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Role of Plant Biotechnology in Agricultural Sustainability and Improvement of Crops

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Abstract The global population is expected to rise steadily from 6.7 to 9 billion through 2050. To satisfy rising food demand, agricultural production must increase by 50% through 2030. But it is now critical to produce more food at a lower cost. As a result, increased agricultural variety and improved allied activities are required. In order to meet current as well as future demands in production and agriculture, it is absolutely necessary to adopt new technologies that guarantee the best potential outcomes. Plant tissue culture as a biotechnology procedure is also one way to address the food accessibility issue in developing nations, which are dealing with a rapidly growing population on a limited amount of land. Agriculture is currently dealing with a number of issues that have a significant impact on the production of food; some of these issues include soil degradation, contamination with hydrocarbons and heavy metals, deforestation, and one option is plant biotechnology. Biotechnology is an advanced technique that contributes to environmental protection and preservation by, e.g., reducing the use of chemical herbicides and pesticides. Plant tissue culture, genetic engineering, marker-assisted technology, nanotechnology, and others are all examples of biotechnology. Crops can be genetically improved to be resistant to rising water, temperatures, salinity, flooding, salinity insects and pathogens. This review would enable us to analyze the impact of plant biotechnology in development on sustainable agriculture and crop improvements in the Indian context.

Keywords Agricultural Production, Crop Improvement, Plant Biotechnology, Plant Tissue Culture, Sustainable Agriculture

1. Introduction

India's economy is expanding rapidly, and so is the use of technology in the country's expanding sectors. Agriculture is still the primary source of income for a large section of the population. India has been independent since 1947 and has been at odds with its agricultural infrastructure, practices, and associated communities. Agriculture's susceptibility to natural disasters such as floods, droughts, storms, cyclones, earthquakes, landslides, and so on is a well-known phenomenon. However, epidemics and pandemics in recent times have exacerbated the negative impacts on yield and farmer income. Agriculture should turn out to be more economical in increasing yield and pay without contrarily affecting the climate, utilizing water, being less dependent on pesticides and manures, and working on the dietary benefit of food. Sustainable agriculture is an idea that alludes to agriculture's capacity to add to general government assistance by reliably giving adequate amounts of food and different administrations in socially accountable, profitable, and economic efficient ways, in addition to aiding in the improvement of environmental quality [1]. Besides crops, these are also used for the production of leaves, wood, fruits, oxygen, wood, and metabolites [2]. Most of these crop plant products must have medicinal values, which contribute to the prevention of medical anomalies [3]. As a result, they play a critical role in maintaining a healthy food chain [4]. Plants, unlike animals and microorganisms, do not have the ability to move. As a result, it is critical for them to obtain nutrients and growth regulators at the site of their growth. Crop plants' sedentary nature can have a variety of effects on their growth and multiplication. The availability of soil nutrients, as well as supporting physical factors such as pH of the soil, temperature, humidity, water level, salinity, and moisture, can all have an impact on growth, both positively and negatively [5-7].

Aside from these factors, abnormalities such as diseases, cattle overgrazing, forest fires, volcanoes, as well as insect pests can decrease the frequency of crop plants in a region. However, the main challenge is determining affordable, suitable, appropriate, and competitive technology. The problem of crop vegetation within the field may be successfully resolved with PTC.

Plant tissue culture is a critical innovation that can produce elite crop plants of superior quality and play an encouraging role in agricultural sustainability [8]. The application of new technologies in agriculture is critical because all these techniques have the capability to improve sustainable farming. Organic agriculture, biotechnology, and other technologies are also available that can be used to make farming profitable. PTC is no longer considered an emerging sector in India. So many agricultural crops are consistently cultivated using the tissue culture approach (anthuriums, bananas, strawberries, sugarcane, orchids, and so on) and have been traded both domestically and internationally for three decades. Plant biotechnology has recently made considerable promises, and it is now a critical tool in the development of agricultural sciences and technologically advanced farming.

2. Plant Biotechnology

Biotechnology is a technique that uses living organisms such as bacteria, yeast, fungi, viruses, plant cells, animal cells, and so on to create new products or modify existing ones, improve certain traits in animals and plants, or engineer microorganisms for particular purposes. Because the demand for food is increasing these days, we can turn to biotechnology to meet that demand. Plant biotechnology offers numerous opportunities for diversification, productivity enhancement, and development while also establishing a far more sustainable agriculture [9]. Plant tissue culture techniques, production of biopesticides, and the use of techniques of molecular biology for breeding, transformation of plants, disease diagnosis, and genomic analysis are all part of this technology [10]. Tissue culture was biotechnology's first conspicuous and widely adopted practical application. It also includes gene-transfer techniques, recombinant DNA technology, genome characterization, molecular genetics, growth of cells, tissues, and organs under in vitro conditions, and plant regeneration, all of which are regarded as plant biotechnologies [11-13]. Biotechnology can possibly play a significant role in the mass production of recently delivered superior harvest assortments (through tissue culture), alongside genetic improvement of different yields [14].

3. Techniques Used in the Sustainable Agricultural Crop Improvement

3.1. Micropropagation

Micropropagation, or the propagation of plant materials via tissue culture, has many benefits over traditional of propagation, such as large-scale multiplication of beneficial crop plants, and the production of virus-free plants. Micropropagation and preservation of top genotypes, which are chosen for their superior traits, require a high level of genetic consistency across regenerated plants [15,16].

Rapid propagation of improved cultivars with increased yield is required for commercial plant production. Herbaceous perennials are favoured over woody perennials for increased production, even if the rate of propagation varies depending on genetic composition and environmental conditions. Meanwhile, it's critical to get rid of plant propagative material if you want a decent harvest in the end. Thus, before culturing, preventive measures such as viral indexing can be undertaken on the explants. It renders the progeny virus-free, resulting in a higher yield [17].

Several fruits and crops have been propagated, resulting in exponential production rates. In terms of mass production and food security, main food crops like wheat, ragi and rice were given priority. Wheat crops were created by stimulating extra plant hormones in immature embryos and leaf segments. Various procedures for producing rice have been devised and refined, even to the point of being launched with greater market prices [18].

3.2. Callus/Suspension Culture

Secondary metabolites have been produced in large quantities using in vitro-regenerated plant cells and tissues. Regarding the goals, biotechnological approaches are used to better understand metabolic pathways and improve plant growth for the production of secondary metabolites [19]. Callus and suspension cultures can synthesise secondary metabolites and can be used to manipulate secondary metabolite biosynthesis pathways [20]. Plants account for nearly 30% of all drugs produced. Secondary metabolites are an abundant source for several drug companies and the manufacturing industry and have been widely produced using micropropagated plants. The use of transgenic plants is now among the most promising techniques for producing antibodies, proteins, and vaccines. Transgenic plants are a more cost-effective alternative to the production of systems based on fermentation. Plant-based antibodies (plantibodies) or vaccines stand out because plants do not cause human disease, which reduces the cost of testing for viruses and bacterial toxins [21].

3.3. Somatic Embryogenesis (SE)

SE is the formation of bipolar structures beginning to resemble zygotic embryos from non-zygotic cells and without any vascular connections to the tissue. Somatic embryogenesis refers to the process by which embryos develop from somatic cells without involvement of gametes [22]. For germplasm conservation through micro propagation and the production of transgenic plants, a biotechnological technique for hereditary improvement and advancement of recovery conventions is required [23,24].

SE is a valuable tool for the improvement of crop species. Somatic embryogenesis, then again, has other reasonable applications in improvement of crop (selection of cell, somatic hybrid, genetic transformation, and polyploidy plant production), virus elimination of virus, in vitro production of secondary metabolites, preservation of germplasm, and in vitro mycorhizal initiation. Embryo culture, which involves the development of immature embryos isolated on a nutrient medium, produces hybrids between species and between lines (rice, barley, maize, wheat, legumes, tomato, rye, cotton etc.) with the desired genes recombined to breed ears and resistant to bacteria, fungi, nematodes, pests and diseases of crops such as tomatoes, corn, rice, cabbage [25].

3.4. Production of Synthetic Seed

The technique of artificial seed production was first used in clonal propagation to cultivate somatic embryos in an artificial endosperm constrained by an artificial seed coat. Artificial seeds are now capsules with a gel envelope that contains stem and root segments as well as somatic embryos and apical buds [26]. Shoot tips, axillary buds, and somatic embryos are cryoprotected using materials such as hydrogel, ethylene glycol, alginate gel, and DMSO (dimethylsulfoxide). The goal is to develop a dependable, cost-effective SE system that can synchronise the production of large numbers of high-quality somatic embryos capable of surviving the stresses associated with encapsulation and sowing without encapsulation. The ability to enter a quiescent state upon desiccation and be stored in this dried state, as well as the ability to germinate in nonsterile conditions in the laboratory or greenhouse/field, would be advantageous [27].

3.5. Protoplast Culture and Somatic Cell Hybridization

Plant protoplasts are essential for plant cell culture, genetics, somatic cell fusion, and breeding [28]. Somatic hybridization is a useful technique for the transfer of genes for resistance to disease and in order to increase the yield and quality of many crop species [29]. For plant improvement, protoplast fusion is an alternative to the traditional method of cross-hybridization. This somatic hybridization method has yielded over 400 plant species from 146 genera and 50 crop plant families, including legumes, cereals, vegetables, fruits, medicinal plants, etc. [30]. Several crop plants, including *Oryza* sp., *Brassica* sp., *Lycopersicum* sp., *Nicotiana*, and others, have successfully transferred cytoplasmic male sterility. Crops with stable CMS lines could be created by introducing alien cytoplasm from relatives via intergeneric or interspecific hybridizations or by mediating mitochondrial rearrangement via somatic fusions [31].

3.6. Genetic Engineering

Genetically modified crops (GMCs) are plants whose DNA has been modified using techniques of genetic engineering (deletion, addition, or manipulation of nucleotides or genes) to achieve changes or desirable properties not found in the environment [32]. The development of a crops of genetically modified is divided into different phases [33]. The successful control of national and international regulatory, legislative, and socioeconomic landscapes is essential for the future of genome-edited crops. In addition to their advantages, genome-editing technologies can speed up the delivery of novel varieties to farmers and lower breeding costs. If the technologies are, however, poorly regulated, some or all of their advantages may be nullified [34]. There are many methods and protocols that are effective for creating genetically modified crops.

3.6.1. Transfer Mediated by *Agrobacterium tumefaciens*

The bacteria *Agrobacterium tumefaciens* is used in this method, which is well established. The tumor-inducing (Ti) plasmid is a genetic element found outside of these bacteria's chromosome. The biotechnologically interesting genes are inserted into the Ti plasmid so that they could be transferred to the plant by bacteria. The above system is capable of transporting large, intact sections of DNA while maintaining stable integration and low numbers of copy. Bt maize is a crop flower which expresses the Cry protein, which *Bacillus thuringiensis* naturally produces (Bt, an insecticide that has been used since 1938). Bt Toxic to beetle insects that die when they eat leaves and stems of corn [35]. Qaim [36] summarised study of the effects of Bt cotton (*Gossypium* spp.) (insect resistant) in three regions of Indian, and finding that improvements in this property will increase productivity by 37, 33 and 24%. This method has been successfully applied to many plants such as tomatoes, potatoes, and tobacco [32,33].

3.6.2. Particle/Gene Guns

It is a technique that uses microparticles of gold or tungsten coated with the desired DNA, which are then accelerated to the target tissues at high speeds. The DNA that was introduced could indeed enter the nucleus and insert itself stably. Inserting sequences into chloroplasts or mitochondria can also promote the expression of desired proteins within those organelles. This ability to transform organelles is remarkably essential in the production of organisms that express recombinant proteins or overproduce enzymes [37]. Two drawbacks are mentioned: silencing of transgenes as a result of multi-copy insertions and low transformation efficiency [32]. Using the particle gun transformation technique, important crops such as cereals (wheat, maize, rice, sorghum, oat, barley, and sugarcane), legumes (soybean, peanut, and common bean) have been genetically engineered.

3.6.3. CRISPR (Clustered Regulatory Interspaced Short Palindromic Repeats)-Cas9

This method makes use of brief, repetitive base sequences found in prokaryotic DNA segments, and after which a spacer DNA is exposed to a foreign DNA (plasmid or virus) [32].

An example is using CRISPRCas9 technology in potatoes and corn (*Zea mays* L.) to produce modified plants with a homogeneous starch composition instead of a mixture (amylose or amylopectin, not both). The key enzyme is required for amylose synthesis, granule-bound starch synthase I (GBSSI), protoplast transfection with preassembled Cas9/gRNA RNPs in tetraploid potato plants [37,38]. The development of pathogen-resistant crops is a critical goal in plant improvement. Plants of wheat (*Triticum* sp.) that are resistant to the fungus *Blumeria graminis* f. sp. *tritici* are one example, which causes powdery mildew disease [39].

3.7. Marker-assisted Selection

Jiang [40] divides genetic markers into two main categories: (1) classical markers, which include cytological markers, morphological markers, and biochemical markers; and (2) DNA/molecular markers, which include RFLP, RAPD, AFLP, SSRs, SNPs, and DArT (diversity array technology). The genetic diversity and fidelity of in vitro regenerated plants can be accessed utilizing DNA-based RAPD molecular markers [41,16]. Molecular markers are useful for studying genetic diversity in a variety of crops. Through marker-assisted selection, molecular markers provided an excellent opportunity to improve the efficiency and precision of crop improvement programmes. In order to evaluate genetic diversity, carry out assignment or parentage tests, and derive accurate demographic inferences, the new set of SSR and SNP markers proved to be perfectly adequate [42]. Gowda et al. [43] used AFLP markers to characterize genetic variation in the *Solanum nigrum* L. complex, and their studies classify taxonomically unknown substances and access the clustering of the studied accessions to their geographic origin.

3.8. Nanotechnology

For long-term agricultural development, nanotechnology can play a crucial role in enhancing productivity by managing nutrients, as well as checking water quality and pesticides [44-46]. Nanotechnology, which is now being used but will be part of the future of agricultural sustainability, assists with lessening pollution by applying synthetics for pest control and fertilizers at the nano level [47,48].

4. Plant Biotechnology Applications in Agriculture

4.1. Increased Crop Productivity

Plant biotechnology has the potential to increase the productivity of crop plants. Plant biotechnology traits and marker-assisted breeding are newer technologies that could be used to develop high-yielding cultivars. Certain technologies can be integrated into crop improvement programmes by breeders, allowing them to exceed previous rates of success in variety development.

4.2. Improved Nutritional Value

Modern agricultural biotechnology can contribute to developing the technology that can be used to correct deficiencies and improve nutritional quality of food crops.

4.3. Enhanced Crop Protection

Genetic engineering can also be used to create new varieties with advantageous traits of plants, such as increased resistance to plant pathogens [49]. Transgenic watermelons with higher resistance to biotic and abiotic stress were developed primarily via regeneration of adventitious shoots [50,51]. This method could also be used to create disease-resistant cultivars that are resistant to plant diseases, reducing crop losses and pesticides consumption.

4.4. Better Flavor

Plant biotechnology can help with the development of complicated flavors as fermentation items as well as single constituents. It can also be utilized to improve the flavour of food crops.

4.5. Food Processing Advancements

Biotechnology can be used to develop new processes and food products. Wheat (*Triticum aestivum*), maize (Zea mays), rice (*Oryza sativa*), oat (*Avena sativa*), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), millet (*Pennisetum* sp.) and rye (*Secale cereale*) have been incredibly significant for plant breeders for decades, because all these crops produce more than half the food eaten by humans. They are also used to make oil, animal feed, flour, starch, sugar, renewable energy, alcoholic beverages, and other products [52]. It can also be utilized to improve existing processes like fermentation and the production of immobilized biocatalysts, as well as offer up new possibilities in food biotechnology [53]. Biotechnology has the potential to produce high-quality foods with fewer substances, for example, flavorings, while also reducing food processing's environmental impact.

4.6. Fresher Fruits and Vegetables

Fresh vegetables and fruits are recommended as part of a balanced diet. Second-era biotech food sources mean saving customers' food fresher for longer timeframes. Researchers have been working away at ways of delaying the ripening of natural products. Assuming natural product maturing is delayed, farmers will benefit by having greater adaptability in showcasing their homestead produce, guaranteeing purchasers that it is "fresh from the garden".

4.7. Environmental Benefits

The following are the environmental advantages of agricultural biotechnology:

i. Biotechnology aids in increasing crop yields of established crops, eliminating the need to force more land into production. There is no need to cultivate marginal or highly erodible land.
ii. Biotechnology has the potential to be used to produce disease and pest-resistant varieties that require fewer pesticide applications. This will aid in the preservation of our environment from pollution.
iii. We are able to create herbicide-tolerant genetically modified crops. If these crop plants are grown, no-till farming practices could be used, resulting in lower production costs. It also aids in reducing erosion, increasing soil moisture content, and limiting emissions of carbon dioxide.
iv. The much more major benefit from using genetically modified crops is reduced in on-farm energy use, which leads to a reduction in carbon emissions from the no farming practices.
v. Biotechnology has the potential to aid in the reduction of waste generated by livestock feedlots and concentrated animal agriculture operations.

5. Support from the Government for the Tissue Culture Industry

To improve plant tissue culture output of various crops, the government of India has encouraged businesses to set up tissue culture facilities in the country. Several state and central government departments in India have launched programmes and declared initiatives to encourage the tissue culture industry [54]. The following schemes and incentives are available:

5.1. National Horticulture Board (NHB)

The NHB provides assistance in establishing a laboratory for tissue culture. There is a capital subsidy provision (not more than 20% of the total project cost, with a maximum of Rs. 25 lakhs per proposal). Subsidies of this type are provided for the construction of greenhouses for the hardening of tissue cultured plantlets, as well as polyhouses and shade houses.

5.2. Department of Biotechnology (DBT)

The DBT funds research and development projects are submitted by universities and research institutions. This project must aim to create and standardize tissue culture protocols for any crop. Another government programme known as the Small Business Innovation Research Initiative (SBIRI) allows private tissue culture laboratories to expand their existing production units as a Phase II activity. To encourage industry and end-user adoption of vitro propagation, the DBT has also established two micropropagation technology parks (MTPs).

The parks are currently located at the Tata Energy Research Institute in New Delhi and the National Chemical Laboratory in Pune, Maharashtra. These parks were created to provide a solid foundation for the transmission of breakthrough research approaches to needy entrepreneurs who work using large-scale or commercial PTC.

5.3. Ministry of Agriculture

The Department of Agriculture and Cooperation, under the Ministry of Agriculture, Government of India, provides financial support for the establishment of tissue culture units up to Rs. 21 lakhs in the public sector and Rs. 10 lakhs in the private sector, subject to a maximum of 20% of the project cost. Under the integrated programmes for the development of fruits, many state governments grant financial assistance up to 50 percent for the procurement of banana tissue culture.

5.4. Agriculture and Processed Food Products Export Development Authority (APEDA)

Under the Ministry of Commerce and Industry, APEDA has established a state-of-the-art airfreight transshipment centre for tissue culture plants at New Delhi, Bombay, and Bangalore airports. Airfreight subsidies of up to 25% of freight costs are provided for tissue culture plants. A 50% subsidy is provided for infrastructure development. Consultancy services, packing, feasibility studies, export promotion, market development, refrigerated vans, development of human resources, and organization buildings are examples of infrastructure. Financial assistance is also provided for ISO 9000 implementation and the strengthening of quality control facilities [55].

5.5. Small Farmers Agri-business Consortium (SFAC)

Tissue culture laboratories can be established by co-operative societies formed by small-scale farmers. SFAC, which is part of the Ministry of Agriculture, provides loan facilities of approximately rupees 50 lakhs for the establishment of small labs for tissue culture.

5.6. State Level Initiative

Karnataka, Andhra Pradesh, Gujarat, and Maharashtra, have created new agro-industrial policies. Under this new policy, they are providing financial support for the establishment of tissue culture units. Karnataka provides financial assistance of 20% on investment opportunities.

The Indian government has established a national facility in New Delhi for virus diagnosis and tissue culture plant quality control. The government also established five satellite centres to assist tissue culture industries throughout the country.

All of the above-mentioned schemes have aided in the development of a tissue culture industry, which has greatly increased demand for tissue culture and resulted in high-quality planting material.

6. Conclusions

Plant biotechnology will facilitate increased production of crop rates and, in addition, improve crop varieties by providing all necessary equipment, treatments, and personnel. Plant tissue culture and genetic engineering is a potent technology with a promising role in agricultural sustainability and the capacity to produce elite plants of superior quality while using few chemicals. PTC has become an important mechanism in the nursery and farming industries since it is a potent technology for mass production of various vegetables, crops, and fruits, and it provides an alternative method to traditional vegetative propagation. Improving and investing in plant biotechnology will most probably have a huge impact on agricultural sustainability as well as the emergence of numerous job opportunities in the agriculture industry.

REFERENCES

[1] Siebrecht N, "Sustainable Agriculture and Its Implementation Gap-Overcoming Obstacles to Implementation," Sustainability, 29, 2020, pp. 3853. DOI: 10.3390/su12093853.

[2] Sen T, S.K. Samanta, "Medicinal plants, human health and biodiversity: A broad review," in Biotechnological Applications of Biodiversity. Berlin, Heidelberg: Springer, 2014, pp. 59-110.

[3] Petrovska B B, "Historical review of medicinal plants usage," Pharmacogn Rev, vol. 6, no. 11, pp. 1-5, 2012. DOI: 10.4103/0973-7847.95849.

[4] Sofowora A., Ogunbodede E., and A. Onayade, "The role and place of medicinal plants in the strategies for disease prevention," Afr J Tradit Complement Altern Med, vol. 5, pp. 210-29, 2013. DOI: 10.4314/ajtcam.v10i5.2

[5] Patil S M., Kumari V B., Sujay S., Tejaswini M., Shirahatti P S., R. Ramu, "Sustainable development of plant tissue culture industry: The Indian scenario," J App Biol Biotech, vol. 9, no. 2, pp. 18-27, 2021. DOI: 10.7324/JABB.2021.9202

[6] Szabados L, Kovacs H, Zilberstein A, A. Bouchereau, "Plants in extreme environments: Importance of protective compounds in stress tolerance," in Advances in Botanical Research. London, UK, Academic Press, pp. 105-50, 2011.

[7] Tardieu F, "Plant response to environmental conditions: Assessing potential production, water demand, and negative effects of water deficit," Front Physiol, vol. 18, no. 4, pp. 17, 2013. DOI: 10.3389/fphys.2013.00017

[8] El-Sherif N A, "Impact of Plant Tissue Culture on Agricultural Sustainability," in Sustainability of Agricultural Environment in Egypt: Part II – Soil-Water-Plant Nexus, HdbEnvChem, Springer International Publishing, 2018.

[9] Garg M., Sharma N., Sharma S., Kapoor P., Kumar A., Chunduri V., P. Arora, "Biofortified crops generated by breeding, aagronomy, and transgenic approaches are improving lives of millions of people around the world," Front Nutr., vol. 5, p. 12, 2018. DOI: 10.3389/fnut.2018.0001

[10] Altpeter F., Springer N.M., Bartley L.E., Blechl A.E., Brutnell T.P., Citovsky V., Conrad L., Gelvin S.B., Jackson D., Kausch A.P., Lemaux P.G., Medford J.I., Orozco-Cardenas M., Tricoli D., Van Eck J., Voytas D.F., Walbot V., Wang K., Zhang Z.J., C.N. Stewart, "Advancing crop transformation in the era of genome editing," Plant Cell, vol. 28, pp. 1510–1520, 2016. DOI: 10.1105/tpc.16.00196

[11] Van Montagu M, "It is a long way to GM agriculture," Annu Rev Plant Biol., vol. 62, pp. 1–23, 2011. DOI: 10.1146/annurev-arplant-042110-103906

[12] Heimann JM, "Using nature's shuttle: The making of the first genetically modified plants and the people who did it," Wageningen Academic Publishers, Wageningen, 2018.

[13] Chilton M.D, "My secret life," Annu Rev Plant Biol., vol. 69, pp. 1–20, 2018. DOI: 10.1146/annurev-arplant-032717-090606

[14] Aamir A., Shagufta N., Fayya A.S.,I. Javed, "An efficient protocol for large scale production of sugarcane through micropropagation," Pak. J. Bot., vol. 40, no. 1, pp.139-149, 2008.

[15] Khatik N.,R. Joshi, "*In vitro* propagation of *Murraya koenigii* by axillary bud proliferation using mature explants," Indian Journal of Biotechnology, vol. 17, no. 2, pp. 379-382, 2018.

[16] Khatik N., R. Joshi, "Assessment of genetic fidelity in microclones of curry leaf plants [*Murraya koenigii* (L.) Spreng.] using ISSR markers," Indian Journal of Experimental Biology, vol. 58, no. 4, pp. 286-291, 2020.

[17] Reinert J,Y. S. Bajaj, "Applied and Fundamental Aspects of Plant Cell, Tissue, and Organ Culture," Berlin, Germany: Springer Science and Business Media, 2013.

[18] Sidhu Y, "In vitro micropropagation of medicinal plants by tissue culture," Plymouth Stud Sci, vol. 4, pp. 432-49, 2011.

[19] Gonçalves S.,A. Romano, "Production of plant secondary metabolites by using biotechnological tools. Secondary metabolites, sources and applications," IntechOpen, vol. 1, pp. 81-99, 2018. DOI: 10.5772/intechopen.76414

[20] Efferth T, "Biotechnology applications of plant callus cultures," Engineering, vol. 5, no.1, pp. 50–59, 2019. DOI: 10.1016/j.eng.2018.11.006.

[21] James C, "Global status of commercialized biotech/GM crops," ISAAA Brief, No. 39. Ithaca, pp. 243, 2008.

[22] Rose R. J., Y. Song, "Somatic Embryogenesis," Encyclopedia of Applied Plant Sciences, pp. 474–479, 2017.

[23] Khatik N., R. Joshi, "Protocol for regeneration of plantlets through somatic embryogenesis from hypocotyl of curry leaf plant (*Murraya koenigii* L. Spreng)," J. Phytol. Res., vol. 28, no. (1 & 2), pp. 25-32, 2015a.

[24] Khatik N., R. Joshi, "Regeneration of plantlets via direct somatic embryogenesis from different explants of *Murraya koenigii*. (L.) Spreng," International Journal of Science & Research, vol. 4, no. 11, pp. 2404-2408, 2015b.

[25] Chawla H S, "Introduction to plant biotechnology," Oxford and IBH Publishing Company Pvt, New Delhi, 2009.

[26] Vdovitchenko Y.M., I.N. Kuzovkina, "Artificial Seeds as a Way to Produce Ecologically Clean Herbal Remedies and to Preserve Endangered Plant Species," Moscow Univ. Biolog. Sci. Bullet., vol. 66, no. 2, pp. 48–50, 2011.

[27] Pond S., S. Cameron, "Artificial Seeds. Encyclopedia of Applied Plant Sciences," pp. 419–427, 2017. DOI: 10.1016/b978-0-12-394807-6.00227-6

[28] Ahmed M.A.A., Miao M., Pratsinakis E.D., Zhang H., Wang W., Yuan Y., Lyu M., Iftikhar J., Yousef A.F., Madesis P., Wu. Binghua, "Protoplast Isolation, Fusion, Culture and Transformation in the Woody Plant *Jasminum* spp.," Agriculture, vol. 11, p.699, 2021. DOI: 10.3390/agriculture11080699

[29] Singh A.K., Mishra N.K., Kumar S., S. Pandey, "Applications of somatic hybridization for the improvement of horticultural crops," Hortic Biotechnol Res, vol. 1, pp. 39-45, 2015. DOI: 10.19071/jhcbt.2015.v1.2897

[30] Basavaraju R, "Plant tissue culture-agriculture and health of man," Ind J Sci Technol, vol. 4, pp. 333–335, 2011.

[31] Prakash S., Bhat S.R., Quiros C.F., Kirti P.B., V. L. Chopra, "Brassica and its close allies: cytogenetics and evolution," Plant Breed. Rev., vol. 31, pp. 21–187, 2009.

[32] Shetty M.J., Chandan K., Krishna H.C., G.S. Aparna, "Genetically modified crops: an overview," J Pharmacognosy Phytochemistry, vol. 7, no.1, pp. 2405–2410, 2018.

[33] Gutierrez D.F., Ruiz R.M. B.C. Xoconostle, "Estado actual de loscultivosgenéticamentemodificadosen México y sucontextointernacional. Centro de Investigación y de EstudiosAvanzadosdelInstitutoPolitécnico Nacional," México, pp. 194, 2015.

[34] Pixley K.V., Falck-Zepeda J.B., Paarlberg R.L. Phillips P.W.B., Slamet-Loedin I.H., Dhugga K.S., H. Campos, "Genome-edited crops for improved food security of smallholder farmers," Nat Genet, vol. 54, pp. 364–367, 2022. DOI: 10.1038/s41588-022-01046-7.

[35] Kumar S., KakraliyaS. K., Lakhran H., Sheoran S., Ram M., R.S. Meena, "Use of *Bacillus thuringiensis* (Bt) Gene: a biotechnological tool for crop improvement," Prog Res, vol. 11, pp. 6247–6251, 2016a.

[36] Qaim M, "The economics of genetically modified crops," Ann Rev Resour Econ, vol. 1, pp. 665–694, 2009. DOI: 10.1146/annurev.resource.050708.144203

[37] Alvarez S.P., Ardisana E.F.H., R.P. Leal, "Plant Biotechnology for Agricultural Sustainability," in Resources Use Efficiency in Agriculture. Springer, Singapore, 2020. DOI: 10.1007/978-981-15-6953-1_12

[38] Andersson M., Turesson H., Olsson N., Fält A.S., Ohlsson P., Gonzalez-Matías N., Samuelsson M.,P. Hofvander, "Genome editing in potato via CRISPR-Cas9 ribonucleoprotein delivery," Physiol Plant, vol. 164, pp. 378–384, 2018. DOI: 10.1111/ppl.12731

[39] Wang Y., Cheng X., Shan Q., Zhang Y., Liu J., Gao C., J.L. Qiu, "Simultaneous editing of three homoeoalleles in hexaploid bread wheat confers heritable resistance to powdery mildew," Nat Biotechnol, vol. 32, pp. 947–951, 2014. DOI: 10.1038/nbt.2969

[40] Jiang G.L., "Molecular markers and marker-assisted breeding in plants," in Plant breeding from laboratories to fields, InTech, Rijeka, pp. 45–83, 2013. DOI: 10.5772/52583

[41] Khatik N., Joshi R., D. Sharma, "Evaluation of Genetic Stability of Micropropagated Plants of *Murraya koenigii* (L.) Spreng Using RAPD Markers," Asian Journal of Microbiology, Biotechnology and Environmental Science, vol. 21, no. 1, pp. 146-151, 2019.

[42] Garcia C., Guichoux E., A. Hampe, "A comparative analysis between SNPs and SSRs to investigate genetic variation in a juniper species (*Juniperus phoenicea* ssp. turbinata)," Tree Genetics & Genomes vol.14, pp. 87, 2018. DOI: 10.1007/s11295-018-1301-x

[43] Gowda B., Chandrika K., Udayakumar H., Sringeswara A.N., Haleshi Teixeira da., Silva J.,A. Shankar, "Analysis of Genetic Variation in the Genus Solanum Using AFLP (Amplified Fragment Length Polymorphism) Markers," Medicinal and Aromatic Plant Science and Biotechnology, vol. 5, no.1, pp. 77-80, 2011.

[44] Gruere GP, "Implications of nanotechnology growth in food and agriculture in OECD countries," Food Policy, vol. 37, pp. 191–198, 2012. DOI:10.1016/j.foodpol.2012.01.001

[45] Mukhopadhyay S.S, "Nanotechnology in agriculture: prospects and constraints," Nanotechnol. Sci., vol. 7, pp.

63–71, 2014. DOI: 10.2147/NSA.S39409

[46] Reddy SS., Chhabra, V., “Nanotechnology: its scope in agriculture,” J. Phys.: Conf. Ser. 2267 012112, 2022. DOI: 10.1088/1742-6596/2267/1/012112

[47] Prasad R., Bhattacharyya A., Q.D. Nguyen, “Nanotechnology in Sustainable Agriculture: Recent Developments, Challenges, and Perspectives,” Frontiers in microbiology, vol. 8, p. 1014, 2017. DOI: 10.3389/fmicb.2017.01014

[48] Khatik N, “Green Synthesis of Nanomaterials and Their Utilization as Potential Vehicles for Targeted Cancer Drug Delivery,” Advances in Pharmacology and Pharmacy, vol. 10, no. 2, pp. 114–121, 2022. DOI: 10.13189/app.2022.100205.

[49] Fermin-Munoz G.A., Meng B., KO K., Mazumdar-Leighton S., Guba A., J.E. Carroll, “Biotechnology: A new era for plant pathology and plant protection,” APS*net* Feature, 2000. DOI: 10.1094/APSnetFeature-2000-0500

[50] Huang Y.C., Chiang C.H., Li C.M., Y. TA, “Transgenic watermelon lines expressing the nucleocapsid gene of Watermelon silver mottle virus and the role of thiamine in reducing hyperhydricity in regenerated shoots,” Plant Cell Tissue Organ Cult, vol. 106, pp. 21–29, 2011. DOI: 10.1007/s11240-010-9889-z

[51] Lin CY, Ku HM, Chiang YH, Ho HY, Yu TA, Jan FJ. “Development of transgenic watermelon resistant to cucumber mosaic virus and watermelon mosaic virus by using a single chimeric transgene construct,” Transgenic Res, vol. 21, pp. 983–993, 2012. DOI: 10.1007/s11248-011-9585-8

[52] Tacer-Caba Z., Nilufer-Erdil D., Y. Ai, “Chemical Composition of Cereals and Their Products,” in Handbook of Food Chemistry. Springer, Berlin, Heidelberg, 2015. DOI: 10.1007/978-3-642-36605-5_33

[53] Samuel S.M, “Application of agricultural biotechnology to improve food nutrition and healthcare products,” Asia Pac. J. Clin. Nutr., vol. 17, no. S1, pp. 87-90, 2008.

[54] Geeta S., S. Sudheer, “Impact of tissue culture on agriculture in India,” Invited Review, Biotechnol. Bioinf. Bioeng, vol. 1, no. 3, pp. 279-288, 2011.

[55] Singh G., S. Shetty, “Impact of tissue culture on agriculture in India,” Biotechnol Bioinforma Bioeng, vol. 1, pp. 147-58, 2011.