TRANSGENIC PLANT AND THEIR ROLE IN ECOSYSTEM

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Abstract

A recent development in agricultural biotechnology is transgenic crops. The pros and cons of transgenic crops on the environment are widely debated. Ecosystems and current agricultural management techniques have an impression on the atmosphere. Any additional negative effects of transgenic crops may lessen the benefits of current agricultural practices and raise the background value of any negative effects resulting from new agricultural techniques. Transgenic plant synthesis and release of transgene products via several pathways in soil may lead to their accumulation over threshold levels if they surpass consumption or biodegradation. This could affect the soil ecosystem in both short-term and long-term ways. Transgenic plant effects are also influenced by temporal and spatial environmental factors. Transgenic plants have been demonstrated to release novel proteins into the soil environment, and the variety of species that can utilise these proteins may be impacted by their presence. When transgenic plants are involved, microbial diversity can be changed, although these effects are erratic and fleeting. In addition to plant species and transgene insertion, environmental variables like field site and sample date also have an impact on the microbial populations associated with soil and plants. Plant variety may have an influence on the dynamics of rhizosphere microbial populations, which in turn may affect plant growth, health, and ecosystem sustainability. This is because even small changes in the diversity of the microbial community can have an impact on soil health and ecosystem functioning.

Key words: Transgenic crop, Ecosystem, Rhizosphere, Environment

Introduction

These are the plants whose DNA has been modified by genetic engineering. The idea is to imbue the plant with a novel trait not typically present in the species. Transgenic plants carry a gene or genes that have been deliberately introduced. A transgene is an added gene sequence that might come from a different species or from a completely other plant. Utilising a variety of genes to enhance a plant's potential for yield and usefulness is the aim. This method has improved quality, longer shelf life, higher yield, resistance to insects, and tolerance to a variety of biotic and abiotic stresses, including heat, cold, and drought. Transgenic plants that express foreign proteins for medical and commercial purposes can also be produced. Plants made of vaccines or antibodies, or "Plantibodies," are especially useful since they reduce the cost of testing for bacterial and viral toxins because they do not host human infections.

In 1983, reports of the first transgenic plants appeared. Since then, a number of significant agronomic plant species, such as tobacco, corn, tomato, potato, banana, alfalfa, and canola, have expressed a large number of recombinant proteins. Traditionally, tobacco plants were used to make vaccinations for humans, but potatoes and bananas are also taken into consideration.

The majority of places where agricultural crop plants are grown suffer greatly from fungus-related illnesses. Fungal infections can cause major production and crop quality reductions in various parts of the world, with output reductions of up to 30%–40% of potential yield. Breeding for resistance, the use of fungicides in concert with disease monitoring and prediction, as well as biological and cultural control techniques, have all been employed as disease-control strategies. The creation of fungal-resistant plants may be advanced by the use of more modern biotechnology and genetic engineering techniques on agricultural crop plants**(Punja 2004).**

Unlocking the potential of transgenic crops

Revolutionary changes in agriculture, industry, nutrition, and perhaps health might be facilitated by transgenic crops. Through the manipulation of plant genomes, it is possible to engineer crops to have higher nutritional value and to withstand biotic and abiotic stresses; plant raw materials can be better tailored to industry needs; and "green factories" can be used to produce a variety of novel products, including pharmaceuticals, in a sustainable and environmentally friendly way. Despite the enormous potential of genetically modified (GM) crops being widely discussed, the technology is still relatively new, and so far, not much has been accomplished.

The disparity between the exaggeration and the actuality of the relatively primitive first-generation genetically modified crops, which are thought by many to benefit solely farmers and seed firms, has led a number of analysts and advocacy groups to declare the technology a failure. Until the bottleneck of developing technologies for the coordinated manipulation of multiple genes or traits is removed, there will be little progress towards second-generation "output trait" products that have direct benefits for consumers in terms of nutrition, the environment, or other areas.

The enormous amount of literature explaining the modification or expression of single valuable gene implants and the very small number of papers addressing the manipulation of numerous genes provide ample proof that this bottleneck, though it may not be commonly recognised, actually exists. However, there are clear benefits to "stacking" or "pyramiding" already-existing GM traits in crops. This approach may enable the engineering of multiple resistance to distinct pathogens or pests, possibly in conjunction with herbicide tolerance. Similar to this, there is a great deal of promise for advanced metabolic engineering in plants, which might result in the creation of plants that can thrive in unfriendly conditions and provide better raw materials or healthier food.

But since flux through biochemical pathways is frequently coordinated with that of competing pathways, and because most metabolic processes that are targets for manipulation depend on the interaction of multiple genes, the only way to effectively manipulate metabolism is to control multiple genes on the same, or interconnected, pathway. For instance, despite the fact that "Golden rice" has been successfully modified to produce provitamin A through the insertion of three carotenoid biosynthesis genes **(Ye et al., 2000),** effective provitamin A absorption might necessitate increasing the resorbable iron content, which might involve adding three more genes. Similarly, it's thought that four to six new genes and changes to many metabolic pathways would be needed to produce crops at acceptable levels of a highly durable biodegradable plastic (a copolymer of polyhydroxy butyrate (PHB) and polyhydroxy valerate) **(Slateret al., 1999).**

Exploring the influence of Transgenic Plant on Soil Ecosystem

The type of recombinant protein—that is, its range of activity—and the degree of exposure will determine how transgenic plants affect non-target soil microbes. According to **McGregor et al. (2000) and Saxena et al. (1999)**, certain transgenic plants that are resistant to insects alter the rhizosphere through root exudates. This can either accelerate or slow down the proliferation of microorganisms in the rhizosphere. Bt endotoxin is released into the soil by transgenic Bt maize and cotton plants from various areas of the plant (leaf, root, etc.); it remains in the soil and retains its biological and immunological activity **[Palm et al., 1994, Pratt, G.E et al., 1993].**

The absence of baseline data on diverse agroecosystems to compare with agroecosystems where transgenic crops have been introduced **[Bruinsma et al., 2002, Dale et al., 2002**] and a generally accepted methodology for conducting impact assessments of transgenic plants on soil ecosystems pose significant challenges to assessing the effects of transgenic crops on soil microbial diversity. Therefore, it is critical to review the literature in order to gain a systematic understanding of the risks associated with transgenic plants and their products that have been observed thus far with regard to soil microbial diversity. Additionally, a framework based on an approach that should be followed globally for the assessment of transgenic crops' effects on soil is proposed.

Interaction of soil microbes with transgenic plants One of the planet's richest environments in terms of species diversity is found in soils, which are home to a variety of organisms such as bacteria, viruses, algae, lichens, protozoa, fungus, and vertebrates. According to **Heywood (1995)**, the variety of soil is frequently orders of magnitude more than that of the aboveground environment. A key factor in preserving the resilience of soil is its microbial diversity **[Mikola et al., 2002].** Because various species or communities react to environmental changes differently, soil biodiversity acts as insurance against these fluctuations and increases the stability of ecosystem features **[Loreau et al., 2001].**

It's crucial to discuss how transgenic plants affect soil ecosystems, but it's necessary to distinguish between how they affect soil function and soil microbial diversity, or the variety of organisms that live in the soil. A decline in soil function may not always result from a reduction in soil microbial diversity. Research on the relationship between diversity and function has revealed that function may be sustained with only a few numbers of species present **[Loreau et al., 2001] and** that variety plays a significant effect in soil function **[Tesfaye et al., 2003].** Researchers generally agree that there is "no predictable relationship between diversity and function" and that species richness does not have a major role in how well soils perform as a whole [**Bardgett, R.D. 2002**].

The primary agents of the soil ecosystem are plants, and the soil offers both soil microorganisms and plants a geographically and temporally varied habitat. Plants affect soil through plant litter, rhizodeposition (root exudates, root cell sloughing, and root turnover), and nutrient, gas, and water interaction. Important nutritional requirements are met by the interaction of soil microbes with plant roots, benefiting the plants as well as the related microorganisms **(Bowen, G. D. 1980).** Transgenic plants and the soil biota interact both naturally and as a result of human activity.

Natural Interactions

On the rhizoplane and in the rhizosphere, naturally occurring soil microorganisms interact with plant roots **[Kennedy, A.C. 1998].** Through the action of rhizospheres, plant roots directly affect the make-up and population density of soil microorganisms. In the rhizosphere, the microbial population is often larger and more active than in the bulk soil. The rhizosphere has distinct physical and chemical properties, but it also supplies most of the substrate needed by microorganisms in the soil for their energy-producing processes and biosynthesis.

Naturally, when transgenic plants are given an introduced transgenic trait, they release different transgene products (Bt toxin and T4 lysozyme) into the soil ecosystem through a variety of pathways. These pathways include the decomposition of senescent leaves and leftover biomass from transgenic plants in the field after the final harvest, leachates from plant injuries, sloughing off root / root cap cells, and exudates from the roots**[Donegan et al., 1997**]. According to reports, Bt endotoxin bound quickly to humic acids, organomineral complexes, and clay minerals including montmorillonite and kaolinite, as well as pollen and agricultural wastes**[Crecchio, C. andStotzky, G.1998**].

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In two of the three transgenic lines, Donegan **[Donegan et al., 1995]** found a temporary but noteworthy increase in culturable aerobic bacteria and fungi. This increase was attributed to unanticipated changes in plant root exudates. The study looked at the effects of decomposing transgenic cotton litter on the structure of soil microbial communities.

Effects on biodiversity

A major aspect in environmental management, particularly in the Northern Hemisphere, is intensive agriculture, which preserves a large portion of the biological variety of those nations in a cultivated landscape **(Krebs et al. 1999).** Changing the existing management system might have a big impact on these nations' biological diversity. It is anticipated that crops resistant to herbicides would enable more effective weed management. There are worries that this could have detrimental effects on the ecological variety of rural areas, particularly in the UK, since fewer blooming plants would remain to provide as food sources for creatures ranging from birds to invertebrates. Modelling was used to estimate the potential impacts of such a situation **(Watkinson et al. 2000).** This author's prediction on the impact of herbicide-resistant sugar beetroot on biological diversity in general was based on a landscape model involving weeds (Chenopodium album) and songbirds (Alauda arvensis, skylarks). Their research suggests that there may be major adverse consequences on birds that eat seeds.

Biotechnology and agrobiodiversity

While biotechnology can provide a wider range of commercial plants, transnational corporations (TNCs) are promoting a tendency of expanding a single product's worldwide market reach, which fosters genetic homogeneity in rural areas. Furthermore, the World Trade Organization's (WTO) support for intellectual property rights and patent protection enhances the possibility that a small number of types may control the majority of the seed market by preventing farmers from sharing, storing, and reusing seeds. Businesses like Monsanto need farmers to sign a pledge agreeing not to sow seeds from their crops in order to ensure that farmers rely solely on their seeds. Moreover, by creating crops whose seeds become incapable of procreating, Monsanto seeks to physiologically enforce what it cannot contractually impose. Dubbed "terminator technology," this kind of seed-sterilizing technology poses serious risks to farmers' capacity to save, replant, and exchange seeds—one of the most effective ways to preserve genetic variety. There are two ecological disadvantages to crop uniformity, despite potential economic benefits.

First, past experiences have demonstrated that a sizable region dedicated to a single cultivar leaves it open to new, compatible disease or pest strains. Furthermore, a loss of genetic diversity results from the extensive usage of a single cultivar **(Robinson 1996).**

Since widespread government efforts pushed farmers to embrace new varieties and to reject many indigenous variations, evidence from the Green Revolution amply demonstrates that the spread of modern varieties has been a major driver of genetic loss (**Tripp 1996**). Farmers face greater risk as a result of the homogeneity brought about by sowing more land to fewer varieties because most of these types perform poorly and may be more susceptible to disease and insect attack.

Transgenic crops as weeds

According to some scientists, some transgenes may impart or improve weediness in certain crops, increasing such crops' ability to survive in agricultural areas. It is unlikely that the majority of genetically modified plants will turn weedy, but those that do pose a significant risk **(Radosevich et al. 1996).** This relates to transgenic seeds that break off during harvest and sprout in crops that rotate the next year. The rivalry between these "volunteer weeds" might become severely yield-limiting if they develop resistance to the pesticides employed on the young crop.

The herbicide glyphosate, which was first sold under the brand name Roundup, has been genetically engineered to render a large number of crops resistant to it. Because of this resilience, farmers can eradicate most weeds from the fields without endangering their crops. It has been shown, therefore, that this kind of alteration is beneficial to a weedy variety of rice even in the absence of herbicide. This implies that such change may have repercussions both in and outside of farms.

By preventing the enzyme EPSP synthase, which is necessary for the synthesis of certain amino acids and other compounds that make up to 35% of a plant's mass, glyphosate prevents the development of plants. The additional EPSP synthase enables the plant to resist glyphosate's impacts. Additionally, in an effort to take advantage of a legal gap in the US that permits the regulatory approval of organisms bearing transgenes not originated from bacterial pests, biotechnology laboratories have tried to increase the synthesis of EPSP-synthase by using genes from plants rather than bacteria. Few researches has examined if transgenes, including those granting glyphosate resistance, might increase the competitiveness of weedy or wild relatives in terms of survival and reproduction once they enter those plants through cross-pollination.

Ecological impacts of herbicides

Businesses claim that when used correctly, glyphosate and bromoxynil break down quickly in the soil, don't build up in groundwater, don't affect creatures that aren't intended targets, and don't leave residues in food. However, there is proof that bromoxynil poisons fish, can lead to birth abnormalities in lab animals, and may even cause cancer in people **(Goldberg 1992).** Bromoxynil is considered to be hazardous to farmers and agricultural workers since it is absorbed dermally and causes birth abnormalities in rodents. According to **Pimentel et al. (1989),** glyphosate has also been shown to be hazardous to certain nontarget species in the soil, including fish and detritivores like earthworms as well as beneficial predators like spiders, mites, carabids, and coccinellid beetles. Concerns regarding food safety also emerge since this herbicide is known to accumulate in fruits and tubers while undergoing minimal metabolic breakdown in plants

Impacts of disease resistant crops

Researchers have tried introducing viral product genes into plant genomes in an effort to genetically modify plants so they would be resistant to harmful infection. The most popular technique uses viral RNA sequences that, when produced in plants, interfere with the virus that is causing the infection, providing so-called "pathogen-derived protection." There are several hazards associated with using viral genes to provide crops virus resistance, despite the potential advantages. First, there's a chance that unrelated viruses attacking the plant may acquire coat protein genes from plants that have them. In some cases, the foreign gene modifies the virus's coat structure and may impart characteristics like altered plant-to-plant transmission.

The second possible concern is that inside the transgenic crop, RNA virus and viral RNA might recombine to form a new pathogen that causes more serious disease issues. According to several studies, recombination happens in transgenic plants and, under some circumstances, results in the production of a novel viral strain with a modified host range **(Steinbrecher 1996).**To investigate the possibility that transgenic virus-resistant plants might expand the host range of some viruses or make it easier for new viral strains to be created through recombination and transpeptidation, careful further experimental investigation is required**(Paoletti & Pimentel 1996).**

Environmental problems of HRCs

Proponents of herbicide-resistant crops (HRCs) claim that this technique is an innovation that allows farmers to reduce the amount of herbicide they apply to postemergence conditions. Instead, they may use a single, broad-spectrum herbicide that decomposes relatively quickly in the soil. Developing herbicide resistance charts (HRCs) for less priced herbicides might be the answer when subsidies for weed control decline. Such herbicide options include, among others, glyphosate, imidazolinones, sulfonylurea, bromoxynil, and glufosinate ammonium.

Creation of “SUPER WEEDS”

Large-scale releases of transgenic crops may encourage the transfer of transgenes from crops to other plants, which may then become weeds, posing a serious ecological risk, despite some worry that transgenic crops themselves would turn into weeds **(Darmency 1994).** Significant biological benefits from transgenes have the potential to change weedy or wild plants into new, worse kinds of weeds **(Rissler & Mellon 1996)**. This is a case of introgression, or the hybridization of different plant species, as a biological process. There is evidence that these genetic exchanges currently take place between agricultural, weed, and wild plants. Crop cousins have the potential to become severe weeds, as seen by the prevalence of shatter cane (Sorghum bicolour), a weedy relative of sorghum, and the gene exchanges between maize and teosinte.

Developing Transgenic Plants for Phytoremediation of Heavy Metal Contaminated Soils

Worldwide, there are serious threats to human health and the environment from heavy metal poisoning of soils. Conventional approaches to soil remediation sometimes include costly and intrusive procedures. Utilising plants to eliminate, stabilise, or break down pollutants is known as Phyto-remediation, and it has shown promise as a substitute. On the other hand, indigenous plant species frequently show low levels of heavy metal tolerance and absorption. The most prevalent contaminants in soil are metals, mostly from mining, agriculture, urbanisation, and industrial processes. These pollutants include cadmium (Cd), lead (Pb), arsenic (As), chromium (Cr), and mercury (Hg) **[Raskin et al., 1997].**

Even in low quantities, these metals have the potential to build up in the soil over time and provide significant dangers to humans, animals, and plants through a variety of routes such as direct consumption, dust inhalation, and crop absorption. Conventional soil remediation techniques, such chemical extraction, landfill disposal, and excavation and incineration, are frequently costly, labour-intensive, and negatively impact the environment **[Clemens et al., 2016].**

Using plants to reduce soil contamination is known as Phyto-remediation, and it has become apparent that this is a viable and environmentally responsible way to deal with heavy metal pollution. According to **Salt et al. (1995),** plants have built-in systems for absorbing, transporting, and detoxifying heavy metals through a variety of physiological and biochemical processes.

Phyto-remediation gives the possibility to minimise environmental disturbance and return polluted soils to a safe and healthy state by utilising these innate skills. **[Wu and others, 2018]** Many plant species that are cultivated in polluted soils show poor rates of metal absorption or display indications of toxicity. To overcome this obstacle, scientists are using genetic engineering to improve plants' capacity for Phyto-remediation.

Transgenic plants, which have undergone genetic modification to express particular genes or features, present a viable way to increase the efficacy and efficiency of phytoremediation. Researchers want to improve plants' capacity to take in, translocate, and store heavy metals in their tissues by introducing genes that encode metal transporters, chelating agents, or enzymes involved in metal detoxification pathways **[Dhankher et al., 2002].** Transgenic plants may be engineered to grow in polluted settings, effectively extract contaminants from the soil, and aid in their immobilisation or destruction by targeted genetic alteration **[Zhao et al., 2009].** Plant biology, molecular genetics, environmental science, and biotechnology are all involved in the interdisciplinary project of creating transgenic plants for the Phyto-remediation of heavy metal-contaminated soils.

Evaluation of Transgenic Plant Performance:

The efficacy and viability of transgenic Phyto-remediation techniques depend on the evaluation of transgenic plant performance in polluted soils. A range of physiological, biochemical, and molecular tests are utilised by researchers to assess different facets of transgenic plant reaction to metal exposure. When comparing transgenic plants to their wild-type counterparts, physiological tests such metal absorption kinetics, metal distribution studies, and plant growth analysis can shed light on how transgenic plants tolerate, accumulate, and translocate metals. The fundamental processes of metal detoxification and tolerance in transgenic plants are clarified by means of biochemical tests, which include measurements of antioxidant enzyme activities, metal chelation capabilities, and metal speciation studies.

Researchers are able to discover critical genes and pathways involved in metal detoxification and tolerance as well as characterise the molecular responses of transgenic plants to metal stress thanks to molecular approaches including gene expression profiling, metabolomic analysis, and proteome profiling.

Ecological Impacts:

Unintentional ecological effects of transgenic plant introduction into natural environments include altered plant-microbe interactions, disturbance of ecosystem dynamics, and gene flow to wild cousins. There have been concerns expressed about the possibility that transgenes might disperse by processes such as seed or pollen dissemination to non-target species, resulting in unexpected gene flow and ecological ramifications.

Additionally, the introduction of transgenic plants into the environment may modify the nutrient cycling and soil microbial populations, which might have an impact on biodiversity and ecosystem functioning. Plant-microbe interactions, soil structure, and nutrient availability may all be impacted by changes in soil microbial diversity and activity, which might have a domino effect on the resilience and health of ecosystems.

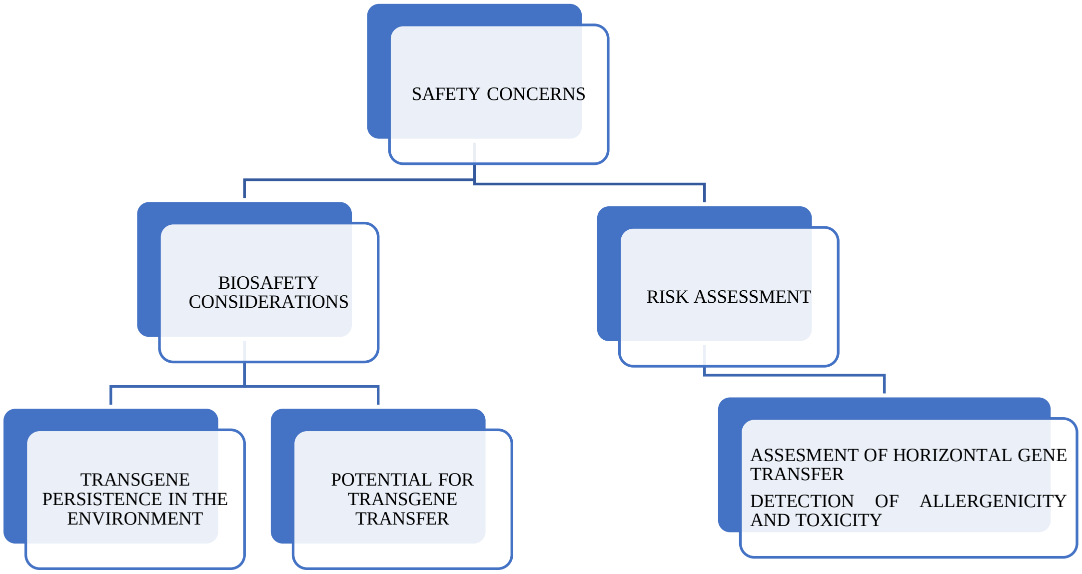

Figure 1: Safety Concerns

Regulatory Frameworks:

Transgenic Phyto-remediation plant development and application are governed by national and international regulations. There are significant regional and national variations in the regulatory frameworks controlling the use of genetically modified organisms (GMOs), including variations in the responsibility clauses, labelling specifications, and approval procedures. Government organisations in charge of agriculture, public health, and environmental protection restrict the introduction of transgenic plants into the environment in many different nations. Regulation agencies use extensive risk assessment methods, such as environmental impact studies, food safety evaluations, and public consultation processes, to evaluate the possible dangers and advantages of transgenic plants. Guidelines are provided for the safe handling, transportation, and use of genetically modified organisms (GMOs), including transgenic plants for environmental purposes, by international accords like the Cartagena Protocol on Biosafety. These agreements seek to balance the potential advantages of biotechnology with the hazards to human health and the environment by promoting openness, public involvement, and scientific collaboration in the regulation of genetically modified organisms (GMOs).

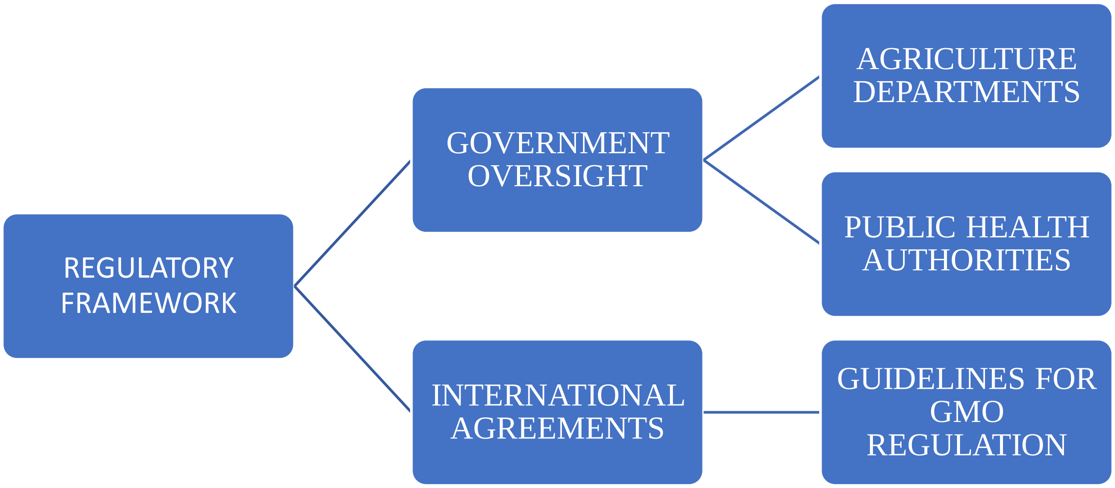

Figure 2: Regulatory Framework

Transgenic Plants and Animals in Agriculture:

Genetically modified plants and animals, or transgenics, have become important tools in contemporary agriculture. These organisms are engineered to display characteristics that are advantageous to agriculture, such improved nutritional value and heightened tolerance to diseases, pests, and environmental stresses. Transgenic organisms may have advantages, but there are also risks to human health and the situation that need to be considered.

Trends towards the production of biologically

Safe marker free transgenic plants

In genetic engineering, foreign material (single or multiple genes) is usually introduced into the host plant, changing its genome in the process. Most plant transformation laboratories worldwide regularly transfer genes for desirable traits to better agricultural plants from entirely other species of plants and animals. Currently, efforts are being made to transfer several commercially relevant genes to other attractive crop species. Since tobacco was the first plant to undergo genetic modification **(Horsch et al., 1985),** numerous transgenic crops have been created that are economically significant. Some of these crops have improved post-harvest and nutritional qualities, while others show resistance to diseases, pests, and herbicides **(Pattanayak and Kumar, 2000).**

The transformation studies were carried out using a variety of approaches, including electroporation, protoplast-mediated transformation, polyethylene glycol-mediated transformation, and agrobacterium-mediated transformation. But none of these techniques—particle bombardment or Agrobacterium tumefaciens transformation—work well **(Rakoczy-Trojanowska, 2002).** Selectable marker genes connected to genes of interest are necessary for the separation of transformed cells or tissues from non-transformants. The scarcity of selectable markers and the bulk of selectable markers' resistance to antibiotics are two potential obstacles to improving crop plants through transformation **(Yoder and Goldsbrough, 1994).**

Since the presence of selectable markers in the environment or food supply chain may provide an unpredictable high danger to the ecosystem or to human health, environmentalists have lately highlighted concerns about the biosafety of transgenic species. The manner in which the gene for herbicide resistance is inherited by weeds, which are related species, is a significant example supporting this claim **(Dale et al., 2002).**

The synthesis of branched-chain amino acids is aided by the ALS Inhibitor Resistance (ALS Gene), PPO Inhibitor Resistance (PPO Gene), ACCase Inhibitor Resistance (ACCase Gene), and Glyphosate Resistance (EPSPS Gene) are important genes that are involved in herbicide resistance in weeds. These genes also cause resistance to herbicides by causing mutations in those genes. It is possible that gut bacteria carrying antibiotic resistance genes will propagate these resistances among people.

Production of SMG free transgenic plants

Plant transformation has effectively made use of around 48 selectable marker genes from various sources, which mostly provide resistance to herbicides and antibiotics (Table). The Ti plasmid of Agrobacterium tumefaciens, or ipt, encodes the enzyme isopentyl transferase, and is now the most widely utilised gene in plant transformation **(Ebinuma et al., 1997b).** More than 95% of transgenic plants are produced with the use of ipt, nptII, hpt, and bar. Furthermore, a number of marker-free gene-transformation techniques for plants have been developed **(Zuo et al., 2002).**

Table: Selectable marker genes for plant transformation

Gene	**Gene product**	**Source**	**Selection**	**Reference**
Ble	Bleomycin reductase	E.coli Tn5 and Streptoalloteichushindustanus	Bleomycin, Phleomycin	Bevan et al. (1983)
Dhfr	Dihydrofolate reductase	E.coli,mouse,C. albicans	Methotrexate	Herrera-Estrella et al. (1989)
SPT	Streptomycin phosphotransferase	Tn5	Streptomycin	Jones et al. (1987)
pat, bar	Phosphinothrycinacetyletransferase	S. hygroscopicus	Php[honothrycin, bialophos	De Block et al. (1989)
EPSP	5-enolpyruvnylshikimate-3 phosphate synthase	Petunia hybrida	Glyphosate	Shah et al. (1986)
Bnx	Bomoxynilnitrilase	K. pneumonia sub sp. Ozanaenae	Oxynils	Freyssinel et al. (1996)

Future Scope

Novel prospects for precise gene editing in plants are provided by advances in genome editing technologies, such as CRISPR-Cas9. These alterations allow for targeted improvements in metal tolerance, absorption, and detoxification. Certain constraints associated with classic transgenic procedures may be avoided by using CRISPR-based technologies to precisely modify endogenous plant genes involved in metal homeostasis and detoxification processes. Approaches to synthetic biology, such as the engineering and construction of new gene circuits and biosynthetic pathways, have the potential to provide specialised solutions for the phyto-remediation of particular metal pollutants. Researchers may develop plants with improved capacities to detect, sequester, and detoxify heavy metals in the soil by building synthetic genetic modules for metal sensing, transport, and detoxification.

Conclusion

To sum up, the usage of transgenic plants and animals in agriculture brings potential and problems for socioeconomic growth, environmental conservation, and sustainable food production. The hazards of genetic modification, such as those related to the environment, food safety, society, and morality, highlight the need for a methodical and evidence-based approach to innovation in agricultural biotechnology. It's important to remember, though, that transgenic organisms have a lot of potential advantages as well, such as higher agricultural yields and productivity, environmental sustainability, reduced poverty, and enhanced food security. Stakeholders can solve urgent issues affecting global agriculture, such as population expansion, resource constraint, and climate change, by utilising genetic modification.

Furthermore, in order to improve our comprehension of the effects of transgenic organisms on ecosystems, socioeconomic systems, and human health, more study, monitoring, and capacity development are required. Stakeholders may promote innovation, fill up knowledge gaps, and strengthen the resilience of agricultural systems by funding multidisciplinary partnerships, information exchanges, and international cooperation.

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