varieties have been developed through plant breeding for crops like potatoes and sugar beet, progress with cereal varieties has been gradual. Consequently, all cereal crops in Ireland are now primarily controlled with aphicides. Creating crops that resist viruses is more challenging since the genes responsible for resistance are frequently not active in the plant tissues where these pests feed, such as phloem or xylem vessels. Given that the main reason for managing aphids is their involvement in virus transmission, it is probable that virus resistance will continue to be the central emphasis of research. Cultivars exhibiting this resistance would greatly assist growers from a crop management perspective and would also provide substantial environmental advantages, as the necessity for regular aphicide applications would be reduced.

Additional avenues in biotechnology involve enhancing the quality of milling wheat. Enhancing wheat quality is a vital research aim focusing on superior milling characteristics and the creation of wheat types with specialty starches/baking enzymes that possess increased protein levels and improved yield. Ireland has a market of about 250,000 tonnes of milling wheat may be met in the future by new and enhanced wheat varieties, potentially providing a substantial share of that demand from Irish cereals instead of the current 50,000 tonnes.

Grass

Similar to other crops, considerable advancements have been made in the last 50 years to enhance grass production by utilizing new and enhanced grass varieties. Enhancements in yield, durability, cold tolerance, and disease resistance have been very beneficial. Unlike cereals, where the harvest index can be adjusted to boost grain yield, grass is considered a total biomass crop, making advancement more challenging and gradual.

Information from Aldrich (1987) shows that the typical yearly enhancement rate for grass yield was 0.6%, which persists to this day. In the future, farmers will require enhanced varieties capable of yielding greater amounts of digestible dry matter for both conservation and grazing purposes. Biotechnology is expected to be very beneficial since numerous gene sequences are shared between wheat and grasses; therefore, researchers can employ a method known as comparative mapping to clarify traits that need to be targeted and integrated into enhanced cultivars [1].

Genetic mapping is poised to greatly influence breeding for grass and clover, as numerous key traits are intricate, prompting the development of quantitative marker systems to enhance grass and clover varieties. For instance, the connection between characteristics like elevated sugar levels and the metabolic pathways involved is being determined. Such research is expected to raise grass sugars by at least fifty percent of their present concentration. This ought to eliminate the necessity for acid-based silage additives, resulting in yearly savings of 5 lakhs. Enhancing grass consumption is necessary to boost milk and beef output, resulting in greater efficiencies. Data from comparisons of animal production with present high and low sugar ryegrasses may lead to a net advantage of 25 Lakh per year.

Research is currently underway on the genetic alteration of protein degradation. The impact of proteases that are increased during senescence and stress is now clearly understood, and new methods that can modify enzyme properties are available. Alteration may result in higher nitrogen levels by making protein losses considerably less impactful. Protein stability after harvest is an important forage trait that greatly influences animal performance.

Biotechnology has enabled effective modification of biosynthetic pathways that regulate tannins, lignins, and phenolics, which significantly affect the nutritional quality of grasses. Enhanced digestibility, improved sustainability, and prolonged grazing season by approximately. Two weeks may aid in lowering the total meal needs, necessitate less indoor feeding, and increase the likelihood of finishing 18-month-old cattle on grazed grass. In total, the net advantage might reach up to 10 million each year. Currently, carbohydrate metabolism and leaf aging are targets for genetic modification.

In clover breeding, enhancing growth, boosting nitrogen fixation, and improving disease resistance are likely to enhance the potential of legumes for lowering outputs and increasing quality. Decreasing the chances of clovers inducing bloat in grazing animals is another long-term goal that could be significantly improved using modern biotechnology techniques. These methods could significantly ease the advancement of sustainable agricultural systems. Achieving these targets could lead to an estimated reduction of around 50 kg of inorganic nitrogen per hectare on at least half the farm area on half the farms nationwide, resulting in yearly fertilizer savings of 2 million, with considerable potential for additional savings.

Given the national significance of grass productivity, it is essential to employ all available methods to sustain progress and notably enhance the nutritional quality of grass cultivated in Ireland. The possible benefits of taking such action are substantial, and it is clear that biotechnology will play a crucial role.

Animal Biotechnology

In the coming decade, the animal-based sector will face a major challenge to uphold its standing, as the commodity value will, in relative terms, keep declining while quality must rise, and production systems will face ongoing pressure to lower input costs. Enhancing output efficiency instead of raising animal numbers is crucial for the economic and physical sustainability of the livestock industry. Animal biotechnology studies are increasingly integral to global livestock research initiatives aimed at enhancing production efficiency and improving product quality.

Biotechnology, especially molecular biology, is currently making a significant impact on the pharmaceutical and agricultural sectors. Moreover, investment in biotechnology research is increasing swiftly as it is considered to provide the possibility of substantial incremental improvements in productivity stemming from various potential advancements. In cattle, this encompasses the advancement of reproductive biotechnologies, the discovery of genetic markers to allow breeders to swiftly produce more efficient [24].

cattle and allow conservationists to preserve livestock diversity. Creating affordable, effective diagnostic tests for managing livestock diseases, enhancing the quality of animal feed, and promoting favorable shifts in rumen microbiota contribute to better animal welfare and improved environmental management.

Biotechnology is anticipated to be the fastest and most efficient path to achievement in all of these fields. This poses a significant challenge for Ireland since we must persist in advancing and utilizing new scientific insights and suitable technological innovations in this field to address the rising opportunities in research and technology needed to support a competitive animal sector.

The utilization of advancements in molecular genetics is expected to enhance animal production, fertility, and the evolution of breeding technologies alongside the enhancement of animal health.

Marker-assisted selection in farm animals

Notable advancements have been, and are still being made in the field of livestock genomics. DNA-based technologies will clearly have a significant impact on cattle breeding by allowing breeding values to be assessed at younger ages and with increased accuracy compared to previous methods. The DNA technologies will enhance quantitative genetics. This technology can pinpoint the genes influencing characteristics like growth speed, meat tenderness, and flavor, alongside traits and products related to both meat and milk that could enhance human health. Alongside the progress in genomics, significant strides are occurring in proteomics that will offer insights into protein structure and function. The volume of genomic and proteomic data expected to be produced in the near future is anticipated to surpass the data generated in the last two decades. Consequently, identifying genetic markers linked to commercially valuable traits in beef cattle and milk quality attributes in dairy cows will likely be very important.

Farm animal reproduction

A greater comprehension of reproductive processes in livestock, especially cattle, has led to several commercial and possibly commercial products. These encompass techniques for managing the oestrous cycle and ovulation for timed AI, in vivo and in vitro (IVF) embryo generation, DNA-based approaches for sexing embryos, cryopreservation of embryos, and pregnancy diagnostic methods. Advancements in embryo technology will persist, including IVF embryo creation from animals with high genetic merit. Techniques for isolating x- and y-chromosome sperm, founded on their DNA composition, are being created to facilitate the pre-selection of offspring sex. Managing reproduction for cattle herds is labor-intensive and will necessitate the creation of in-line biosensors that can concurrently measure multiple analytes, such as reproductive hormones and health indicators in the milk stream. Coordinated breeding, centered on accurate ovulation management, will enable enhanced utilization of genetically outstanding dairy and beef bulls via artificial insemination.

Animal production

As mentioned previously, progress in animal nutrition will be essential to make the most of high genetic merit dairy and beef livestock. Particular focus will be placed on intake research involving genetically altered grasses, as well as rumen activity, which encompasses the genetic modification of the rumen microflora community aimed at enhancing nutrient extraction from consumed grass and forage. Advancements in forage preservation technology driven by biotechnology could be crucial for minimizing storage losses and improving animal performance [3].

Farm animal health and welfare

The infectious diseases affecting livestock continue to be a significant limitation on production efficiency and have consequences for animal welfare. The standard control method is vaccination or chemotherapy. Illness will persist as an issue, particularly due to rising resistance to antibiotics and chemotherapy agents. Creating precise and reliable methods for disease diagnosis and improving vaccination and immune response control is crucial. Research will focus on DNA-based tests for diagnosing infectious diseases and molecular typing of pathogens. The advancement of precise DNA-based diagnostic methods for diseases and immune strategies for managing livestock illnesses will probably occur, yielding considerable benefits for animal welfare [5].

Food Biotechnology

Only recently, with the emergence of current advancements in plant biotechnology and cloning in higher animals, has the potential for genetic modification in food systems genuinely been recognized. Although the effectiveness and safety of numerous biotechnology products are now clearly established in the pharmaceutical sector (for instance, recombinant drugs like insulin and interferon), the application of this technology in food is not as advanced. However, there are exceptions to this, notably the common use of enzymes like recombinant chymosin for milk coagulation in cheese manufacturing; for instance, over 90% of Cheddar cheese produced in Ireland

https://doi.org/10.63954/spnxy683

utilizes this recombinant enzyme, which is occasionally (beneficially) advertised as "Vegetarian Cheddar." Recently, advances in plant biotechnology have resulted in a range of genetically modified foods available in the market. Most of these new foods have originated from studies conducted by commercial firms and are enhanced in several instances regarding their industrial characteristics like chosen herbicide resistance and extended shelf life [14].

There is no doubt that biotechnology will significantly impact the food we consume in years to come. A glance at the current trends in crop production reveals that nearly all soya supply, for instance, will be the genetically modified type in the near future (Figure 1). The primary breeding objectives for cereals include disease resistance, yield, and specific traits that vary by crop, such as enhanced brewing or baking qualities.

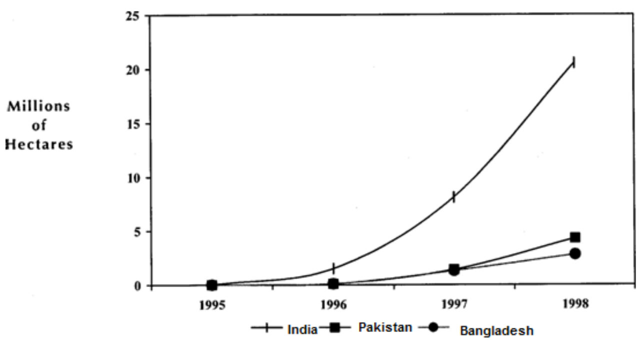

Figure 1. Global Area of Transgenic crops: 1995 to 1998 by country

A significant aspect where genetic engineering could greatly benefit the dairy sector is in the genetic alteration of lactic acid bacteria (LAB), which are frequently utilized as starter cultures in making fermented dairy products. Specifically, the genetic alteration of LAB might offer these potential advantages:

They can be utilized to enhance food safety by boosting the generation of antimicrobial substances. An instance of this would be the creation of genetically altered LAB that generate the wide-ranging bacteriocin lacticin 3147. This food-grade bacteriocin consists of two peptides subjected to post-translational modification and targets a wide range of Gram-positive food borne pathogens, including Listeria monocytogenes and Clostridium botulinum. For the last 5 years, the C-BAC group has focused on the bacteriocin, which has demonstrated effective elimination of specific pathogens from food products like cottage cheese, baby formula, and powdered soup. Moreover, the genetic factors that govern the production (and immunity) of the bacteriocin have been identified and introduced into different strains. The creation of food cultures that generate this strong anti-microbial in food systems may offer an additional barrier against food pathogens and could be particularly crucial for specific foods, like those made with raw milk [23].

The beneficial health effects of probiotic bacteria might be enhanced or implemented into different bacteria. They could result in the creation of oral vaccines made from LAB altered to generate surface antigens of harmful bacteria. They might result in the creation of a new generation of starter cultures enhanced in their processing traits, including resistance to bacteriophage (bacterial viruses).

Diagnostic Techniques

The emergence of Monoclonal Antibody technology has changed the way human diseases are diagnosed. So far, the primary commercial application of diagnostic methods in agriculture has been for detecting viruses (and, to a lesser degree, fungal and bacterial pathogens) in seeds, nursery plants, and certain field crops. This kind of technology will probably not take the place of fungicides; nonetheless, it will assist in creating decision-oriented disease management strategies. In this context, upcoming management systems that utilize fast diagnostic methods will be significant. Diagnostic kits are accessible for detecting Barley Yellow Dwarf Virus and specific potato viruses that already significantly contribute to strategies aimed at reducing chemical inputs.

In the field of animals, it is probable that the progress of sensitive and precise disease diagnosis methods, along with improved vaccination and immune management systems for disease control, will be achievable through innovative biotechnological techniques. DNA-based tests for diagnosing infectious diseases and molecularly typing pathogens will remain a significant focus in future production systems. Such tests may also significantly contribute to the development of molecular markers for stress [11].

DNA-based diagnostic techniques will be crucial in the food industry, as rapid and precise assays are vital for detecting spoilage organisms and pathogenic bacteria.

Conclusions

In the near future, the sustainability of Irish agriculture will be significantly affected by policy choices and the capability of farmers to enhance production efficiency using current technology. New technology will focus more on lowering the cost of inputs, especially those regarded as environmentally harmful or unacceptable to consumers. Biotechnology and genetic engineering certainly play an important role in this category. Numerous concerns have been expressed in this country and in India overall regarding this emerging field of science, such as insufficient product labeling, environmental impacts, antibiotic markers utilized in the selection process, along with ethical, moral, and social considerations. These matters require discussion since genetic engineering is an incredibly potent tool, and consumers, as is their entitlement, are understandably wary. It should be noted, though, that this field has an extensive safety history spanning many years since its inception. Public sentiment in areas like India has largely progressed to understanding that genetic engineering, when adequately regulated, offers numerous benefits. This discussion and confirmation should occur in this nation grounded in solid scientific rationale and findings from scientific studies. So far, more than 25,000 field trials have been conducted across 30 countries on 56 different crops, with no negative impact on human health or the environment observed. Currently, India has 20 million acres of genetically modified crops actively being produced commercially.

In India, obtaining regulatory approvals for genetically modified research and marketing is challenging and governed by the environmental, food, and feed regulations. There are also worries in certain circles that commercial biotech firms can now possess genes through patents. Nonetheless, although these firms are entitled to gain from patients. In India, the regulatory approvals for experimentation and marketing of genetically modified organisms are rigorous and fall under the country's environment, food, and feed regulations. Some groups are also worried that commercial biotechnology firms can now acquire ownership of genes through patenting. Nonetheless, although these companies have the entitlement to gain from a particular use of an original, non-obvious, and beneficial invention for a limited duration, they do not possess ownership of a gene. It's important to note that these companies do not have an automatic entitlement to use their invention unless they comply with all health, safety, and environmental regulations, including international agreements.

Conflict of Interest: NIL

Funding Sources: NIL

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Declarations:

Authors' Contribution:

- All Authors Conceptualization, data collection, interpretation, drafting of the manuscript and intellectual revisions
- The authors agree to take responsibility for every facet of the work, making sure that any concerns about its integrity or veracity are thoroughly examined and addressed

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https://doi.org/10.63954/spnxy683