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Asian Biotechnology and Development Review
Vol. 24, No. 2, pp 1-3

Editorial Introduction

Krishna Ravi Srinivas*

Welcome to Asian Biotechnology & Development Review, issue of Vol. 24 No 2. This issue has three articles and a book review.

Bi-lateral and international co-operation among countries in biotechnology is common, so are the collaboration of research institutes and firms across countries. There are distinct advantages in such collaboration. On the other hand there are contextual related issues, risks and opportunities as well as challenges in maintaining long-term collaboration. Hence we need case studies and detailed analyses that deepen our understanding. In 'Advancing Indo-Australia Agricultural Biotechnology Cooperation', Manasi Mishra gives an extensive analysis of emerging issues in India-Australia co-operation in agricultural biotechnology with examples of success stories. She also brings in the Quad dimension and suggests a way forward for better co-operation in future. Given the increasing co-operation between India and Australia, this article makes good sense. As both countries are to sign a Free Trade Agreement soon, greater co-operation in agricultural biotechnology can be expected.

Plant Tissue Culture (PTC) is a technology that has been successfully adopted in developing countrie\, particularly in horticulture. It is an employment generator, particularly for women. A great advantage with PTC is that is suitable when land is not available or soil quality is poor. Another advantage is PTC is well suited for pathogen-free plants. In 'Commercialisation of Plant Tissue Culture in India'

Pracheta Salunkhe, Moksh Mahajan, Pradeep Vinod Sharma and Darshini Trivedi describe the technology, its adoption in India and how it has grown significantly over the years. They describe the challenges and emerging opportunities in PTC in India.

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ABDR has published many articles on synthetic biology, and a Special Issue as well. In this issue we carry an interesting and controversial theme , De-extinction and Synthetic Biology. While this as of now is in the realm of speculation and discussion with no approved project..In their article Shyama Kuriakose and Sachin Sathyarajan discuss the issue in detail and examine it in the context of environmental law and policy in India. Such a contextualized article adds substance to the debates and alerts us to the ground reality. While de-extinction through technology is a fascinating idea, use of synthetic biology for that makes it all the more alluring as well as scary to many . The article gives a pragmatic perspective in this debate.

The book review by Amit Kumar adds value to the issue. Your comments and suggestion on this issue as well for enhancing quality and relevance of ABDR are welcomed.

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Asian Biotechnology and Development Review
Vol. 24, No. 2, pp 3-26

Advancing Indo-Australia Agricultural Biotechnology Cooperation

Manasi Mishra*

Abstract: Cooperation in areas of science & technology is a crucial element in the India-Australia strategic partnership. Both countries have promoted research & innovation in the areas of biotechnology through research grants, exchange of scholars, visits of Indian scholars to Australian institutions, etc. Indo-Australian Biotechnology Fund for Collaborative Research Projects was established under the Indo-Australia innovations partnership. Research relating to Biotechnology in the fields of agriculture, food security, biomedical devices and implants, and marine sciences has been of prime focus in the Australia-India Strategic Research Fund (AISRF). Research promotion in biological systems is one of the crucial areas in recent initiatives taken by both countries in advancing critical and emerging technologies. Today Indian agriculture & allied sectors face numerous challenges from climate change, drought, declining water levels, and substantial losses to crop pests, including insects, rodents, nematodes, fungal pathogens, bacteria, viruses, etc. Abiotic stresses like drought, extreme temperatures, salinity, and mineral toxicity negatively impact the growth of crops. New challenges, therefore, require energizing science diplomacy for greater collaboration with nations, which have developed scientific cultures and advanced systems of facilitating and nurturing innovations in the field of biotechnology and agriculture sciences. In the broader policy framework of science diplomacy, science & technology cooperation, including new technology for the agriculture sector, has been a crucial element of Prime Minister Modi's foreign policy. In addition to bilateral initiatives, the scope for India-Australia science & technology cooperation through multilateral formats such as G20 and Quad should be explored. In this context, the article analyses the India-Australia cooperation in biotechnology and how it can be further expanded in addressing new areas. The paper also analyses India-Australia cooperation and offers an overview of Indo-Australian Career Boosting Gold Fellowships from the Department of Biotechnology and first-hand research experience of La Trobe University, Melbourne, under the programme. IACBGF has been instrumental in widening the exposure and capacity building of independent young researchers working in the domain of biotechnology in Indian academic institutions.

Keywords: Biotech innovations, Agriculture growth, Agri-biotech Challenges, Crop losses, Food security, Indo-Australia biotechnology cooperation

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Introduction

The agricultural sector continues to play a pivotal role in the Indian economy as it engages around 50 per cent of the total workforce in India. The majority of the population still relies on agriculture and allied sectors for their food, livelihoods, and income. These sectors are central to not only food and nutritional security but also to inclusive development. To substantiate, it is the primary source of livelihood for about 58 per cent of the population. Gross Value Added (GVA) by agriculture, forestry, and fishing was estimated at US$ 276.37 billion in 2020[1]. The share of agriculture and allied sectors in GVA of India at current prices stood at 17.8 per cent in 2020. The importance of the Indian food industry and food processing industry has gradually been increasing.

The Indian agriculture sector has improved in several aspects like reforms, investment and technology, leading to substantial development over the period. However, the country still faces multiple challenges which have originated post-Green Revolution. Various challenges such as climate change, depleting water resources, and crop losses due to pests have the potential to undermine food production, agriculture growth, and the welfare of farmers. A viable and profitable farm sector is inevitable for alleviating poverty in India and ensuring nutritional security. Low input and high output are akin to achieving the national goal of sustainable agriculture and growth in India. There needs to be greater research and science and technology collaboration with scientifically advanced countries to bring in the latest technologies and innovations. India's science diplomacy initiatives with developing countries have aspired to undertake collaborative projects of mutual interest, focus on innovation, and achieve self-sustenance in technology (Goel 2021). The paper attempts to explain some of the problems faced by Indian agriculture and how new biotechnological innovations could be useful in solving them. In the framework of India's science diplomacy, which stresses 'integration of science and technology into the diplomatic and foreign policy framework' (Balakrishnan 2019), it further contends how scientific cooperation with advanced nations could support growth in agriculture and allied sector. Finally, the paper focuses on the prospects for Indo-Australia cooperation in the biotechnology sector in a broader framework of their technological cooperation and strategic partnership.

Contemporary Agri-biotech Challenges in India

In the past three decades, India has increased its food production three-fold, mainly by application of genetics in improving crop varieties and better management practices. The use of synthetic fertilizers, agrochemicals, and improved hybrid varieties of cereal crops like maize (corn), wheat, and rice had helped India further enhance food security as well as nutritional security (Pental 2021). The global area under cereal crops increased by 12 per cent, yields per hectare by 201 per cent, and an increase in total production by 238 per cent was observed between 1961 and 2018 during the green revolution era (Kingsbury *et al* 2014; Rangasamy *et al* 2009).

Though the green revolution and other measures have helped India to achieve self-sufficiency in food grains yet, India's productivity has not observed a comparable growth rate as compared to the United States, Brazil, and China. For instance, while Brazil's and China's yields for rice increased 3-4 times (tonnes/ha) between 1981 to 2011, India registered less than 2 times growth for rice during the same time (Prabhu 2019)[2]. Although in 2013, India reported a contribution of 25 per cent to the world's pulse production, 22 per cent to rice production, and 13 per cent to wheat production, its agro yield (quantity of a crop produced per unit of land) is lower in the case of most crops as compared to China, Brazil and the US (Deshpande 2017 PRS). However, several factors contribute in increasing crop productivity. Low crop yield is also attributed to the short growing seasons, varied agro-climatic conditions, and weather extremities. Indian farmers also grow more than one crop therefore, overall crop yield could be considered comparable to advanced countries.

Biotic Stresses

India faces massive losses to crop pests, including insects, rodents, nematodes, fungal pathogens, bacteria, and viruses. Despite an extensive increase in pesticide consumption, there have been massive losses in major crops like wheat (10.1-28.1 per cent), rice (24.6-40.4 per cent), maize (19.5-41.1 per cent), potato (8.1-21 per cent), and soybean (11-32.4 per cent) worldwide (Savary et al 2019). Under the global climate change conditions, these losses are expected to increase (Deutsch *et al* 2018; Velasquez et al 2018). As noted by P.K. Chakrabarty, "*Nematodes, consisting* *of roundworms, threadworms, and eelworms, are causing loss of crops to the tune of almost 60 million tonnes or 10-12 per cent of crop production every year*" The Hindu 2017)[3]. According to estimates, about 30-35 per cent of the annual crop yield in India gets wasted because of pests. At a global level, India has the lowest yields of prominent oilseed crops- groundnut, soybean, and mustard leading to a huge edible oil deficit in India. Pests and pathogens are considered major constraints to the yield of prominent crops. Better control of pests and pathogens is required to sustain the crop yield requirements with the growing population. Crop protection and improved yields of crops like soybean and chickpea can also help meet the protein requirements of a malnourished population. Hence, these major thrust areas seek active biotechnological intervention (Rajendran 2016).

Abiotic Stresses

Abiotic stresses like drought, water logging, extreme temperatures, salinity, and mineral toxicity negatively impact the growth, quality, and yields of crops in a substantial manner (Gull et al 2018). Some of these challenges are going to escalate with the second-generation problems of the Green Revolution and now serious risks posed by climate change. These are decreased availability of arable land and fast depleting natural resources like water, poor soil health, loss of soil organic carbon, ground and surface water pollution, use of chemical fertilizers and pesticides, water-related stress, increased incidence of pests and diseases, the adverse impact of climate change, etc. India needs R&D-based solutions for these challenges as well to create drought resistance, terminal heat tolerance, and adaptation to water-logging in crop plants (Martignago *et al* 2020).

With the increasing population estimated to touch 1.66 billion by 2050, India would need to produce 70 per cent more food grains than what it is producing today, that too from declining natural resources. To meet the growing demand for food, feed, and fodder agricultural sector will have to meet a growth rate of at least 4 per cent per annum. A strong and effective agricultural system is pivotal to the overall economic growth of the country and achieving the vision of sustainable development and '*Atmanirbhar Bharat*'. Arguably, increasing productivity and farmers' income are two big challenges as the size of the land holdings decreases. Access to scientific knowledge & innovations, limited or, to some extent, lack of advanced infrastructure in rural areas, and mismanagement of grains post-harvesting are major setbacks to the profitability of this sector. Problems related to infrastructure for irrigation, power, markets, and roads adversely affect farm operations and, thus, the profitability.

Translational R&D Approaches for Agriculture Growth

Genetic enhancement of crops through plant breeding and biotechnological approaches and optimal use of advanced agrochemicals have augmented the output in the agriculture sector over the past three decades (Moose et al 2008) such as the development and release of India's Pusa Basmati rice in 2003 jointly by ICAR and Indian Agricultural Research Institute (AARI), doubled the yield of basmati cultivation from 2.5 tonnes/ha to 5 tonnes. It earned the country Rs 25,000 crore/annum by way of exports, which has also increased the income of Basmati farmers. Another example is the Samba Mahsuri variety, developed through marker- assisted selection (MAS) and cultivated over 130,000 ha during the five years from 2011-2016, giving an economic return of Rs 1,250 crore.

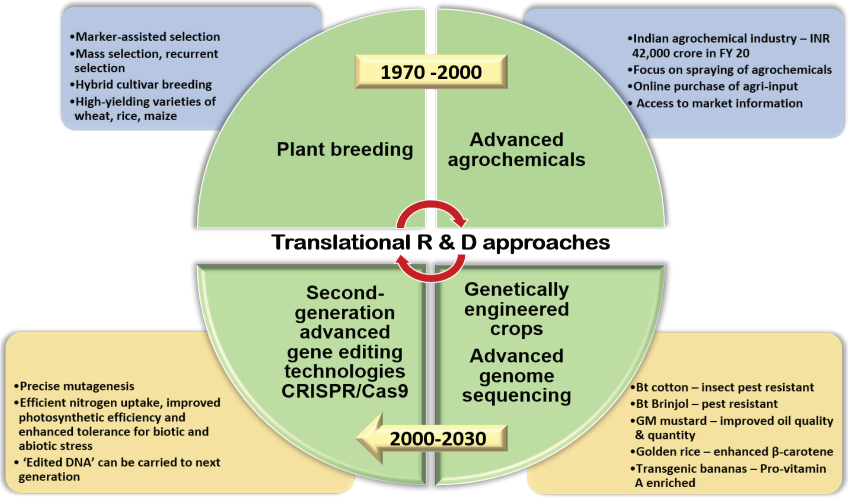
The advancement of genome sequencing technologies (short-read next-generation sequencing (NGS) has improved the production of highly contiguous genome assemblies and now the challenge is to make effective utilization of this enormous sequence data (Giani *et al* 2020). Genetic engineering and gene editing are the two most important technologies to be focused on to bring new avenues for the genetic improvement of crops (Prakash 2000; Sussex 2008; Bailey-Serres *et al* 2019). For example, the cultivation of pest-resistant transgenic Bt cotton resulted in an increase in production by 9.25 per cent and a reduction in the use of pesticides by 82 per cent. Here an insecticidal bacterial gene was introduced into the cotton plant to confer resistance to lepidopteran pests of the crop. Despite the boost from Bt cotton since 2003, India's cotton yields are much lower as compared to other countries at a global level. However, pest-resistant Bt-Brinjol and transgenic brassica (GM mustard) with improved oil quality and quantity are yet to receive approval for commercial release and use in India (Dang *et al* 2015).

Golden rice harbors genes from different species for enhanced β-carotene content, a precursor of Vitamin A (Paine *et al* 2005; Swamy *et al* 2019). Golden rice has played important role in combating prevalent vitamin A deficiency in children from sub-Saharan Africa and South Asian countries (UNICEF, 2021)[4]. Pro-Vitamin A- enriched transgenic bananas have been developed through gene editing technology acquired from Australia and are currently undergoing laboratory trials (Paul *et al* 2017). Despite bringing significant quality enhancements in crop products and enhancing the sustainability of small landholders, genetically engineered agricultural products face substantial opposition from environmental and anti-globalization activists. Thus, India significantly lags behind the world in the use of genetic engineering and gene editing technologies.

Second-generation advanced gene editing technologies like CRISPR/Cas9, which allow precise mutagenesis hold immense potential for crop improvement and are required for meeting the needs of the agricultural sector (Jaganathan *et al* 2018). Untapped possibilities for efficient nitrogen uptake improved photosynthetic efficiency, and enhanced tolerance for biotic and abiotic stress can be achieved using these technologies. Unlike the transgenic approach, this tool produces a defined mutant and has an added advantage that 'edited DNA' for the desired trait is carried to the next generation (Malzahn *et al* 2017). Such genome- edited varieties can be further used in breeding programmes and may face relatively lesser regulatory and acceptability issues as compared to conventional GM crops (Waltz 2018).

CRISPR/Cas9 technique is being used most extensively to edit model plant genomes (*Arabidopsis*, Rice, Tobacco). It has been adopted in several crop species as well for yield improvement, biotic and abiotic stress management (Ricroch *et al* 2017). Biotic stress on crops by pathogenic microorganisms accounts for more than 42 per cent yield loss and around 15 per cent global decline in food production (Oerke 2005). CRISPR/Cas9-based knocking out of specific genes has been utilized to increase crop disease resistance in rice, wheat, maize, tomato, soybean, citrus, cotton, potato, grapes, alfalfa, and legumes as reported in published scientific articles as 'proof-of concept' studies (Liu *et al* 2012; Shan *et al* 2013; Shan *et al* 2014; Endo *et al* 2016; Liu *et al* 2017). Now, matching policy support and regulatory framework is required to render the path of modern agricultural innovations and sustainable growth.

Figure 1: Translational R&D approaches for crop improvement and their changing facets across past decades.



Source: Author's research

Need for Promoting Research and Innovations in Biotechnology

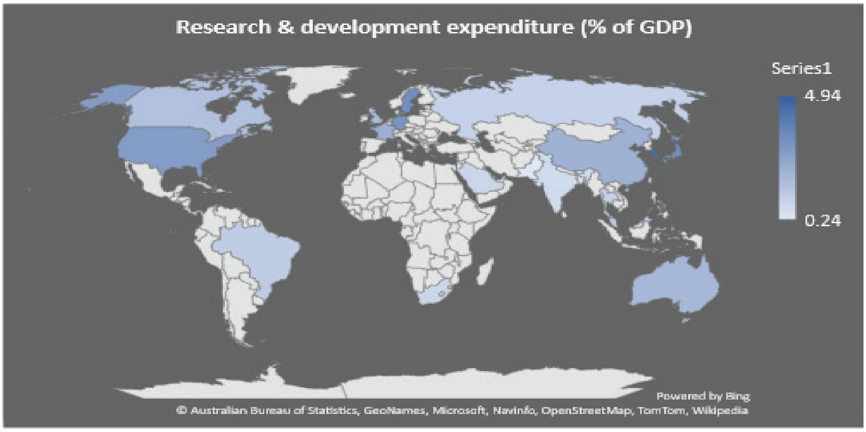
The current scenario demands robust government support to encourage modern biotechnological interventions in agriculture to improve the quality, productivity, and income of the farming systems safely and sustainably. The implementation of the biotechnological innovations in the farming systems also needs to be better attenuated to the perspectives and needs of the key stakeholders, i.e. farmers. A synergy between the scientific fraternity, investment partners, government, and farmers is required to implement new technologies for achieving sustainable development goals (ICTSD Technical Note 2008)[5]. Research efforts and investments in biotechnological interventions can enhance crop productivity, increase yields and ultimately ensure food security. Technology, like agri-biotechnology, if used diligently, can play an important role in improving our agricultural output, especially in the light of our limited land and water resources, which have become a serious challenge.

India is on its national mission of doubling farmers' income. Agriculture biotechnology is emerging as a great enabler of these transformations, such as the quality of the agriculture produce and reducing some of the challenges of the farmers. The 2019 strategy document of the Department of Biotechnology- "*Agriculture Biotechnology for Human Welfare*" seeks a robust, time-bound, flexible and transparent regulatory system for harnessing agri-biotechnology for injecting new life into India's farmlands (Uma Keni Prabhu 2019/Sunday Gauardian)[6]. Agriculture, medicinal and aromatic plants, bioprospecting food fortification, and biofortification are some of the sectorial priority areas identified to accelerate the pace of the growth of biotechnology at par with the global level (strategy/dbtindia.gov.in)[7]. There is a pressing need for a strong policy framework for the development and commercial release of agri-biotech products and the release of the long-pending Biotechnology Regulatory Authority of India (BRAI) Bill. The availability of whole genome sequences of crop plants, high throughput genomics and functional data, and the emergence of advanced technologies of gene editing have immense capacity to address the various challenges in agriculture and allied sectors. A well-defined and actionable roadmap must be crafted through a policy framework to harness the potential of these biotechnologies through bilateral cooperation and exchange programmes targeted at researchers and technologies. India needs to "develop an end-to-end package of interventions and strategic policy support, tailored to local needs of particular crops and agro-ecologies" (Singh & Anand 2020)[8].

India still hovers at 0.40 per cent of agricultural GDP when it comes to spending on agricultural R&D, while most of the developed countries spend up to 1 per cent. Figure 2 shows Israel, the Republic of Korea, Sweden, Japan, Germany, the US, and China have the highest research and development expenditure as a total per cent of GDP (The World Bank Data)[9]. Figure 3 shows South Asian nations, including India, lag much behind in the research and development expenditure (per centage of GDP) as compared to America and European Union.

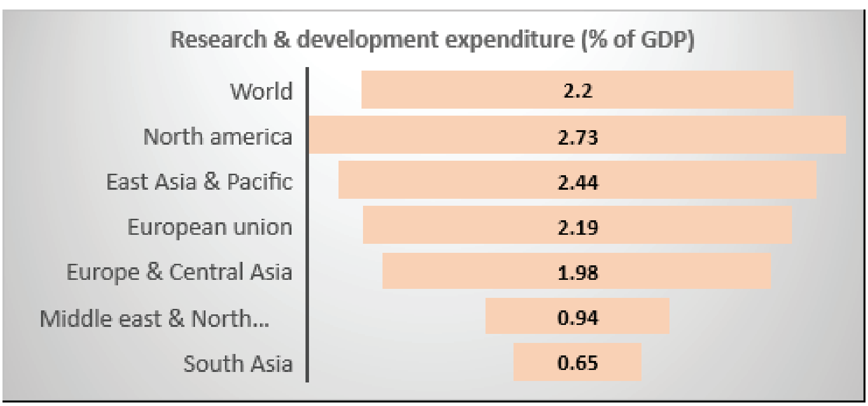
According to Singh & Anand, 'Central and state government budgetary allocation should recognize the importance of expenditure on agricultural R & D for economic, environmental and livelihood sustainability'. Therefore, this calls for revitalizing the scientific fraternity with a focus on problem-solving, state-of-art infrastructure, capacity building at the human resource level, and fostering R&D funding. Conducting comprehensive mission-mode research ventures is necessary to realize the full potential of science & technology in boosting the agricultural sector. An equally significant role can be played by the increased private expenditure in the agricultural sector. Public investment can strengthen the infrastructure of the agriculture sector and private investment can enhance the productive capacity. Policy reforms

Figure 2: Research and Development Expenditure at Global Level (% of GDP)



Source: World Bank [UNESCO Institute for Statistics. Data as of September 2021]

Figure 3: Research and Development Expenditure in all Economies at Global Level (% of GDP)



Source: World Bank [UNESCO Institute for Statistics. Data as of September 2021] like ‘The Model Agriculture Produce & Livestock Marketing (Promotion & Facilitation) Act 2017’, ‘The Model Agriculture Produce & Livestock Contract Farming & Services Act (Promotion & Facilitation) Act, 2018’ and 100 per cent FDI in food retail has encouraged private investments in establishing post-production infrastructure to strengthen the food supply chains (PIB, Ministry of Agriculture & Farmers Welfare, GoI, 19 JUL 2019)[10]. Private investments in R & D and technology transfer are the need of the hour to enable the doubling of farmers’ real income in India.

Advancing Indo-Australia Biotech and Agriculture Co-operation

Agriculture has undergone remarkable changes in developed nations in the last century. Developments in agriculture research and related technological areas provided a sound basis for robust growth and transformation in agriculture and allied sectors. In a broader ecosystem of foreign policy and science diplomacy, India has expanded international cooperation in agriculture and allied sectors in various countries and international organizations in both bilateral and multilateral frameworks. Prime Minister Narendra Modi has emphasized greater technological cooperation for infusing new technology for transformation in the agriculture sector. For instance, the ICAR has entered into 57 MoUs [America – 17, Australia – 12, Africa -6, Asia – 14, Europe – 8] with different countries/organizations/ Foreign Universities and Institutions for furthering collaborative research (Arunachalam and Misra 2020).) Besides, ICAR also participates in multilateral cooperation under the aegis of IBSA, BRICS, SAARC, ASEAN, India-Africa Forum, BIMSTEC, etc11. The ICAR also engages in active collaborative research with many institutions through CGIAR (Consultative Group on International Agricultural Research). CGIAR is an international R&D network comprising 15 Research Centres across the world. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), headquartered in Hyderabad and Telangana, is the nodal center of India and the South Asia region. The MoUs and work plans focused on addressing specific national problems, study visits, training of scientists, exchange of technical knowledge, and supply of germplasm have proven very applicable (Arunachalam and Misra 2020). For example, improved lines of wheat from CIMMYT and rice from IRRI significantly contributed to India’s Green Revolution.

India has also been sharing its experiences, best practices, and capacity building with other developing countries bilaterally as well as in partnership with international organizations. Agriculture cooperation is one of the main themes of the India-Africa development partnership and one of the main pillars of the India-ASEAN partnership. Indian agriculture has performed well in terms of production and export during the COVID-19 pandemic[12]. As it is seen that New Delhi has extended medical cooperation to developing countries during the COVID-19 pandemic, it also offers to share its knowledge and capacity building with developing nations. The ASEAN-India Partnership action programme primarily focuses on capacity-building activities and technology transfer. The priority implementation areas include: IT application for agricultural extension, Seed quality control system, Disease diagnosis, Agroforestry interventions, Farm machinery, and Genetic improvement of parental lines (Joint press statement, 4th ASEAN-India ministerial meeting on Agriculture and Forestry held on 12th Jan. 2018, New Delhi, India)[13].

Technological cooperation between India and Australia is expanding in recent times. Both India and Australia are taking initiatives for building long-term technological cooperation in areas of critical and emerging technologies. In his virtual address to the Bengaluru Technology Summit held from Nov 17-19, 2021, Australian Prime Minister Scott Morrison expressed his country's commitments to technological cooperation and establishing a Center of Excellence for Critical and Emerging Technology Policy in India (Gargeys 2022, Policy Forum)[14]. In a similar vein, Prime Minister Narendra Modi also emphasized the technological cooperation in India-Australia strategic partnership, when he addressed Australia's Strategic Policy Institute's Sydney Dialogue (Nov 17-19, 2021) (Gargeys 2022). It is also recognized in the recently held 2nd Indo-Australia virtual summit 2022 (March 21, 2022)[15].

Australia-India Strategic Research Fund (AISRF)[16] is jointly managed and funded by the governments of India and Australia and is a major platform for bilateral collaboration in science. Since its establishment in 2006, AISRF has supported several leading-edge projects in areas like agriculture, health, and the environment by bringing together top researchers in India and counterparts at premier research institutes and universities in Australia. Focus areas have been - vaccine development for malaria, research into cancer therapies, nanotechnology, and the development of drought and disease-resistant crops (Australian High Commission)[17]. In the virtual 2nd Indo-Australia summit on 21st March 2022, the extension of the AISRF - a pillar of collaboration on science, technology, and research and the commitment to build on the successful 2021 India Australia Circular Economy Hackathon has been welcomed and appreciated (Joint statement: India-Australia Virtual Summit, March 2022). AISRF-Collaborative Research Project Grant Round 14, 2022, invited proposals in priority areas like Remote sensing, Downstream processing, Groundwater resource management, Digital health, and Biomaterials, to be specific.

India and Australia are the two biggest democracies in the Asia-Pacific region, with diverse demography and English as the main language of education, commerce, and industry. Hence, this offers ample opportunities for knowledge exchange and business. Australia India Business Exchange (AIBX)[18] was launched in 2021 to advance trade and investment links with India. There have been several commercial partnerships between the two countries in the healthcare sector and digital health sectors. Companies like Biocon, Dr. Reddy's, Indian Immunological, and Bharat Biotech are collaborating with top-tier universities, and research institutions for the development of therapeutics. Similar remunerative models of business need to be nurtured in the agricultural biotechnology sector with the involvement of the private sector and agribusiness companies.

As greater policy synergy has been evolving between the two nations, science diplomacy would indeed be quite crucial in widening and deepening their partnership. When the benefits of technology reach beyond the scientific community to people and bring changes in their life, these bilateral relations further strengthen. There are examples of certain technologies which could be useful for India. 'Banana Bio-fortification' project is an excellent example of technology transfer collaboration between the Biotechnology Industry Research Assistance Council (BIRAC) on behalf of Govt. of India and the Queensland University of Technology, Australia (supported by Horticulture Innovation Australia)[19]. QUT, Australia, has done extensive work on the efficient regeneration & transformation of bananas for provitamin A (PVA) & iron bio-fortification. They have also obtained good leads related to Banana Bunchy Top Virus (BBTV) and

Fusarium Wilt resistance. This project aimed to develop, validate and transfer these specific traits in two Indian banana varieties cv. Grand Nain and Rasthali. Under this agreement, QUT shared the gene constructs, data on performance, bioavailability studies, biosafety data, and protocols for efficient regeneration and transformation in bananas. Indian institutions like NABI, Mohali; NRCB, Trichy; BARC, Mumbai; TNAU, Coimbatore and IIHR, Bangalore, were involved as technology transfer partners.

Several institutions in Australia hold close cooperation with Indian public institutions intending to promote and accelerate research and training in various disciplines of agricultural research. A memorandum of understanding (MoU) exists between the Indian Council of Agricultural Research (ICAR), New Delhi, and the Western Sydney University (WSU), Australia. The University of Western Australia has an MoU with Acharya N.G. Ranga Agricultural University, Guntur, Andhra Pradesh, India, for cooperation in agricultural research and education with a focus on the exchange of scientists, technologists, students, joint Ph.D. programmes; exchange of germplasm and breeding material; exchange of scientific literature, information, and methodology. ICAR also holds an MoU with the University of Queensland, Australia, to strengthen linkages in the area of Agriculture.

The University of Queensland holds prominence in three key areas of research: horticulture crop improvement, animal vaccines, and sorghum breeding and crop protection. Horticulture Australia Limited (HAL), with close collaboration with academia in Queensland, is playing a pivotal role in horticultural crop improvement (with a particular focus on mango). Institute of Agriculture at the University of Sydney has a research focus on plant breeding, and productive translatable traits concentrated on cereals, legumes, ornamentals, and crops in need of protection. They have strong interactions with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India, for grain legumes research and improvement. Promoting legume research for increased production & horticultural crops can have a significantly positive impact on farmers, the economy, and the environment.

Table 1: List of Prominent MoUs/Cooperations between Indian and Australian Institutions in Agribiotech Sector

S.No.	Indian Institution	Australian Institution	Focus area of research
1	Biotechnology Industry Research Assistance Council, GOI	Queensland University of Technology Horticulture Innovation Australia	Banana Bio-fortification Pathogen, virus resistance in crop plants
2	Indian Council of Agricultural Research (ICAR)	Western Sydney University (WSU), Australia	Exchange of germ plasm and breeding material
3	Acharya N.G. Ranga Agricultural University, Guntur, Andhra Pradesh	University of Western Australia	Exchange of germ plasm and breeding material
4	Indian Council of Agricultural Research (ICAR)	Horticulture Australia Limited (HAL) Centre for Plant Science, University of Queensland	Horticulture crop improvement (Mango) Animal vaccines Sorghum breeding and crop protection
5	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Institute of Agriculture, University of Sydney	Plant breeding and crop improvement (Cereals, legumes, ornamentals and crops)
6	Plant breeding and crop improvement (Cereals, legumes, ornamentals and crops)	Australian Council of International Agricultural Research (ACIAR)	Biotic and abiotic stress tolerance in Wheat
7	ICAR-Indian Institute of Wheat and Barley Research	Adelaide University	Biotic and abiotic stress tolerance in Wheat

Table 1 continued...

Table 1 continued...

8	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Australian Council of International Agricultural Research (ACIAR)	Nutritive value of Pearl millet
9	International Centre for Genetic Engineering and Biotechnology, New Delhi	University of Queensland	Heat tolerance in crop plants
10	ICAR-Indian Agricultural Research Institute Jawaharlal Nehru University International Crops Research Institute for the Semi-Arid Tropics	University of Western Australia	Drought tolerance in Chickpea

Source: Endnotes No. 11, 19, and https://www.icrisat.org/indo-australia-genomics-project-for-chickpea-drought-tolerance-gains-momentum/

Both India and Australia are members of the multilateral platform G20[20], which brings together both developed and emerging economies. Thematically, various areas of science and technology which are related to biotechnology as well as agriculture have come into discussion in G20, such as genomics, genetic editing, market share, and sustainable food systems. The MACS (Meeting of Agricultural Chief Scientists)-G20 was formed in 2011 under French Presidency. The G20 declaration also emphasized scientific cooperation for agricultural growth and development. G20 is yet to come up with a specific institutional setup or initiatives for regular emphasis on the exchange of expertise in G20. However, some efforts have been made to discuss the potential cooperation within G20. A stock take meeting was held during the Argentina Presidency in 2018 (G20 Summit declaration). The MACS-G20 provides a platform for discussing research and scientific cooperation. It aims to build consensus for sustainable and equitable development at the agro-industrial level and explored cooperation in areas of climate change, genetic editing, and soil care during the Argentina summit.

The Quad[21] is taking initiatives for expanding science and technology cooperation. To promote research and innovations and also expand joint research and development, Quad Fellowship is announced in 2021. It is 'first-of-its-kind' scholarship programme, which will be operated and administered by a philanthropic initiative and in consultation with a non-governmental task force comprised of leaders from each Quad country. The Quad fellowship aims to bring together exceptional American, Japanese, Australian, and Indian master and doctoral students in science, technology, engineering, and mathematics to study in the US. It is also seen that government is keen to give a bigger role to the private sector in development partnerships and research and innovation. This new fellowship will develop a network of science and technology experts committed to advancing innovation and collaboration in the private, public, and academic sectors, in their nations, and among Quad nations. If the programme is successfully implemented, it may promote research and develop a network of scholars which includes both India and Australia. Secondly, it is also stated that the Quad will monitor trends in critical and emerging technologies, starting with advanced biotechnologies, including synthetic biology, genome sequencing, and biomanufacturing. In the process, Quad countries will identify related opportunities for cooperation among them (Fact sheet: Quad leaders' summit).

India and Australia, with other member countries, can focus more on science diplomacy, so the concrete outcomes could come in establishing joint research funds, fellowships, and institutions which could foster technological cooperation which can contribute to the welfare of people. Additionally, it would further widen, deepen and enrich different spheres of Indo-Australia cooperation in terms of resources and technological expertise.

Mobilizing Australia's Strength in Biotechnology and Agriculture

The Australian agricultural sector has been continually using biotechnology to innovate for extending benefits to farmers and communities. For example, Australia enabled its farmers to use genetically modified cotton for pest resistance very early in 1996. This enabled them to reduce their use of pesticides and also significantly increase their farm income. Australia has invested substantially in increasing product quality, reducing chemical applications, better management of pests, weeds, and diseases, developing functional products for industry use, and increasing productivity amid mitigating the adverse effects of the environmental challenges (Biotechnology and agriculture in Australia: policy snapshot 2018)[22]. Australia is known for its advanced technologies of crop breeding and management practices like soil ameliorant strategies that restore landscape health, conserve soil water and improve soil resilience to environmental stresses. These can also be potential areas for widening and deepening knowledge exchange and scientific cooperation. It is noted that Australia holds expertise in developing nutrient-rich, climate- resilient, and highly productive crop varieties which can be useful for the Indian Agriculture sector.

Genetically modified crop technology is being used not only for developing insect resistance and herbicide tolerance but also for increasing the nutritive value and productivity of crops. For instance, researchers at the University of Adelaide are working on the biofortification of wheat for increased iron levels (OGTR 2017)[23]. For a country like India, where Wheat is a staple crop, and iron deficiency is very common, this may prove a promising technology. Engineering plants to produce specific metabolites, including medicines, biofuels, and functional products, can boost the development of bio-industries and also promote investments in public-private partnerships. Crop Biofactories Initiative (CBI), under the aegis of CSIRO and Grains Research and Development Corporation (GRDC), is engineering oilseeds like Safflower and Canola for the production of long-chain polyunsaturated fatty acids (PUFA) like Oleic acid (Fazer 2018). PUFA is not only an excellent substitute for fish oil but also has applications in many bio-industries, such as cosmetics, plastic additives, resins, polymers, biofuels, and diet supplements. Such translational approaches for the production of value-added crops in the Indian agriculture system can substantially boost the farmer's income and alleviate economical growth. Hence, necessary technological collaborations, joint research initiatives, and more institutional level joint cooperation for long- term research in new technology development should be implemented in India-Australia biotechnology cooperation.

Australia holds a strong economic partnership with India, including agribusiness. Australia can forge a long-term partnership with India by investing in the latest agri-technologies, infrastructure development, investment in post-harvest storage, and supply of premium food products to harness the future demands of agri-produce in India. Round table meeting in 2018 on Agribusiness cooperation between Australia and India organized at Western Sydney University with support from the Indian High Commission and the Commonwealth Department of Foreign Affairs and Trade (via Australia- India Council) had recommended strategic priority areas related to agribusiness for bilateral partnership between Australia and India which includes joint technology development and shared market access ensuring demand-based export, modernizing farming systems and post-harvest storage infrastructure development in India to increase productivity and innovation and commercialization of emerging tools (satellite-based, big data, genomics, bio-based solution, climate-smart agriculture) for sustainable increases in crop productivity (Singh, 2018). Emphasis was given to the regular exchange of ideas in a network of scientists, policymakers, and stakeholders to ensure innovation and technology development, and also recommended establishing an Australia- India Center of Excellence for Agribusiness with a public-private partnership. These points appear to be relevant to defining the agenda for robust science diplomacy between India and Australia.

Experiences of Indo-Australian Career Boosting Gold Fellowships

The government of India had been promoting collaborative research projects and knowledge transfers through various country-specific calls by DST and DBT on a timely basis. Indo-Australian Career Boosting Gold Fellowships (IACBGF) from the Department of Biotechnology has been supporting young researchers from India in performing collaborative research projects in Australian host institutions. Such schemes have been instrumental in honing skills, capacity building, and bringing in new technologies to India in biotechnology research. The 5^{th} call (2018) under the scheme awarded seven researchers under various projects ranging from plant biotechnology to nutraceuticals, myself being one of the beneficiaries of this scheme. This scheme is extremely beneficial and provides this opportunity to young researchers (age <35) who are in their early years as independent researchers. IACBGF gave me a unique opportunity by making an India-

Australia Specific programme. My host institution, the La Trobe Institute for Molecular Sciences, La Trobe University is one of the world's premier institutions recognized for its excellence, and multi-disciplinary approach to driving innovation and producing translatable research outcomes. Both scientific expertise and research laboratories with advanced equipment provided the most appropriate environment for conducting research on plant-derived defense proteins and peptides (cyclotides). In this project, we could express native and 'grafted' cyclotides in model plants (*Nicotiana benthamiana*) in the laboratory. The outcomes of this project are extremely relevant in coming times with reference to crop improvement (insect pest resistance) and food security which are key areas for both India and Australia.

Conclusion

New developments in biotechnology offer solutions to several challenges faced by Indian agriculture and allied sectors. Additionally, applications of these technologies may spur new momentum in agriculture growth and development. India is also prioritizing preserving underground water, reducing pesticide pollution, increasing biodiversity, minimizing environmental damage, enhancing the supply chain, etc. Indo-Australia cooperation can bring skills, technology, and opportunity for scaling up collaborative research initiatives, especially in the emerging areas of sustainable agriculture. However, India needs tofocus more not only on research and development in terms of investment and building research infrastructure but also on greater cooperation with institutions of advanced countries for long-term research collaboration. Technological and scientific cooperation is an essential element in Indian foreign policy and science diplomacy. Recently, India has been expanding its science and technology cooperation with countries in different parts of the world. India and Australia are expanding their horizons in critical technologies, which may also include agriculture and allied sectors. Arguably, one of the potential challenges in the implementation of biotechnological interventions and transgenics is the concern about the monopoly of large transnational corporations in the production and distribution of transgenic seeds, which are protected as intellectual property and are often self-terminating after one season. These factors raise apprehensions about potential harm to small farmers in developing countries. The technology is now within sight, and must not be let loose. Integrating all that knowledge to enhance agriculture and allied sectors is essential for durable economic growth and inclusive socio-economic development in the country. Here it is pertinent to note that the new National Education Policy encouraging international cooperation in higher education and research and academic exchanges, also provides opportunities for Indian institutions to further expand their academic and research network within global partners such as Australia. As associated with the majority section of the population and the nation's inclusive development, Agriculture and allied sectors would be important in widening and deepening their technology cooperation in the future. Both countries can address new priorities such as improving resilience to climate change, producing more nutritious food, and adapting to shifts in consumption patterns in the country.

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Endnotes

1 India Brand Equity Foundation. 2022. "Agriculture in India: Information about Indian agriculture and its importance industry report". Retrieved in June 2022 from https://www.ibef.org/archives/industry/agriculture-reports/agriculture-presentation

2 SundayGuardianLive. October 19, 2019. "Agri biotech can help unleash second Green Revolution" Uma Keni Prabhu. TSG. From https://www.sundayguardianlive.com/news/agri-biotech-can-help-unleash-second-green-revolution

3 The Hindu. February 25, 2017. "Pests eat away 35% of total crop yield, says ICAR Scientist". From https://www.thehindu.com/news/national/pests-eat-away-35-of-total-crop-yield-says-icar-scientist/article17368426.ece

4 UNICEF data. 2021. "Vitamin A deficiency". Retrieved on October 2021 from https://data.unicef.org/topic/nutrition/vitamin-a-deficiency/

5 International Centre for Trade and Sustainable Development. April 2008. "A Framework for Policymaking on Trade, Agricultural Biotechnology and Sustainable Development". From https://www.semanticscholar.org/paper/A-Framework-for-Policy-Making-on-Trade%2C-and/a4ad3f03a62aa382fda1edf0c25882d02af37c78

6 SundayGuardianLive. October 19, 2019. "Agri biotech can help unleash second Green Revolution" Uma Keni Prabhu. TSG. From https://www.sundayguardianlive.com/news/agri-biotech-can-help-unleash-second-green-revolution

7 Department of Biotechnology, Ministry of Science & Technology, Government of India "National Biotechnology Development strategy". From https://dbtindia.gov.in/about-us/strategy-nbds

8 Singh, N.P., Ranjith, P.C. & Anand, B. Economic Times in ET Commentary, Edit Page, India, ET February 16, 2020 "Time to get Aggro on Agri R&D". From https://economictimes.indiatimes.com/blogs/et-commentary/time-to-get-aggro-on-agri-rd/

9 UNESCO Institute for Statistics. "Research and development expenditure (% of GDP)". Data as of September 2021. From https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?end=2019&most_recent_value_desc=true&start=2009&view=chart

10 Press Information Bureau, Ministry of Agriculture & Farmers Welfare, Government of India. 19 July, 2019. "Increasing private expenditure in agricultural sector". From https://pib.gov.in/Pressreleaseshare.aspx?PRID=1579545#:~:text=As%20per%20report%20of%20the,at%202004%2D05%20prices

11 Indian Council of Agricultural Research, Ministry of Agriculture and Farmers Welfare. "International relations". From https://www.icar.org.in/content/international-relations

12 Press Information Bureau, Ministry of commerce & industry, GoI, June 2021. "India registered excellent growth in Agriculture Exports during 2020-21" by Wadhawan, A. Retrieved from https://pib.gov.in/Pressreleaseshare.aspx?PRID=1725891

13 Joint Press Statement. "The fourth ASEAN-India ministerial meeting on Agriculture and Forestry". January 12, 2018. From https://asean.org/the-fourth-asean-india-ministerial-meeting-on-agriculture-and-forestry/#:~:text=1.,Mr.

14 Policy Forum, Asia and the Pacific Policy Society. "Why India-Australia technology cooperation Is a welcome development" by Arjun Gargeys. January 24, 2022. From https://www.policyforum.net/why-india-australia-technology-cooperation-is-a-welcome-development/

15 Ministry of External Affairs, Government of India. "JOINT STATEMENT: INDIA-AUSTRALIA VIRTUAL SUMMIT" March 21, 2022. From https://www.mea.gov.in/bilateraldocuments.htm?dtl/35008/JOINT_STATEMENT__INDIAAUSTRALIA_VIRTUAL_SUMMIT

16 Department of Industry, Science, Energy and Resources, Australian Government. "National innovation and science agenda report". From www.innovation.gov.au/AISRF

17 Australian High Commission. https://india.embassy.gov.au/ndli/pa5410.htm

18 Australian Trade and Investment Commission. "Australia India Business Exchange-Partnering for prosperity". From https://www.austrade.gov.au/australia-india-business-exchange

19 Biotechnology Industry Research Assistance Council (BIRAC). "Development and Transfer of Technology from Queensland University of Technology, Australia to India for Bio-fortification and Disease Resistance in Banana". From https://birac.nic.in/desc_new.php?id=96

20 G20 Information centre, University of Toronto. "G20 Meetings of Agriculture Ministers". From http://www.g20.utoronto.ca/2018/2018-07-28-agriculture.html

[21] Ministry of External Affairs, Government of India. "Fact sheet: Quad Leaders' Summit" Bilateral/Multilateral Documents September 24, 2021 https://www.mea.gov.in/bilateraldocuments.htm?dtl/34319/Fact_Sheet_Quad_Leaders_Summit

[22] Department of Agriculture and Water Resources, Australian Government. "Biotechnology and agriculture in Australia: policy snapshot" October 2018. From https://www.agriculture.gov.au/agriculture-land/farm-food-drought/biotechnology/biotechnology-agriculture-australia-policy-snapshot

[23] OGTR 2017, DIR 128 "Limited and controlled release of wheat and barley genetically modified for abiotic stress tolerance or micronutrient uptake" Office of the Gene Technology Regulator, accessed 20 June 2018.

References

Arunachalam, A. and Misra, A.K. 2020. "DARE-ICAR Global Reach". Indian Council of Agricultural Research, New Delhi. pp 30.

Bailey-Serres, J., Parker, J., Ainsworth, E.A., Oldroyd, G.E.D. and Schroeder, J.I. 2019. "Genetic strategies for improving crop yields". *Nature*, 575: pp. 109-118.

Balakrishnan, B. 2019. Distinguished Lectures, Ministry of External Affairs, GoI. "Changing dynamics of Indian Foreign Policy – the Science and Technology Dimension". Published on September 2. From https://www.mea.gov.in/distinguished-lectures-detail.htm?846.

Dang, H., Gilmour, B. and Kishor, N. 2015. "India's Agri-Biotech policies, Regulations and decision making". *AgBioForum,* 18(1): pp. 87-97.

Deshpande, T. 2017. Policy Analytical Report, PRS Legislative Research. "State of Agriculture in India". From https://prsindia.org/policy/analytical-reports/state-agriculture-india#:~:text=In%202013%2C%20India%20contributed%2025,for%20the%20past%20several%20years.

Deutsch, C.A., Tewksbury, J.T., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B. and Naylor, R.I. 2018. "Increase in crop losses to insect pests in a warming climate". *Science*, 361: pp. 916-919.

Endo, A., Masafumi, M., Kaya, H. and Toki, S. 2016. "Efficient targeted mutagenesis of rice and tobacco genomes using Cpf1 from *Francisella novicida". Scientific Reports* 6(38169): pp. 1-9.

Frazer, S. 2018. CSIROscope, CSIRO, Canberra. "OM(e)G(a)! Omega-3 canola gets the green light". Retrieved 23 February 2018 from https://blog.csiro.au/omega-omega-3-canola-gets-green-light/.

Giani, A.M., Gallo, G.R., Gianfranceschi, L. and Formenti, G. 2020. "Long walk to genomics: History and current approaches to genome sequencing and assembly". *Computational and Structural Biotechnology Journal*, 18: pp. 9-19.

Goel, M. 2021. "India on a Road to Science Diplomacy" In: Science Diplomacy for South Asian Countries. Springer, Singapore. Pp. 53-66. From https://doi.org/10.1007/978-981-16-3025-5_5.

Gull, A., Lone, A.A. and Wani, N.U. 2018. “Biotic and abiotic stresses in plants” In de Oliveira, A. (ed.). 2019, *Abiotic and Biotic Stress in Plants*, IntechOpen, London. 10.5772/intechopen.77845.

Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S. and Venkataraman, G. 2018. “CRISPR for Crop Improvement: An Update Review”. *Frontiers in Plant Science* 9(985). doi: 10.3389/fpls.2018.00985.

Liu, D., Chen, X., Liu, J., Ye, J. and Guo, Z. 2012. “The rice ERF transcription factor OsERF922 negatively regulates resistance to *Magnaporthe oryzae* and salt tolerance”. *Journal of Experimental Botany* 63: pp. 3899–3912. doi: 10.1093/jxb/ers097.

Liu, X., Wu, S., Xu, J., Sui, C. and Wei, J. 2017. “Application of CRISPR/Cas9 in plant biology”. *Acta Pharmacologica Sinica* B 7: pp. 292–302. doi: 10.1016/j.apsb.2017.01.002.

Matta, C., Kingsbury, N. 2014. “Hybrid: The History & Science of Plant Breeding” In *History and Philosophy of the Life Sciences*, University of Chicago Press, Chicago, USA. 36: pp 129-130.

Malzahn, A., Lowder, L. and Qi, Y. 2017. “Plant genome editing with TALEN and CRISPR”. *Cell & Bioscience* 7: pp. 21. doi: 10.1186/s13578-017-0148-4.

Martignago, D., Rico-Medina, A., Blasco-Escamez, D., et al. 2020. “Drought resistance by engineering plant tissue-specific responses”. *Frontiers in Plant Science*, 10, 1676: pp. 1-19. https://www.frontiersin.org/articles/10.3389/fpls.2019.01676/full.

Moose, S.P. and Mumm, R.H. 2008. “Molecular plant breeding as the foundation for 21st century crop improvement”. *Plant Physiology* 147: pp. 969-977.

Oerke, E.C. 2005. “Crop losses to pests”. *The Journal of Agricultural Science* 144: pp. 31–43. doi: 10.1017/ s0021859605005708.

Paine, J., Shipton, C., Chaggar, S. et al. 2005. “Improving the nutritional value of Golden Rice through increased pro-vitamin A content”. *Nature Biotechnology* 23: pp. 482–487.

Paul, J.Y., Khanna, H., Kleidon, J., Hoang, P., Geijskes, J., Daniells, J., Zaplin, E., Rosenberg, Y., James, A., Mlalazi, B., Deo, P., Arinaitwe, G., Namanya, P., Becker, D., Tindamanyire, J., Tushemereirwe, W., Harding, R., Dale, J. 2017. “Golden bananas in the field: elevated fruit pro-vitamin A from the expression of a single banana transgene”. *Plant Biotechnology Journal* 15(4): pp. 520-532.

Pental, D. 2021. Dialogue: Science, Scientists and Society. “Challenges for India in agriculture and the pivotal role of R & D in meeting these”. From http://www.dialogue.ias.ac.in/article/50188/challenges-for-india-in-agriculture-and-the-pivotal-role-of-rampd-in-meeting-these.

Prakash, C.S. 2000. “Can India benefit from the Agricultural biotechnology?” *Asia Pacific Biotech News* Vol. 4(4): pp. 76-78.

Rajendran, T.P. 2016. “Emerging trends in agricultural biotechnology: An Indian perspective”. *Asian Biotechnology and Development Review* 18(3): pp. 25-39.

Rangasamy, N. and Elumalai, K. 2009. “Market opportunities and challenges for Agri-Biotech products in India”. *Agricultural Economics Research Review* 22: pp. 471-481.

Ricroch, A., Clairand, P. and Harwood, W. 2017. “Use of CRISPR systems in plant genome editing: toward new opportunities in agriculture”. *Emerging Topics in Life Sciences* 1: pp. 169–182. doi: 10.1042/etls20170085.

Savary, S., Willocquet, L., Pethybridge, S.J., Esker, P., McRoberts, N. and Nelson, A. 2019. “The global burden of pathogens and pests on major food crops”. *Nature Ecology & Evolution* 3: pp. 430-439.

Shan, Q., Wang, Y., Li, J. and Gao, C. 2014. “Genome editing in rice and wheat using the CRISPR/Cas system”. *Nature Protocols* 9: pp. 2395–2410. doi: 10.1038/nprot.2014.157.

Shan, Q., Wang, Y., Li, J., Zhang, Y., Chen, K., Liang, Z., et al. 2013. “Targeted genome modification of crop plants using a CRISPR-Cas system”. *Nature Biotechnology* 31: pp. 686–688. doi: 10.1038/nbt.2650.

Singh, B. 2018. Round Table meeting between Indian High Commission and Western Sydney University. “Agribusiness cooperation between Australia and India. Expert report and recommendations”. From https://www.westernsydney.edu.au/__data/assets/pdf_file/0008/1472390/Agribusiness-Round-Table_Report.pdf.

Sussex, I. 2008. “The scientific roots of modern plant biotechnology”. *Plant Cell* 20: pp. 1189-1198.

Swamy, B.P.M., Samia, M., Boncodin, R., Marundan, S., Rebong, D.B., Ordonio, R.L., Miranda, R.T., Rebong, A.T.O., Alibuyog, A.Y., Adeva, C.C., Reinke, R., MacKenzie, D.J. 2019. “Compositional Analysis of Genetically Engineered GR2E “Golden Rice” in Comparison to That of Conventional Rice”. *Journal of Agriculture and Food Chemistry*67(28): pp. 7986-7994.

Velasquez, A.G., Castroverde, C.D.M. and He, S.Y. 2018. “Plant - pathogen warfare under changing climate conditions”. *Current Biology* 28: pp. 619-634.

Waltz, E. 2018. “With a free pass, CRISPR-edited plants reach market in record time”. *Nature Biotechnology*, 3(6): pp. 6–7. doi: 10.1038/nbt0118-6b.

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Commercialisation of Plant Tissue Culture in India: A Review

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Abstract: Plants are the basic source of our fruits and vegetables. Due to the increasing population in our world, we need an abundance of edibles for survival. In the contemporary era, plants can be used for several purposes like food, medicine etc. PTC is one of the trending technologies in the plant biotechnology research field, which has been commercialised for large- scale production of plants. In recent times, pathogen- free plants are being produced internationally, metabolites from plants are used in biopharmaceuticals. Using plant tissue culture techniques, they are being produced for larger production of secondary metabolites. This review article intends to discuss commercialisation and today's scenario of economic status in Plant tissue culture.

Keywords: Commercial, Industry, Economic, Metabolites, Plant Tissue Culture.

Introduction

According to Street(1977), Plant tissue culture is the technique using aseptic culture of cells, tissues, organs and their components under well-defined invitro physical and chemical conditions. It is an important field in plant biotechnology which includes various techniques like somaclonal variation, micropropagation, somatic hybridisation, synthetic seed production, haploid culture, somatic embryogenesis, secondary metabolite production, etc., which complements crop production and plays a major role in agriculture and pharmaceutical production. It has been widely used as an alternative

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method to the vegetative propagation of plants, for the mass multiplication and regeneration of novel plants from genetically engineered plants. alternative means to vegetative propagation of plants. Viral, bacterial, and fungal eradication and maintenance of disease free plants have also been achieved in cultures. Shoot proliferation is much safer and preferred for in vitro clonal multiplication of plants.

It has been estimated that around 250,000 species of flowering plants at the global level, of which 3,000 are regarded as food sources, and about 200 species have been domesticated. Global diversity in vegetable crops is about 400 species, with 80 species of major and minor vegetables are reported to be originated in India. Deforestation and over-exploitation of native resources have greatly affected the biodiversity (Shukla et al. 2021). Indigenous plant species are also utilised in pharmaceuticals, nutraceuticals and many industries depend on these for their raw materials (Shukla et al. 2021). The tissue culture technique is being utilised for micropropagation and commercialisation of agricultural crops, mass multiplication of desired plant variety, germplasm protection, development of newer cultivars with specific desirable traits, raising disease free plants and proliferation of elite and endangered plants (Pant and Mehta 2016). These plants are much in public demand in the market. Thus. this review article, is aimed to describe the expansion of plant tissue culture, its financial prominence, and its status in India.

Development of Commercialisation of Plant Tissue Culture

The commercial application of plant tissue culture was first established in the US with micropropagation of orchids in the 1970s. The first commercial tissue culture company in India was named as A.V Thomas Company, Kerala, established in 1987. They did clonal propagation for the improvement of a selected variety of cardamom plants containing superior genotypes (Patil *et al*, 2021). National Chemical Laboratory (NCL), Pune, India, released these plants whose production was done in an indigenously developed small scaled laboratory- based industry. This technology made efficient mechanisms for more production, economically feasible, and quality service with the help of a UK-based firm (Mascarenhas 1999). Reports of hybrid flowers and vegetables nursery with imported plant tissue culture laboratory were obtained from the second plant, an Indo-American

Hybrid Seeds at Bengaluru, Karnataka. From 4 units in 1988 to around 50 laboratories across the country, the plant tissue culture has seen a rapid rise throughout this phase. Indian micropropagation industry has increased from 5 million to 190 million in a span of 8 years from 1988 to 1996. The current state of affairs of the Indian subcontinent proves that the services created have made our units spirited to those from leading countries such as US and Netherlands. Indian units necessitate putting effort into generating unique products based on demand in both domestic and international markets (Govil *et al*. 1997). Countries from throughout the world have started commercialisation of plant tissue culture, which has become a globalised, due to the major demand from developing countries. With the help of micropropagation techniques, the Indian plant tissue culture industry has become successful in various sectors such as agriculture, medicine, and forestry. (Patil *et al*. 2021). The major consumers of tissue culture plants (TCPs) are the State Agriculture Department, Agri Export Zones (AEZs), the sugar industry and private farmers. (Dudhare and Jayewaar 2021). As India has a rich diversity of medicinal plant species, they are screened and cultured in vitro with the help of PTC. These plants can be regenerated and produced on larger scale production as required by the pharmaceutical industries (Kumar *et al*. 2013).

Now India has more than 73 commercial PTC units, most of which are present in Maharashtra and Karnataka. Central research laboratories, research centres, such as the Indian Council of Agriculture Research, Delhi and National Chemical Laboratory, Pune and universities, and some PTC units are also involved in commercial micropropagation. Few of the laboratories work regularly, while some depend on financial and technological help from the government for promoting the tissue culture industry in the country. Rajasthan and Darjeeling have their units fully operative but vary in their management and production. Maximum yield is obtained by Kalindi Biotech, located in Rishikesh, Uttar Pradesh (20 million plants per year). The lowest amount of plants is produced in Costford Promoted Unit, Thiruvananthapuram, Kerala, and Rallis India Ltd, Bengaluru, Karnataka, with only 0.1 million plants per year. Most of them lie in the range between 5 and 10 million plants per year. In terms of production and number of units present, Maharashtra tops the list of annual production with 31 million plants per year with 25 units. Karnataka comes second in line with 31 million plants with 9 units. Odisha and Rajasthan are reported to produce the lowest amount of plants, 1 million per year having only one unit (Mascarenhas 1999). Apart from these research institutions, agricultural universities, and National Certification System for Tissue Culture Raised Plants (NCS-TCP) also extend support for commercial production [NCS-STP 2020].

Commercialisation of Crops

The agriculture sector is one of the most profitable sectors due to the commercialisation of PTC. Agricultural research institutes, public and private Universities and translational research institutions are involved in research on various aspects of crop improvement, plant breeding, in vitro studies etc. Several crop plants and fruits have been propagated and resulting in an exponential rate of production. Major food crops such as wheat, rice, and ragi have been given preference with respect to mass production and food security. Crops such as bananas, sugarcane, mango, grapes, and other herbs are in great demand and therefore, production using tissue culture methods can fulfil the needs. By seeing the rate of banana consumption, it will remain the most reliable source of income and a nonstop market. Several laboratories are having the highest yields in banana tissue culture. In Maharashtra, 52,000 Ha. The land is under cultivation and 50 per cent of the plantation has been completed using tissue-cultured plants, with an annual production of 125 million plants (Sidhu 2011, Prakash 2004).

The reports say the production of sugarcane efficiently enhancing. Research institutes in Uttar Pradesh, Tamil Nadu, Maharashtra, and others carrying are working on increasing the production of sugarcane (Yadav et al. 2012). India is one of the largest exporters of mango fruits to the world market, it presently accounts for 39 per cent of production and over 1 million Ha. The land is used for mango cultivation. In vitro studies on other crops have also been reported, such as plant productions from callus cultures of the immature healthy embryo of sorghum and from aseptically germinated sorghum seedlings, genetic improvement of the major cereals such as maize (*Zea mays*) barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), millet (*Pennisetum* sp.), oat (*Avena sativa*) and rye (*Secale cereale*)(Shukla *et al.* 2021).

Commercialisation of Medicinal plants

India comprises a great wealth of medicinal plants which have been used by tribals and locals since ancient times. With a worldwide demand of 14 billion dollars, medicinal plants in India estimates to cost up to 1 billion per year. A total of 560 species of India are added to the Red List of threatened species, where 247 of them are in the threatened category by the International Union for Conservation of Nature and Natural Resources (IUCN) (Yadav 2016). The commercialisation of PTC can be done to protect medicinal plants through mass production and also for the conservation of rare and endangered species. The pharmaceutical industry produces a variety of secondary metabolites, which include tannins, steroids, quinones, alkaloids, terpenoids, and phenylpropanoids (Yadav *et al.* 2012).

More than 100 medicinal plant species have been regenerated using PTC methods in India. It has been estimated that India can produce more than 350 million cultured plants per annum. Plant species, such as Aloe vera, Geranium, Mentha, Paulownia and Banana, have been internationally marketed (Misra and Shukla 2010). Protocols for species, such as *Bacopa monnieri* (Scrophulariaceae), *Datura metel* (Solanaceae), *Chlorophytum borivilianum* (Liliaceae), and *Catharanthus roseus* (Apocynaceae) have been developed (Debnath *et al*. 2006). Plants such as *Celastrus paniculatus, Commiphora mukul, Aegle marmelos, Acorus calamus,Peganum harmala,Simmondsia chinensis, Sapindus mukorossi, Prosopis cineraria, Spilanthes acmella*, and *Stevia rebaudiana* have also been mass propagated (Yadav *et al*. 2012).

The recent research on various plant species' potential for commercialisation is being carried out as an effort to provide a comprehensive database on the production of natural products/medicines, which are very important for sustainable development (Shukla *et al*. 2021).

Economic Status of Tissue Culture in India

In India, the Agriculture sector contributes to about 13.9 per cent of the Gross Domestic product and employs about 54.6 per cent of the total workforce in the country (Wagh and Dongre 2016) (Figure 1). Agricultural growth has been a power for poverty reduction, more balanced regional economic growth, and improved food security. India's population can be expected to reach 1.7 billion by the year 2050 and in order for this number to remain sustainable, there must be equal distribution of food. In order to reduce poverty and bring about economic growth within India, (Shukla et al. 2021), crop production and various plant breeding techniques are relying more on biotechnological methods, such as plant tissue culture, for increasing plant quality enhancement and resulting in economic sustainability. Farmers are keener to produce diseases and pest-resistant crops, elite plant varieties produced with the help of Plant tissue culture technologies which contribute to the economy of the country.

Apart from crop production and the agriculture sector, Plant tissue culture technologies are used to produce pharmaceutically important secondary metabolites, and their commercial mass production using a bioreactor has generated economic interest in the pharmaceutical industry. Reserpine from *Rauwolfia serpentina*, vincristine and vinblastine from *Catharanthus roseus*, ginseng from *Panax ginseng* are some of the examples of phytocompound obtained through plant tissue culture (Gulzar et al. 2020).

Indian Council of Agriculture Research (ICAR), a government research institute having various branches, has been utilising plant biotechnology and plant tissue culture techniques technology for crop improvement. ICAR of the Indian Institute of Spice Research Calicut, Kerala, in working on improving spices such as Black pepper, small cardamom and turmeric. Indian Institute of Pulses Research Kalyanpur, Kanpur is working on Cluster beans, Cowpeas, Moth Bean, Horse gram, Central Citrus Research Institute Nagpur is involved in improving *Citrus reticulata* and Nagpur mandarin, Indian Institute of Oilseed Research Hyderabad is involved in improving Mustard, Niger, Safflower, Indian Institute of Natural resins and gums, Ranchi is involved in improving Bahera (*Terminalia bellerica*), Indian Institute of vegetable research, Varanasi is involved in improving Tomato, Brinjal, Red chilli, Peas, Bitter gourd, Bottle gourd. (Shukla et al. 2021)

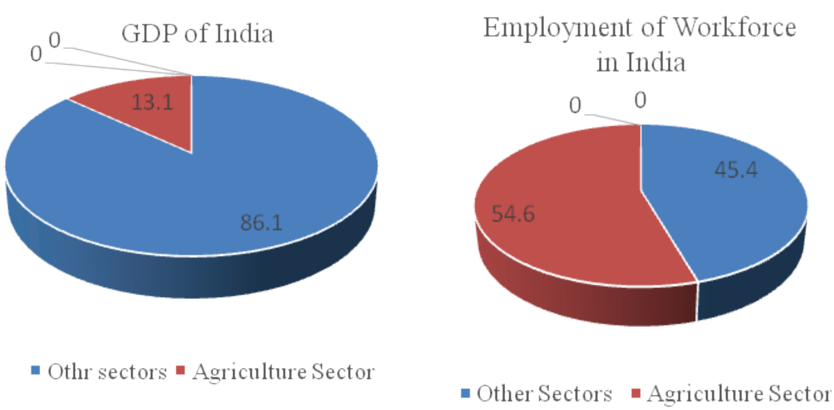
The plant tissue culture industry is valued at approximately to be US $150 billion (50-60 per cent of agriculture. About 10 per cent of the US $15 billion is fulfilled by the annual plant tissue culture- raised products and shows a growth rate of 15 per cent. According to Press Information Bureau, a Government of India report published in May 2022 Government of India via the Agricultural and Processed Food Products Export Development

Authority (APEDA) in collaboration with the Department of Biotechnology (DBT) has conducted various awareness programs, such as webinars to improve exports of tissue culture plants. According to the above report, India's exports around tissue culture plants amount to US$ 17.17 million. Netherland is a major importer of India's TC plants occupying a share of 50 per cent of shipments. Other countries which import India's tissue-cultured plants include Australia, Italy, USA, Canada, Japan, Senegal, Kenya, Ethiopia and Nepal.

Currently, the plant tissue culture industry is a billion-dollar industry producing 500 million to 1 billion plantlets annually. The floriculture sector, which includes ornamental plants and food and vegetables, are growing market for tissue culture industries in India. (Bhatia and Sharma 2015).

To make Plant tissue culture products economically feasible in India so that they could be accepted by farmers, especially in developing countries, there are collaborations with government agencies that provide certain incentives or funded projects to farmers (Pant and Mehta 2016). To improve and produce export quality Plant tissue culture materials, APEDA provides market analysis, market development, promotion and exhibition of India's tissue- cultured plants at various international exhibitions. APEDA has also been at the forefront in sending trade delegations to foreign countries in order to recognise potential new markets for Indian Tissue culture plants and their importers.

Figure 1: Economic Status of PTC in India



Source: Authors' compilation.

Initiatives taken by the government of India to counter the threat of distribution of inferior micropropagated plants (subjected to viruses and variations) to farmers include effective testing (indexing procedures) prior to commercial propagation. Thus, the Department of Biotechnology (DBT), Government of India has established a National Certification System for Tissue Cultured Raised Plants (NCS TCP). As the demand for tissue- cultured plantlets increases at a global stage, India can take advantage of its low-cost skilled labor and scientific manpower also, factors such as plant biodiversity and tropical climate enables greenhouses with low energy consumption. Presently the domestic market of the plant tissue culture industry is about Rs 200 crores having an annual growth rate of 20 per cent. In India, commercial tissue culture units follow the standard protocol developed by research institutes or universities with the support of DBT. Approximately 5 acres of land is required to set up a plant tissue culture unit (The average cost of land in India is 5 Lakhs). On a scale-up, the unit should have a capacity of producing 3 million plantlets annually (examples of a mix of plants used for the unit profile are Banana, Sugarcane, ginger, medicinal plants such as *Aloe barbadensis* and ornamental plants such as orchids like *vanilla*). Initial investment including Land development, equipment, Utilities, Green House, and miscellaneous expenses is around 163.95 Lakhs. The government's schemes and incentives to promote the economy through Plant Tissue culture units in India includes State Level Incentives: Subsidies are given on initial investments and on power consumption. The subsidy level should not exceed 20 per cent of the entire single project or scheme, where the cost of the entire project should be around 25 lakhs. A state like Karnataka provides a 20 per cent subsidy for setting up a tissue culture unit, whereas Gujarat provides a 6 per cent subsidy for the same. Small Farmers Agri Business Consortium provides loans of up to 50 lakhs to small-scale farmers who have formed a cooperative society for setting up small tissue culture laboratories. Also, farmers are provided with subsidies for the purchase of tissue cultured plants (under the government scheme "Development of Commercial Horticulture through production and Post-Harvest Management of Horticulture crops) and even Financial Assistance by Banks: National Bank for Agriculture and Rural Development (NABARD) provides financial aid to such schemes (Shukla 2008). Financial assistance of Rs. 21 lakhs for the public sector and Rs. 10 lakhs for private- sector commercial units has been provided by the Department of Agriculture and Cooperation under the Ministry of Agriculture, Government of India (Patil et al. 2021).DBT is the principal supporter of the research and development of PTC in India in various universities, laboratories, and research institutes. For promoting industrial PTC research, micropropagation technology parks (MTPs) are set up (Singh and Shetty 2011), of which two of the parks are in National Chemical Laboratory, Pune, Maharashtra and Tata Energy Research Institute, New Delhi. (Patil *et al*. 2021). NHB, Ministry of Agriculture, Government of India, was established in 1984 for promoting the healthy development of the horticulture industry. A back-ended capital subsidy below 20% of the total cost and up to Rs. 25 lakhs of cost are funded by NHB and also extended for the construction of greenhouses (Singh and Shetty 2011). Apart from this, financial support is extended by different banks run by the Government of India. Under the Indian Companies Act 1956, the Indian government established Biotech Consortium India Limited, supported by the Department of Biotechnology, Government of India, for the development of technology, project consultancy, syndication of funds, dissemination of information, and training of manpower (NCS-STP 2020).

The states of India, which include Andhra Pradesh, Maharashtra, Gujarat and Karnataka, facilitate financial assistance under the agro-industrial scheme, for establishing PTC units. All these agencies have helped in the establishment, production, and marketing of tissue culture products in the micropropagation industries, which can become a landmark global market in the 21st century (Patil *et al*. 2021).

Harnessing Plant Tissue Culture for Socio-Economic Development

With respect to the scenario in India, DBT (Department of Biotechnology, Government of India) created National Certification System for Tissue Culture Raised Plants in 2006 under the 1966 Seeds Act to promote Plant Tissue culture Technologies. Plants that are commercially grown in India are Anthurium, Apple, Bamboo, Banana, Date palm, Gerbera, Lilium, Orchids, pineapple, potato, pomegranate, strawberry, sugarcane, and teak (Gulzar et al. 2020). Reduced cost and benefits of obtaining economically important healthy agricultural or horticultural or floricultural plants (Pant and Mehta

2016). It provides greater opportunities and greater comparative advantages for developing countries. (Aladele *et al*. 2012)

It is estimated a global market of more than US $ 15 billion for tissue-cultured plants and products. Initially, in India, plant tissue culture units had the main function of exporting exotic and ornamental plantlets to Europe. Currently, the function has shifted from exporting plantlets to producing various plantation crops, fruits, and ornamentals for domestic markets (Reddy 2007). Advances in the in- vitro techniques like suspension cultures, and hairy root cultures are currently used for large-scale production of economically important plant metabolites (Espinosa *et al*. 2018)

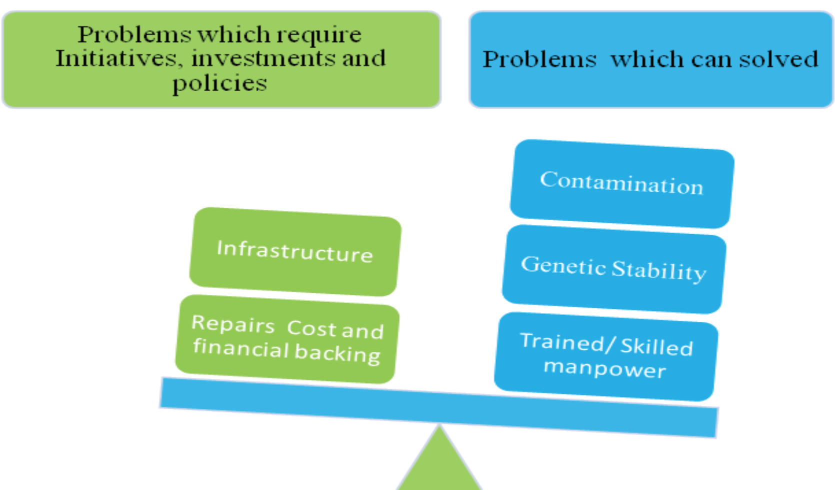
Indian plant tissue culture industry has been successful and has been revolutionised due to advances and use of technology for in situ conservation, germplasm conservation and exchange and their protocol refinement. A huge surge in the requirement of food products as well as medicines was created due to Globalization, this led to the establishment of well-equipped PTC laboratories in India for extensive production of plants and plant products which are needed by the pharmaceutical industries. Plant tissue culture industries in India produce plants and plant products which are in demand in both domestic and international markets and help in earning the essential foreign exchange. Though the Indian PTC industry has had a lag of about 10 years from its western counterparts, the Indian PTC industry can flourish due to the cost-effective labor and various initiatives from the government initial results of which can be seen as India PTC industry making its presence at a global scenario (Patil *et al*. 2021).

Certain socio-economic impacts of tissue cultured plants (Banana crop in Kenya, Africa) are the revival of the crop, reliable and regular source of income for rural families, solving problems like food insecurity and malnutrition, economic security for the farmer's family, empowerment of women as many households domains belong to women and women contributed to a substantial amount of labor, higher income contributed to the improvement of other quality of life indicators like better education, improved housing, At the community level, social impact was the formation of cohesive farmers group which tried to address the agronomic issues, developmental activities at the community level, formation of community development funds (Njuguna *et al*. 2010).

Challenges in Plant Tissue Culture

With the advancement in Plant tissue culture technologies, its application was used in vitro method of plant conservation which faced limitations in traditional approaches. Some challenges in the use of Plant tissue culture for conservation include scientific or technical aspects, as each species of plant may respond differently at any stage of the in vitro culture. Aseptic conditions, acclimatisation, maintenance of genetic diversity/ genetic fidelity, and monitoring of plants also elevate another aspect or challenge with respect to Cost. Plant tissue culture requires skilled manpower and appropriate infrastructure. Also, when it comes to plant conservation, cost differs concerning endangered species propagation and commercial propagation, which might not be always economically feasible (Pence 2010). Challenges associated when using Plant tissue culture for medicinal and commercially important plants start with the selection of explants. Browning of explants is a sign of a reduction in cell division and regeneration plants. This influences the output of tissue- cultured plants. One of the approaches for controlling plant tissue culture contaminants is using molecular identification techniques for detecting, identifying and characterising them (Herman 2017) (Figure 2). Another major challenge of in vitro plants is their hardening and acclimatisation, as their propagation depends on field survival. Unsuccessful hardening and acclimatisation influence the overall survival rate of the tissue-cultured plants (Singh 2018). Through tissue culture economical and natural secondary metabolites can be produced, especially when the original plant source material provides a low yield and is slow-growing. This moreover brings the challenge of genetic stability of in-vitro generated plants (Figure 2). Somaclonal variation, particularly in producing industrial important phytochemicals, leads to economic consequences. This challenge is a hindrance in the production of bioactive metabolites utilising plant tissue culture techniques. Lack of cell differentiation and rare uniformity in physiological characteristics in cell cultures causes the low yield of secondary metabolites, another challenge associated with in vitro cultures. Prolonged usage of cell lines producing selected bioactive metabolites leads to loss of their ability to produce desired metabolites, another obstacle in the usage of in-vitro cultures (Espinosa-leal *et al*. 2018) For mass propagation of commercial plants using plant tissue culture techniques brings the need of bioreactors. Bioreactors bring their own challenges with respect to special care and handling, contamination which, if not taken care of, can cause heavy economic losses. Quality Control in the production of tissue-cultured plant is another major challenge as it is necessary to secure consumer confidence (Hussain *et al*. 2012) Some common challenges associated with Plant Tissue Culture Research and Development in developing countries involves an inadequate number of trained and experienced tissue culture personnel, limited available engineers or qualified technicians for maintenance and repair of tissue culture equipment and facility, Problems associated with infrastructures especially unreliable utility services such as electrical power and water supply, Restricted financial support by the federal or regional government, Poor incentives and irregular policy framework, Poor linkages, weak collaborative partnership among different stakeholders and limited awareness (Abebaw *et al*, 2021). Axenic Plant Tissue culture is a challenge faced by most tissue culturists, as sterilising the explant often has a harmful effect on the explant. Thus, the production of vigorous tissue cultured plants takes

Figure 2: Challenges in Plant Tissue Culture



Source: Authors' compilation.

time for development (Garcia- Gonzales *et al*. 2010) Physiological and developmental problems such as shoot tip necrosis, fasciation, epigenetic changes and developmental problems due to the use of Plant Growth Regulators (Bairu and Kane 2011) Hyperhydricity and hooked leaves are physiological problems associated with the proportion of inorganic nutrients found in various plant tissue culture medium (Sivanesan and Park 2014).

Plant Tissue Culture market

The global plant tissue culture market size was valued at $382.305 million in 2020 and is estimated to reach $895.006 million by 2030, growing at a CAGR of 8.5 per cent from 2021 to 2030. The plant tissue culture technique has been useful for more than 30 years. The COVID-19 has affected many agrosystems and livelihoods across the globe, with continued effects expected in the coming years. However, after the lockdown opened, the crisis from COVID-19 is expected to have a significant positive impact on plant tissue culture market growth across the globe. In addition, the rise in developing prospects in developed countries will further provide potential chances for the growth of the plant tissue culture market in the coming years. The plant tissue culture market is divided on the basis of types of crops, stages, plant types, types of media, etc. By crop type, the market is categorised into plants like banana, floriculture, wood producing, fruits and vegetables, ornamental, aquatic etc. By stage, the market is divided into the preparation of explant and establishment, multiplication and hardening. By plant type, it is separated as annual, biennial, and perennial plants. By types of medium, the market is categorised into MS media, LS media etc. The rapid developments in plant tissue culture techniques and the great demand for disease-free and hybrid plants will expand its market and also have significant growth opportunities in the future (Srivas and Sumant 2021). In 2021, the micropropagation technique used by farmers to cultivate crops dominated the market and was expected to continue over the forecast period. Micropropagation has become more prevalent in the agriculture sector, and it is expected to avoid food scarcity problems in developing economies owing to the rapidly growing population in a limited amount of land, which is driving the market growth. Micropropagation market produce and exports crops such as ornamental flowers, bananas, tomatoes, corn and others. Advanced technology, such as greenhouse horticulture and the high demand for disease-free and hybrid plants are exponentially increasing in the market. The production of high-quality planting materials is rising with the increased tissue- cultured industrial crops, and food crops in the forecast period. Farmers are getting huge profits from new crops on unutilised lands. As a result, farmers' incomes are expanded, increasing sustainability and the need to replicate industrial crops and food crops through micropropagation technology.

Conclusion

Therefore, plant tissue culture is widely accepted by many countries and research is going on to reach a disease-free plant society. All nations are continuously working hard to develop various methods to protect plants from infectious microbes. In the olden days, there was no such development of plant tissue culture. However, these days, the importance of plant tissue culture is elevated. The upcoming opportunities could be dealing with the plant genetic resources conservation, and genetic transformation so that we are able to get quality food that would deal with global hunger needs. Various methods are in trend and work efficiently. There are plenty of opportunities there for plant tissue culture, mainly in food, cosmetics as well as pharmaceuticals. Plant tissue is yet to reach the pinnacle of research and it has to be globalised.

References

Abebaw, Y. M., D.C. Tobiaw, , B.A. Abate, B, B.K. Eshete, , S.K. Seymour, S. K, & K. Tesfaye. 2021."Plant Tissue Culture Research and Development in Ethiopia: A Case Study on Current Status, Opportunities, and Challenges". *Advances in Agriculture*, https://doi.org/10.1155/2021/9979549

Aladele, S. E., A.U. Okere, , E. Jamaldinne, , P.T. Lyam,, O. Fajimi, , A. Adegeye, & C.M. Zayas. 2012. "The Science of Plant Tissue Culture as a Catalyst for Agricultural and Industrial Development in an Emerging Economy". *Recent Advances in Plant in vitro Culture*. InTech. https://doi.org/10.5772/51843

Bairu, M. W. andM.E. Kane. 2011. "Physiological and developmental problems encountered by in vitro cultured plants". *Plant Growth Regulation*,63(2): pp. 101–103. https://doi.org/10.1007/s10725-011-9565-2

Bhatia, S., andK. Sharma. 2015. "Plant Tissue Culture-Based Industries". *Modern Applications of Plant Biotechnology in Pharmaceutical Sciences*, pp. 405–417. https://doi.org/10.1016/B978-0-12-802221-4.00014-5

Dudhare M.S., and N. Jayewar. 2021. “Tissue cubltured plants and domestic market in India”. *South Asian Journal of Agricultural Sciences*. 1(2): 98-101.

Espinosa-Leal, C. A., C.A. Puente-Garza, andS. García-Lara. 2018. “In vitro plant tissue culture: means for production of biological active compounds”. *Planta*, 248 (1). Springer Verlag. https://doi.org/10.1007/s00425-018-2910-1

García-Gonzáles, R., K. Quiroz, B. Carrasco, andP. Caligari. 2010. “Plant tissue culture: Current status, opportunities and challenges”. *Ciencia e Investigación Agraria*, 37(3) www.rcia.uc.clliteraturereview

Govil S, Gupta SC. 1997. “Commercialization of plant tissue culture in India”. *Plant Cell Tissue and Organ Culture*; 51:65-73.

Gulzar, B., A. Mujib, M. Qadir Malik, J. Mamgain, R. Syeedand N. Zafar 2020. “Plant tissue culture: Agriculture and industrial applications.” Transgenic Technology Based Value Addition in Plant Biotechnology, pp. 25–49. https://doi.org/10.1016/B978-0-12-818632-9.00002-2

Herman, E. B. 2017. “Plant tissue culture contamination: Challenges and opportunities”. Acta Horticulturae, 1155: pp. 231–237. https://doi.org/10.17660/ActaHortic.2017.1155.33

Hussain, A., I Ahmed, H. Nazir, andI. Ullah .2012. “Plant Tissue Culture: Current Status and Opportunities”. Recent Advances in Plant in vitro Culture. InTech. https://doi.org/10.5772/50568

Kumar, V.S., Navaratnam V. 2013. “Neem (*Azadirachta indica*): Prehistory to contemporary medicinal uses to humankind”. *Asian Pacific Journal of Tropical Biomedicine*, 7:505-14.

Mascarenhas A.F. 1999. “Scope of the tissue culture industry in India. In: Plant Biotechnology in Vitro Biology in the 21st Century”. Dordrecht: Springer; pp.713-20.

NCS-STP, Recognition of Tissue Culture Production Facilities. Available from: https://www.dbtncstcp.nic.in/-Recognition-of-TissueCulture-Production-Facilities. [Last accessed on 2020 Apr 12

NCS-STP, Plant Tissue Culture-Techno-commercial Feasibility. Available from: https://www.dbtncstcp.nic.in/Portals/0/Images/ Plant-Tissue-Culture.-Techno-Commercial-Feasibility.pdf. [Last accessed on 2020 Apr 12]

Njuguna, M., F. Wambugu, S. Acharya, M. Mackey and A. Mackey. 2010. “Socio-Economic Impact of Tissue Culture Banana (Musa spp.) in Kenya through the Whole Value Chain Approach”. *Acta Horticulturae,* 879: pp. 77-86

Pant, M., and R. Mehta. 2016. *The Economics of Plant Tissue Culture: An Indian Perspective*, 9

Patil, M.S., V.B. Chandana Kumari, K. Sumana, S. Sujay, M. Tejaswini, P.V. Shriahatti,R. Ramu. 2021. “Sustainable development of plant tissue culture industry: The Indian scenario”. *Journal of Applied Biology and Biotechnology*, 9 (2): pp. 18-27

Pence, V. C. .2010. The possibilities and challenges of in vitro methods for plant conservation, 65. http://about.jstor.org/terms

Prakash J. 2004. “Micropropagation industry in India: Biology and business”. *International Symposium on in vitro Culture and Horticultural Breeding*; 725:293-300.

Reddy, C. R. 2007. “Plant tissue culture industry and women’s participation: “Nimble fingers” or docile labor?”.Gender, Technology and Development, 11(2): pp. 179–198. https://doi.org/10.1177/097185240701100203

Shukla S S 2008. "Plant Tissue culture: Techno Commercial Feasibility"'. Biotech Consortium India Limited, Department of Biotechnology Ministry of Science and Technology, Govt. of India

Shukla S., Thomas S., and R.Bhutani. 2021 "Plant tissue culture,plant based products and prospects of Commercialization: A drive from nature towards nature".*International Journal of Biotechnology and Recent Advances,* 3(1):68-73.

Sidhu Y. 2011. "In vitro micropropagation of medicinal plants by tissue culture". *Plymouth Stud Sci*; 4:432-49.

Singh, C. R. 2018. "Review on Problems and its Remedy in Plant Tissue Culture". Asian Journal of Biological Sciences, 11(4): pp. 165–172. https://doi.org/10.3923/ajbs.2018.165.172

Singh G., and Shetty S. 2011. "Impact of tissue culture on agriculture in India". Biotechnology, Bioinformatics Bioengineering; 1:pp.147-58.

Sivanesan, I., and S. W. Park. 2014. "The role of silicon in plant tissue culture". Frontiers in Plant Science, 5. Frontiers Research Foundation. https://doi.org/10.3389/fpls.2014.00571

Srivas, A., and O. Sumant. 2021. "Plant Tissue culture market statistics Industry Forecast-2030". www.alliedmarketresearch.com/plant-tissue-culture-market-A14265.

Street, H. E. 1977. "Introduction" in H. E. Street (ed.). *Plant tissue and cell culture* pp. 1–10. Oxford, UK: Blackwell.

Wagh, R., and A P. Dongre .2016. "Agricultural Sector: Status, Challenges and it's Role in Indian Economy". Journal of Commerce and Management Thought, 7(2): pp. 209. https://doi.org/10.5958/0976-478x.2016.00014.8

Yadav N. 2016. "Conservation of some endangered and economically important medicinal plants of India-a review". *Journal of International Science and Technology*; 2: pp.59-62.

Yadav S.W., Ahmad A.Q., Rastogi J.Y., Lal M.A. 2012. "Tissue culture strategies in sugarcane (Saccharum officinarum L.)". *International Journal of Pharmacy and Biological Sciences*; 3:pp.1-16.

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Perspective

De-extinction and Synthetic Biology–Legal, Ethical and Environmental Challenges

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Sachin Sathyarajan**

The Jurassic Park film franchise has been around for 20 years or more. The Michael Crichton book of the same name was inspired by the discovery of amber fossilized DNA. The possibility of cloning prehistoric animals from their DNA started being explored in the mid-90s. As we watch the fifth film in the franchise, which got released in 2022, science-fiction is colliding with science in real- time. The hope, as well as the hype of resurrecting extinct animals and what the technology can create, was portrayed well in the movies. However, the movies also evoked fear of what is possible with the technology going to the wrong hands or the resurrected dinosaurs escaping captivity.

We all grew up with the story of "Frankeinstein" where Mary Shelley explored the possibility of technology enabling "human-made" life. Shelley created the fictional world of a maverick scientist who transforms a corpse into a gruesome looking creature. One of the first science fiction works, the novel published in 1818 became a major pop culture phenomenon inspiring several movies, TV series and video games. Shelly's "creature" soon became a metaphor for artificial life.

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De-extinction- A reality

De-extinction refers to the process of resurrecting extinct species mainly due to the advances in synthetic biology and genetics (Rogers, Britannica). Technologically, now humans are at a point where we can actually play god owing to our ability to manipulate life via biotechnology (Fletcher 2020). The idea of de-extinction grabbed the spotlight at the 2013 TEDx De-extinction conference. Steward Brand, who promoted this idea, famously quotes, "We are as gods and might as well get good at it," thus calling out for a new form of anthropocentric environmentalism way back in 1970 when he created the Whole Earth Catalogue (Kirk 2018). In his talk in 2013, he spoke about "Revive and Restore" to preserve genetic and biological diversity and to fix some of the damage done to our ecosystems (Brand 2013).

De-extinction has become possible thanks to some breakthrough advancements in the last two decades. Synthetic biology has enabled humans to design, select and influence the "natural" world and not just be a set of pawns in nature's game of chance. There is now a possibility of reversing the extinction of species which was hitherto not possible.

In this article, we look at some of the ongoing efforts in de-extinction globally. We also attempt to breakdown the underlying technology which is making de-extinction possible. We will be simultaneously exploring the obvious ethical, legal and environmental dilemmas. How would conservation efforts benefit from such projects? Are there risks involved in de-extinction projects? Is India's legislative and policy framework prepared for the same? Should time and energy be spent on species which disappeared ages ago, or whether the focus should be on species that are threatened at present?

There have been major episodes of mass extinctions on earth. "The sixth extinction", which is caused by human beings, is currently underway. Do humans have a moral obligation to repair some of the damage? Globally, wildlife is being wiped out by human activities contributing to habitat degradation, climate change, pollution and invasive species. According to the IUCN, 28000 species are under threat of extinction (Hanson 2019). Anthropocene extinction levels are 100-1000 times larger than any previous mass extinction (Lawton & May 1995).

Biotechnology based applications in Conservation

As a response to the extinction crisis, various approaches have been taken by conservationists. The two most prominent ones are de-extinction and genetic rescue, both of which use biotechnological applications. The genetic rescue, which helps maximize genetic diversity and minimize in-breeding, is more established in mainstream conservation, whereas de-extinction is still taking root (Fletcher, 2020). One of the useful applications for synthetic biology towards genetic rescue is for the control of invasive species, as could be seen with a gene drive to control the grey squirrel population in the United Kingdom through the dispersal of a female infertility gene within a targeted population (Faber & McFarlane 2021). Eradicating wildlife diseases is another important application especially given the context of the recent pandemic. Habitat restoration is also a useful application wherein, for instance, modified microorganisms capable of consuming hydrocarbons were deployed during the 2010 Gulf of Mexico oil spill (Redford & Adams 2014). Further, there are studies going on in Australia's Great Barrier Reef to reverse the effects of heat waves and ocean acidification on corals through cross- breeding (Cornwall 2019).

Examples from India

Closer to home, scientists, especially geneticists from India, are engaged in multiple projects aimed more towards genetic rescue than de-extinction. The Endangered Species Recovery Plan envisaged by the Wildlife Institute of India (WII) focuses on endangered species, namely the Great Indian bustard, Gangetic dolphin, dugong and Sangai deer (WII 2016). The Plan intends to use genetic tools to get more insight into mitochondrial and nuclear genetic variations, individual identification, population estimation, demographic patterns, population connectivity, genetic structure, migration pattern and rate, among others. Another initiative of WII, the Wildlife Forensic and Conservation Genetics Cell, uses genetic tools to assist with wildlife crimes by helping with the identification of species from a variety of wildlife parts and products and maintaining a repository of wildlife reference samples (WII 2020).

Participation of 24 Indian institutes in the Earth Bio Genome Project, including the Jawaharlal Nehru Tropical Botanic Garden and Research

Institute (JNTBGRI) will contribute towards sequencing of the genetic codes of all of earth's biodiversity over a period of 10 years. This knowledge will have applications in various sectors ranging from conservation to ecosystem restoration to public health (Nandakumar 2020). A few more illustrative examples from India are as follows:

- Centre for Cellular & Molecular Biology (CCMB) and Council of Scientific and Industrial Research (CSIR): Genome sequencing and identification of genome variants in Bengal tiger (Panthera tigris tigris) to understand how gene variants play a role in adaptation to the environment and disease susceptibility (Mallikarjun 2018).
- National Center for Biological Sciences and WII: Genome sequencing tigers from Ranthambore to identify signatures of in-breeding; from Sunderbans to know more about their uniqueness and how they are different from mainland tigers (Dixit 2018).
- CCMB: Development of a DNA barcoding method called Universal Primer Tech to accurately and quickly identify species from tiny biological samples. This method can also be applied in monitoring and studying the distribution and migration of animals, including species' molecular signatures (Nandakumar 2018).

International De-extinction projects

Coming to de-extinction projects, it is pertinent that we discuss a few of the important ones. Dinosaurs cannot be brought back to life, since the DNA is way too old (Griffin & O'Connor 2018). One of the most ambitious de-extinction projects was kickstarted by George Church, who is trying to bring back the mighty woolly mammoth. The woolly mammoth was a "keystone" species that disappeared in the Pleistocene era, 4000 years ago (Kalshian 2017). A "keystone" species is the most vital member of an ecosystem without which the ecosystem may even cease to exist altogether. The woolly mammoth kept the permafrost layer stable, and it is shown as a possible defense against climate change (Griswold-Tergis 2014).

One way to bring back the woolly mammoth was through the cloning process similar to the much controversial example of somatic cell nuclear transfer in the case of "Dolly the sheep". However, an animal that became extinct thousands of years ago might not survive in the present- day climatic conditions. George Church started working backwards, with a fully intact healthy cell of the closely related Asiatic elephant and included the genetic fragments from the preserved specimens (Fletcher 2020).

Other important examples of de-extinction projects include – Tasmanian tiger native to Australia (Aneesa 2022) and the passenger pigeon native to North America (Fan 2018). Both these species were hunted down to extinction by colonial settlements. The Christmas Island rat (Gibbs 2022) and the gastric breeding frog (Groves 2021) are a few smaller species on which de-extinction efforts are underway.

Law and policy support for De-extinction

The underlying technology behind de-extinction projects is that of synthetic biology. The international governance of synthetic biology is quite a complex task, considering the wide range of applications and the cross-cutting nature of synthetic biology. It is difficult to draw a clear line of action between various international initiatives applicable to the governance around de-extinction projects. There is no single international mechanism to regulate de-extinction projects as a whole.

Globally, countries have agreed upon safeguards within several conventions when it comes to genetic engineering and synthetic biology. These include the Agreement on Applications of Sanitary and Phytosanitary Measures (SPS), the Agreement on Technical Barriers to Trade (TBT), Trade- Related Aspects of Intellectual Property Rights (TRIPS), among others. However, the Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species (CITES) and World Health Organization (WHO) initiatives are most relevant in this context.

Convention on Biological Diversity

Principles expounded within CBD, such as transboundary harm and environmental impact assessment are relevant for managing risks emerging from efforts to bring back endangered species (CBD 1993). The resulting specimens of the de-extinction projects will fall under the bracket of Living Modified Organisms (LMOs) as governed by the CBD and its Cartagena Protocol for Biosafety (CPB). CPB is especially of note when it comes to the safe transfer, handling and use of Genetically Modified Organisms (GMOs)/ LMOs that may affect the conservation and sustainable use of resources. Since India ratified the CPB in 2003, it is required to manage risks associated with LMOs; establish domestic, regulatory and administrative measures; and provide information on LMOs transferred to any party. The CBD- CPB framework also covers unintentional and transboundary movements of LMOs. Further, in CBD's 2010 decision, parties were urged to apply a precautionary approach before the field release of synthetic life, cell or genome, due to the risks associated (CBD 2010). At the time of writing this article, several of these aspects are being discussed and will be considered for the Post-2020 Global Biodiversity Framework, which will be finalized during CBD's Fifteenth Conference of Parties in December 2022.

Convention on International Trade in Endangered Species

CITES is crucial in providing a framework to ensure that trade in specimens of wild flora and fauna does not threaten their survival. In 2016, the CITES began focusing on how trade in wildlife products created from synthetic or cultured DNA is impacting the conservation of endangered or threatened species (CITES 2017). Parties were requested to provide information on such trade which fed into the "Study on Wildlife Products Produced from Synthetic or Cultured DNA" (CITES 2018). Based on its findings, the Standing Committee of CITES recommended that given the almost identical nature of bio-engineered and natural specimens, the regulations should cover bio-engineered specimens as well. In 2018, it was noted with concern that even rhino horns were being produced through biotechnology which could lead to further demand and exploitation of animals in the wild (CITES 2018). Traceability concerns in the bioengineered specimens, as to whether these are from the wild or produced in a lab, should be considered as well. The Animal and Plants Committees of CITES are currently monitoring any emerging uses of biotechnology related to CITES related species (CITES Decision).

World Health Organization

The WHO is a specialized agency of the UN which has a mandate for international public health. WHO has been pushing several initiatives aimed at managing risks emerging from life sciences research. One such example is the Global Guidance Framework for the Responsible Use of Life Sciences meant to address potential risks caused by accidents and misuse (WHO 2010). Further, WHO with the United Nations Office for Disarmament Affairs (UNODA) is part of a Bio-risk Working Group seeking to strengthen the response of the UN system when it comes to natural, accidental or biological events (UNODA 2021). In 2020, WHO clarified that all new potentially beneficial technologies, such as synthetic biology, should be governed such that health, environmental and ecological impacts are understood beforehand. This clarification was in specific reference to the use of genetically modified mosquitoes for the control of vector-borne diseases wherein physiological changes have been introduced into mosquito vectors to either bring down their population or to reduce their susceptibility to infection and their ability to transmit disease-causing pathogens (WHO 2020).

Indian legal framework

In light of these international developments, it will be interesting to note that India already had in place the Rules for Manufacture, Use, Import, Export and Storage of Hazardous Micro-organisms, Genetically Engineered Organisms or Cells, 1989 (GEO Rules 1989) under Environment Protection Act, 1986. The definition of genetic engineering, which includes modification, deletion or removal of parts of heritable material, implies that all new technologies will be subject to regulation under these Rules (Ahuja 2018). According to these Rules, deliberate or unintentional release of GMOs is disallowed and any person using GMOs for scale up or pilot projects needs to obtain permission from authorities prescribed in the Rules (Ahuja 2018). The rules have been administered jointly by the Ministry of Environment, Forest and Climate Change (MoEFCC) and the Department of Biotechnology under the Ministry of Science. The authorities competent under the rules are:

- Institutional Biosafety Committees
- Review Committee on Genetic Manipulation
- Genetic Engineering Appraisal Committee
- State Biotechnology Coordination Committees
- District Level Committees

Thus there is a three- tier mechanism to manage research, development and large-scale commercialization of GMOs)/ LMOs, along with monitoring of projects post approval to see that there are no violations. However, despite such a mechanism, it has been observed that these rules have not been implemented properly (Sharma 2020). Further, the multiplicity of bodies working on bio-safety, in addition to state- specific interests, makes coordination very difficult (Sharma 2020). Also, while the regulations cover GMOs, DNA and RNA sequences with virulent genes ordered for commercial purposes are not covered (Sharma 2020). The recent Guidelines for Safety Assessment of Genome Edited Plants, 2022 have exempted new genome edited plants from obtaining permissions under the Rules, and this has caused concerns to environmentalists and farmers' organizations due to the risk of unintended consequences of such plants (Koshy 2022).

Safeguards within the Biological Diversity Act, 2002 is limited to research entities taking permissions from the National Biodiversity Authority whenever there is a requirement of transferring research relating to biological resource occurring in, or obtained from India to any foreign entity (BDA 2002). Biological resources include "plants, animals and micro-organisms or parts thereof, their genetic material and by-products….. but does not include human genetic material". Further, research in this context can include "study or systematic investigation that involves any technological application that uses biological systems, living organisms and/or their derivatives" (BDA 2002). The Protection of Plant Variety and Farmers Rights Act (PPVFRA), 2001 provides safeguards for commercial plant breeders and farmers who have developed new plant varieties, from being exploited. At present, both the BDA and PPVFRA have no provisions addressing risks from unintended consequences of research on biological resources. If appropriate amendments are made to these laws, then read along with the 1989 Rules, these have the potential to be a bulwark against risks from GMOs.

The Biotechnology Regulatory Authority of India (BRAI) Bill from 2013 sounded promising in this regard as an independent authority was envisaged under this law to regulate all kinds of modern biotechnology products. However, the Bill expired and was never reintroduced (Sathyarajan & Pisupati 2021).

Conclusion

The biggest dilemma with respect to de-extinction projects is whether bringing back a species that went extinct a long time ago makes sense when countries are struggling to maintain wild populations of existing species (Mishra 2022). On a positive note, de-extinction projects has opened up great possibilities in an era of unprecedented biodiversity loss. It brings hope in restoring genetic diversity in threatened species too. We can bring back species which can come back to a favorable environment. There is no question about the viability of the technology as long as the genome of the extinct species can be obtained from fossil remains and other forms of DNA. Keystone species are particularly important to help largescale ecosystem revival and conservation efforts.

Synthetic biology applications bring great value to conservation, especially with regard to wild animals' population estimation, whether it is used to examine signs of in-breeding, dispersal rates, response to the environment, disease susceptibility, etc. For instance, when there is more dispersal amongst a species, there are less chances of in-breeding and more chances for gene variation and plasticity, thereby making the species adapt better to their environment. Another useful application of synthetic biology is to check for elusive species, which is not possible through visual means such as camera trapping. Genome sequencing offers non-invasive possibilities in such cases (Mishra 2022).

Having looked at the positives, it is also important to examine the challenges. For developing countries like India, where humans and wildlife compete for space, the money invested into such science projects, might be put to better use in projects on livelihood and participatory conservation. The costs incurred in creating and sustaining the life of the woolly mammoth could be used to save conservation efforts for several critically endangered species. For instance, in the case of the Great Indian Bustard, an independent conservation scientist opined that captive breeding might actually help. The same expert feels that these funds should go into more vital issues of conservation, including climate change mitigation efforts and targeted geo-engineering (Mishra 2022). On the law and policy front, there is a long way to go as well since the current framework is not equipped to address issues of ethicality, ownership and risks especially when it comes to de-extinction projects. Additionally, in the interest of bringing back extinct species, are we de-incentivizing the conservation of existing species (Fletcher 2020)?

On a global level, what will be the impact of these technologies on the course of natural history? It is certainly an opportunity for humans to rectify past harms inflicted on other species. Several species have gone extinct due to habitat loss and many of those habitats have been altered dramatically. In nature, it is surely survival of the fittest, however, this adage fitted when the environmental cycle was normal. Now, this cycle has become aggravated by human interventions and therefore threatened species require extra hand holding (Mishra 2022). Whatever side of the debate one stands on, decision-making must be absent of bias and based on evidence and transparency.

References

Ahuja, A. 2018."Regulation of emerging gene technologies in India". *BMC Proc* 12 (Suppl 8), 14 (2018). https://bmcproc.biomedcentral.com/articles/10.1186/s12919-018-0106-0

Aneesa, P.A. 2022. "Explained: How scientists are planning to 'resurrect' the extinct Tasmanian Tiger". The Indian Express. https://indianexpress.com/article/explained/explained-sci-tech/tasmanian-tiger-de-extinction-project-explained-8098355/

Biological Diversity Act. 2002. http://www.nbaindia.org /act/act_english.htm

Brand, S. 2013. "The dawn of de-extinction. Are you ready?". TED. https://www.youtube.com/watch?v=XKc9MJDeqj0

CBD. 1993. "Convention on Biological Diversity"

CBD. 2010. "New and Emerging Issues". COP Decision.Convention on Biological Diversity. http://cbd.int/kb/record/decision/12279?Event=COP-10

CITES. 2017. Sixty-ninth meeting of the Standing Committee Geneva (Switzerland). 27 November – 1 December 2017. Convention on International Trade in Endangered Species of Wild Fauna and Flora. https://cites.org/sites/default/files/eng/com/sc/69/E-SC69-35.pdf

CITES. 2018. "Study On Wildlife Products Produced From Synthetic Or Cultured DNA". Convention on International Trade in Endangered Species of Wild Fauna and Flora. Annex 6 to Document SC70 33. https://cites.org/sites/default/files/eng/com/sc/70/E-SC70-33-A6.pdf

CITES. 2018. Seventieth meeting of the Standing Committee Rosa Khutor, Sochi (Russian Federation). SC70SR.https://cites.org/sites/default/files/eng/com/sc/70/exsum/E-SC70-SR.pdf

CITES. Decisions 18.147 - 18.150 Specimens produced through biotechnology.https://cites.org/eng/taxonomy/term/42062

Cornwall, W. 2019. "Researchers embrace a radical idea: engineering coral to cope with climate change". Science. https://www.science.org/content/article/researchers-embrace-radical-idea-engineering-coral-cope-climate-change.

Dixit, K. 2018."Genome sequencing to help prevent inbreeding among tigers". The Economic Times. https://economictimes.indiatimes.com/news/science/genome-sequencing-to-help-prevent-inbreeding-among-tigers/articleshow/62995759.cms

Faber, N.R. and McFarlane, G.R. et. al. 2021. "Novel combination of CRISPR-based gene drives eliminates resistance and localises spread". *Sci Rep* 11, 3719. https://www.nature.com/articles/s41598-021-83239-4

Fan, S. 2018. *De-Extinction Is Now a Thing—Starting With Passenger Pigeons*. Singularity Hub. https://singularityhub.com/2018/10/23/de-extinction-is-now-a-thing-starting-with-passenger-pigeons/

Fletcher, A.L. 2020. "De-Extinction and the Genomics Revolution-Life on Demand". Palgrave Macmillan

GEO Rules. 1989. Rules for Manufacture, Use, Import, Export and Storage of Hazardous Micro-organisms, Genetically Engineered Organisms or Cells, 1989

Gibbs, A. 2022. "An extinct rat shows CRISPR's limits for resurrecting species". ScienceNews. https://www.sciencenews.org/article/crispr-de-extinct-christmas-rat-species-gene-editing

Griffin, D. and O'Connor, R. 2018. "Jurassic World: Can We Really Resurrect a Dinosaur?". SCIENTIFIC AMERICAN. https://www.scientificamerican.com/article/jurassic-world-can-we-really-resurrect-a-dinosaur/

Griswold-Tergis, L. 2014."Can woolly mammoths save the world?". Tedx Talks.https://www.youtube.com/watch?v=wO0wyICAAqg

Groves, M. 2021. "A last-ditch attempt to find the Eungella gastric-brooding frog in the wild fails — but could they be cloned from extinction?". ABC Rural. https://www.abc.net.au/news/rural/2021-11-15/eungella-gastric-brooding-frog-extinct-cloning-/100595258

Hanson, M. 2019. "Has Jurassic Park fostered misunderstanding about extinction?". Big Think. https://bigthink.com/hard-science/could-jurassic-park-happen/

Kalshian, R. 2017. "What if the Lazarus returns". *Down to Earth*. https://www.downtoearth.org.in/news/science-technology/what-if-the-lazarus-returns-57784

Kirk, A. 2018. "50 Years Ago, the Whole Earth Catalog Launched and Reinvented the Environmental Movement". Smithsonian Magazine. https://www.smithsonianmag.com/innovation/50-years-ago-whole-earth-catalog-launched-reinvented-environmental-movement-180969682/

Koshy, J.P.2022. "Norms eased for genetically modified crop research". The Hindu. https://www.thehindu.com/news/national/biotechnology-department-eases-norms-for-research-on-gene-editing-plants/article65439953.ece

Kuriakose, S. 2022. Interview with Zeeshan Mishra, an independent researcher and conservation scientist.

Lawton, J. H. and May, R. M. 1995. "Extinction Rates". *Journal of Evolutionary Biology*. 9 (1): 124–126. doi:10.1046/j.1420-9101.1996.t01-1-9010124.x.

Mallikarjun, Y. 2018. "Royal Bengal tiger genome sequenced". The Hindu. https://www.thehindu.com/sci-tech/science/royal-bengal-tiger-genome-sequenced/article23937958.ece

Nandakumar, T. 2018. "New forensic tool to crack wildlife crime". The Hindu. https://www.thehindu.com/news/national/kerala/new-forensic-tool-to-crack-wildlife-crime/article24547838.ece

Nandakumar, T. 2020. "JNTBGRI to play key role in sequencing of Indian species". The Hindu. https://www.thehindu.com/sci-tech/science/jntbgri-to-play-key-role-in-sequencing-of-indian-species/article31409526.ece

Redford, K.H. and Adams, W. et. al. 2014."Synthetic biology and the conservation of biodiversity".Oryx, Volume 48, Issue 3, July 2014, pp. 330 – 336. https://www.cambridge.org/core/journals/oryx/article/synthetic-biology-and-the-conservation-of-bi odiversity/3FADF2D127D8F61389946FD3BBC3CA4C

Rogers, K. Britannica. https://www.britannica.com/science/de-extinction

Sathyarajan, S. and Pisupati, B. 2021."Regulating Risks in Synthetic Biology". *Asian Biotechnology and Development Review*. Vol. 23, No.3, pp 101-112. available at https:/ris.org.in/sites/default/files/2022-03/ABDR%20Novermber%202021_0.pdf

Sharma, S. 2020."Biological Risks in India: Perspectives and Analysis". Carnegie Endowment for International Peace. https://carnegieendowment.org/2020/12/09/biological-risks-in-india-perspectives-and-analysis-pub-83399.

UNODA. 2021. "The UN Office for Disarmament Affairs continues to actively pursue its mission – a 2021 update on the work of disarmament during the pandemic". UN Office for Disarmament Affairs. https://www.un.org/disarmament/unoda-continues-its-mission-on-covid-19/

WHO. [2010]. "Responsible life sciences research for global health security: a guidance document". World Health Organization. https://apps.who.int/iris/handle/10665/70507

WHO. 2020. "Evaluation of genetically modified mosquitoes for the control of vector-borne diseases, Position statement". World Health Organization. https://www.who.int/publications/i/item/9789240013155

WII. 2016. "Molecular Biology". Wildlife Institute of India. https://wii.gov.in/campa_molecular

WII. 2020. "Wildlife Forensic & Conservation Genetics Cell". Wildlife Institute of India. https://wii.gov.in/wildlife_forensic

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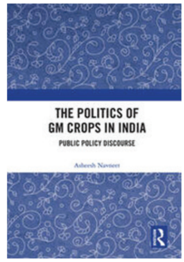
Book Review

The Politics of GM Crops in India: Public Policy Discourse



Author: Asheesh Navneet
Publisher: Routledge
Year: 2021
Pp: 200
e-ISBN: 9780429329432
Price: GBP 33.29

The debates and discourse around the Genetically-Modified crops (GM Crops) have been there in India since last couple of decades now. In fact, ever since the government's approval for the commercialization of the *Bt* Cotton in 2002, there have been a sustained discussions regarding the benefits and hazards of the introduction of GM crops in India. More often than not, the stances taken by the various stakeholders could easily been seen to be polarized ones; with one set of such stakeholders arguing for the GM crops while other set of stakeholders arguing against it. There is a vast literature available on the success or failure of *Bt* Cotton in India, authored by both national as well as international researchers. This volume by Asheesh Navneet is an important addition to the existing literature in a sense because in this book the author had exclusively focused on the discourse from the perspective of public policy by analysing the apprehensions and stances of various key stakeholders involved in the debate.

The book is ogranised in seven chapters dealing with various policy-related aspects regarding the GM crops in India. The first chapter i.e. the introductory chapter of the book broadly deals with the importance of the biotechnology for the agriculture. It highlights some literature related to the ongoing debate on GM technology in terms of potentialities and scopes, concerns and complications in their uses such as corporate monopolization, impact on human and animal health, impact on biodiversity, ownership rights, IPRs and labour displacement. It also discusses briefly the position of the Indian government on the issue of GM technology. It further elaborates on the food politics in the EU and the USA and explains the regulatory approaches and frameworks of the EU and the US in detail.

The second chapter on the critical analysis of India's regulatory approach highlights the gradual development of the legal regulatory framework with the coming of GM crops in India. It focuses upon the importance of the guidelines framed under the Environment Protection Act (EPA) of 1986, 1989 Rules and its revisions in subsequent years. The chapter then describes the role of six regulatory competent authorities (Institutional Biosafety Committee, Review Committee on Genetic Manipulation, Genetic Engineering Appraisal Committee, Recombinant DNA Advisory Committee, State Biotechnology Coordination Committee and District-level committee) formed to monitor, regulate and then approve whether GM crops are suitable for field trials and, further, for commercial cultivation. It critically analyses the functioning of these six regulatory bodies, and points out the roles (often conflicting) of two key ministries viz. Ministry of Science and Technology (Department of Biotechnology) and Ministry of Environment, Forests and Climate Change (MoEFCC). The chapter also highlights the potential nexus between the corporate seed companies and the government regulating agencies in promoting GM crops without giving much concern for the safe handling of GMOs and public health.

The third chapter deals with the politics around the GM crops with subsequent governments and their ministers taking different stands on the approval. The chapter gives a brief account of the historical background of cotton cultivation in India and how it plays a significant role in its contribution to the national economy. The chapter further captured the controversies around India's first GM crop i.e. *Bt* Cotton by elaborating on the view points flagged by various prominent people and reports made by the expert committees appointed by the government and Supreme Court of India.

The fourth chapter reflects upon the theoretical framework adopted to analyse the complications and questions related to policymaking on GM crops. The author has made a case for adopting Advocacy Coalition Framework (ACF) for this exercise of analysis by understanding the issue at two levels i.e. macro level (policy subsystem and external factors), micro level (individual model and belief systems) . With the help of ACF theory, coalitions either supporting or opposing the use of GM crops were recognised. Therefore, to understand the priorities of different coalition members, the theory was combined with the co-dynamic model of Millstone. Using the ACF theory and the co-dynamic model together, the chapter further highlights how this methodology was adopted for the field study in three phases to analyse the priorities of different stakeholders as members of different coalition groups.

The fifth chapter is anchored on the interviews done by the author with 'policy elites' i.e. key voices, commentators and advocates, drawn from reputed research institutes, regulatory bodies, civil society organisations (CSOs). Through the interviews of these 'policy elites', the author has attempted to understand the rationale and logic behind the decisions to support or oppose GM technology. The compilation of the varied arguments made by those people makes it quite interesting to read.

The sixth chapter is also based on primary data wherein the author has compiled the various data and viewpoints coming from the field surveys of about 200 farmers belonging to the states of Telengana and Maharashtra. The chapter highlights the second and third phases of the field study. In these phases, perceptions of the farmers in Telangana and Maharashtra were also collected. The data captured in this chapter provides an insightful understanding of the issue from the farmers point of view. It also highlights the level of awareness among the farmers regarding the proper cultivation practices of GM seeds.

The final chapter gives an overall summary of the book and brings out the arguments of all the stakeholders together for analysis. Using ACF theoretical framework, it reflects upon how various stakeholders, as members of various coalitions formed to support or oppose the use of GM technology in agriculture and also highlights their various concerns to influence the policymaking process. These concerns were found to be related to higher yield for income, biodiversity conservation, human and animal health and ownership-related issues. At the end, the author argues that the '*future of GM technology depends on finding a way in which different scientific truths can be brought together…..to reconcile conflicting arguments of stakeholders*.' (p. 209)

The author has attempted to capture the debate and discourse around the

GM technology in India especially with the focus on GM crops, by mapping and analysing the stances taken by the key stakeholders, however, for a book getting published in the year 2021, many data used in the writing of this volume is quite old. Furthermore, the author has missed out on many relevant literatures on the topic of GM crops in India. Chaturvedi and Srinivas (2019) had edited a very comprehensive volume on GM crops, based on an extensive research study funded by the MoEF&CC under the UNEP-GEF programme. In that edited volume, the data collected from more than 1500 farmers and other key stakeholders from across six states of the country was analysed and a comprehensive socio-economic impact assessment was done. It would have been much better if the author has updated the data and literature for his book. Nevertheless, this book is a good read for anyone who is interested to know about the contestations and the key voices around the GM technology in India till some recent past. This book can be found useful by the policymakers, researchers, academicians and social activists, who are engaged mostly into the , sociological, agricultural and development policy studies.

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Reference

Chaturvedi, S. and K.R. Srinivas (Eds.). 2019. *Socio-Economic Impact Assessment of Genetically Modified Crops: Global Implications Based on Case-Studies from India.* Springer.

Guidelines for Contributors

1. ABDR is a refereed multi-disciplinary international journal. Manuscripts can be sent, preferably as email attachment, in MS-Word to the Managing Editor, Asian Biotechnology and Development Review, Research and Information System for Developing Countries (RIS), Core 4B 4th Floor, India Habitat Centre, Lodhi Road, New Delhi 110003, India (Email: editor.abdr@ris.org.in; Tel. +91-11-24682177-80; Fax: +91-11-24682173/74). Submissions should contain institutional affiliation and complete mailing address of author(s). All submissions will be acknowledged on receipt.
2. Manuscripts should be prepared using double spacing. The text of manuscripts should not ordinarily exceed 7,000 words. Manuscripts should contain a 200 word abstract, and key words up to six.
3. Use 's' in '-ise' '-isation' words; e.g., 'civilise', 'organisation'. Use British spellings rather than American spellings. Thus, 'labour' not 'labor'.
4. Use figures (rather than word) for quantities and exact measurements including percentages (2 per cent, 3 km, 36 years old, etc.). In general descriptions, numbers below 10 should be spelt out in words. Use thousands, millions, billions, not lakhs and crores. Use fuller forms for numbers and dates— for example 1980-88, pp. 200-202 and pp. 178-84.
5. Specific dates should be cited in the form June 2, 2004. Decades and centuries may be spelt out, for example 'the eighties', 'the twentieth century', etc.

References: A list of references cited in the paper and prepared as per the style specified below should be appended at the end of the paper. References must be typed in double space, and should be arranged in alphabetical order by the surname of the first author. In case more than one work by the same author(s) is cited, then arrange them chronologically by year of publication.

All references should be embedded in the text in the anthropological style–for example '(Hirschman 1961)' or '(Lakshman 1989:125)' (Note: Page numbers in the text are necessary only if the cited portion is a direct quote).

Citation should be first alphabetical and then chronological–for example 'Rao 1999a, 1999b'.

More than one reference of the same date for one author should be cited as 'Shand 1999a, 1999b'.

The following examples illustrate the detailed style of referencing:

(a) Books:

Hirschman, A. O. 1961. *Strategy of Economic Development*. New Haven: Yale University Press.

(b) Edited volumes:

Shand, Ric (ed.). 1999. *Economic Liberalisation in South Asia.* Delhi: Macmillan.

(c) Articles from edited volumes:

Lakshman, W. D. 1989. "Lineages of Dependent Development: From State Control to the Open Economy in Sri Lanka" in Ponna Wignaraja and Akmal Hussain (eds) *The Challenge in South Asia: Development, Democracy and Regional Cooperation*, pp. 105-63. New Delhi: Sage.

(d) Articles from Journals:

Rao, M.G., K. P. Kalirajan and R. T. Shand. 1999. "Convergence of Income across Indian States: A Divergent View". *Economic and Political Weekly,* 34(13): pp. 769-78.

(e) Unpublished Work:

Sandee, H. 1995. "Innovations in Production". Unpublished Ph.D thesis. Amsterdam: Free University.

(f) Online Reference:

World Health Organisation. 2000. "Development of National Policy on Traditional Medicine". Retrieved on March 31, 2011 from http://www.wpro.who.int/sites/trm/documents/Development+of+National+Policy+on+Traditional+Medicine.htm

The first article in this issue is on India-Australia cooperation in agricultural biotechnology exploring developments and suggesting way forward, while the second provides a review and survey of Plant Tissue Culture in India, describing its growth and future prospects and the third article is de-extinction and synthetic biology demystifying the issue, underscoring the regulatory challenges and the environmental law policy scenario in India for synthetic biology based de-extinction.

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