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Banana Cultivation and Micropropagation in India: Addressing Challenges and Exploring Future Prospects

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India is a major leading global producer of bananas and plantains, which is an essential staple source of food to fulfill the carbohydrates and micronutrients requirement. Successive increased productivity and significantly expanded cultivation areas are driven by awareness of their nutritional value, economic potential, and serving export opportunities. Tissue culture has become crucial in meeting the high demand for quality planting material, with private companies playing a key role in crop improvement. However, challenges persist, including farmer reluctance to adopt tissue-cultured plantlets and concerns over genetic fidelity, quality, and disease resistance. The industry's underdevelopment in certain regions further exacerbates the gap, with over 2000 million plantlets needed annually. Addressing this requires strategic marketing policies to reduce post-hardening losses and ensure timely availability of certified plantlets. Additionally, tissue culture techniques like micropropagation offer solutions to microbial pathogen threats, enhancing banana cultivation with increase in yield production. Therefore, economic losses face by farmers can be easily addressed by incorporating tissue culture approaches such as micropropagation. In the present study, authors collected the data from various stockholders and companies to understand the challenges, production and demands to meet the population in the current year. This study highlights the need for collaboration between industry stakeholders and farmers to improve production and ensure a sustainable banana supply.

Keywords: Banana; Farmers; Industries; Micropropagation; Tissue Culture.

Agriculturally based food products are fundamental to human survival, serving as a cornerstone of nutrition and sustenance. The rapid increase in global population has intensified pressure on agricultural food systems, highlighting the crucial role of nutrition as a basic human requirement. Projections indicate that by 2050, food production must double compared to 2000 levels, while using the same amount of land and reducing water and other resource inputs[1]. Technological advancement is accelerating exponentially, with some forecasts predicting a 400 per cent increase

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in disruptive technologies over the next five years, making biotechnology a key industry to monitor[2]. Agricultural biotechnology encompasses plant tissue culture (PTC), applied microbiology, and applied molecular biology, all contributing to the production of crops with enhanced food, feed, fiber, and fuel qualities.

The concept of cell culture, first proposed by the German botanist Gotthilf Haberlandt in 1902, laid the groundwork for plant tissue culture (PTC), which has now become an integral tool in crop improvement programs[3]. Over the past decades, PTC technique has successfully evolved from a theoretical concept to widespread commercial application. This transition has led to remarkable growth within the industry, with PTC generating substantial revenues. This success is evidenced by the widespread adoption and implementation of PTC techniques in various agricultural sectors, leading to improved crop production and substantial economic benefits. For nearly four decades, various crops have been routinely propagated using tissue culture techniques and traded both domestically and internationally[4]. As a powerful method for mass production, PTC has become essential in the nursery and farming industry, driving the second green revolution in our country. This review article discusses the growth of the PTC industry in India, its impact on market demands, business potential, and the challenges it faces. Extensive global research in this field has significantly impacted agriculture and related industries, providing high-quality plants necessary to meet the escalating global demand.

Micropropagation, a tissue culture technique that enables the propagation of genetically identical plants under *in vitro* conditions, has been extensively utilized to meet the increasing demand for elite planting material in the current century. There is a substantial need for superior-quality, disease-free plants across ornamental, horticultural, floricultural, and agro-forestry sectors, which are critical components of agriculture[5,6]. This demand has been effectively met through the micropropagation of economically viable plants, successfully translating technological advancements into commercial applications.

Over the past three to four decades, a new industry based on this technology has emerged globally, particularly in India, evolving into a multi-million-dollar enterprise[7]. In India alone, approximately 200 commercial plant tissue culture units operate with a combined production capacity of around 500 million plantlets per annum. The Indian plant tissue culture market is estimated at Rs 500 crore[8]. With a minimum production capacity of about 1 million plants per industrial unit per year for various prioritized species like banana, grapes, pineapple, strawberry, sapota, sugarcane, potato, turmeric, ginger, vanilla, cardamom, aloe, geranium, stevia, patchouli, neem, gerbera, carnation, anthurium, lily, syngonium, cymbidium, teak, teak, bamboo, eucalyptus and populus, the Indian industry produces approximately 350 million plants annually[9].

The demand for micropropagated plants continues to rise, as conventional propagation methods often fail to meet the required quantities and can be cumbersome. Among the major players, 20 companies produce 5 to 10 million plants per year, while numerous smaller firms focus on single species such as banana, gerbera and bamboo, with production ranging from 0.2 to 0.5 million plants. Key consumers of tissue culture plants include State Agriculture and Horticulture Departments, Agri Export Zones (AEZs), floriculturists and farmers. It has observed that the installed production capacity is not fully utilized, with only 50-60% typically being operational[9].

Beyond industrial scale technological advancements, further investigation is necessary to address the gap in technology adoption among farmers. Developing comprehensive marketing strategies is essential to minimize losses during the hardening and post-hardening phases of plant production[10]. In India, the majority of tissue culture industries concentrate on banana plant production[11,12]. Besides, banana micropropagation eliminates the disease invasion, caused by pest and pathogens and ultimately increases the mass-production, which is significantly essential in commercial aspects. It has been noticed that banana production is declined by 30%-50% by the devastating pathogens such as fusarium wilt, bunchy top virus, and the black sigatoka[13]. Recent study reported that incorporating the appropriate concentration of plant growth regulators, and explant sterilization leads to improvement in banana cultivation with elimination of disease severity[14]. Therefore, it is crucial to examine

current consumption patterns between farmers and industries at a pilot level. Indeed, it is the need of an hour to develop transgenic banana which is having resistant source that will ultimately boost the banana production for the augmenting population. The primary objective of this article is to identify the challenges associated with tissue culture in banana cultivation, exploring future advancement in banana micropropagation, and understand the dynamics of related industries and propose potential solutions for mutual benefit of farmers and industry.

MATERIALS AND METHODS

This investigation utilized a systematic survey approach to collect quantitative data through interactions with various stakeholders, including individual farmers and contact farmers at district and state levels. Additionally, data were gathered from financial managers and industry personnel affiliated with recognized laboratories across several states in India during the 2022-23 period. Also, critical challenges were assessed during banana cultivation using tissue culture approaches such as micropropagation.

The initial phase of data collection focused on Vaishali district in Bihar, located in the eastern region of the Indo-Gangetic plain, with geographical coordinates of latitude 25° 45' 0'' N and longitude 85° 25' 0.012 E. This district was strategically selected due to its significant area for dedicated to banana cultivation, where both tissue culture bananas and sucker bananas are predominantly grown. Data were gathered from personnel associated with the District Agriculture and Horticulture Departments in Dighi Kalan, Hajipur, as well as the Krishi Vigyan Kendra located at Satihara Chowk, Hariharpur, Hajipur, District Vaishali, and Rajendra Prasad Central Agriculture University (RPCAU) in Pusa, District Samastipur.

Following interactions with various stakeholders, including financial managers and industry personnel, obstacles encountered at the interface between farmers and the industry were identified. Data collection involved computer-assisted telephonic interviews (CATI) with personnel from recognized laboratories, utilizing structured canvassing questionnaires to ensure comprehensive data acquisition. Data analysis using both tabular and functional approaches was adopted. Tabular analysis focused on key aspects such as resource cultivation, production levels, profitability, and farmers perception regarding challenges in production and marketing. Simple statistical tools, including averages and percentages, were employed to interpret the results effectively.

RESULTS AND DISCUSSION

Bananas Production and Productivity

Bananas (*Musa* spp.) are crops of significant importance in developing countries, serving both subsistence living and as a substantial source of economic growth, income, food security and nutrition[15,16]. Globally bananas rank as the fifth-largest agricultural commodity by production (following sugarcane, rice, grapes, and citrus fruits) cultivated in more than 134 countries, with an annual production of 145 million tons[17,18].

Bananas Production in India

According to FAO estimates, India occupies the largest area dedicated to banana cultivation, about 11 per cent of the total global area under banana production contributing approximately 23 per cent to the worldwide banana production pool[18,19]. For the past decade, India has maintained its position as the largest banana producer globally, and currently contributes 19.37% of the world's banana production, yielding > 33 million tons from an area of 9.24 lakh hectares[20]. These bananas are cultivated across various regions ranging from humid tropics to humid subtropics and semi-arid tropics, up to an elevation of 1,500 m above sea level, including Tamil Nadu, Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Assam, and Odisha (Table 1). The national average productivity is 38.25 tons per hectare, with Gujarat recording the highest at 66 tons per hectare, followed by Maharashtra at 58.2 tons per hectare, and Tamil Nadu at 47.9 tons per hectare[21].

In India, germplasm of nearly 500 accessions have been assembled by the ICAR-National Research Centre for Banana, Tiruchirappali, Tamil Nadu and approximately 50 distinct varieties are cultivated commercially[21,22].

Among these, only the Cavendish groups constitute the mainstay for Indian farmers due to their high yield, widespread market acceptability, short crop duration, and high economic returns per unit area[23,24].

The increase in production is attributed not only to the expansion of cultivation areas but also to enhanced productivity per unit area. This boost in productivity has been achieved through the use of tissue culture (TC) plants of high-yielding

Table 1. Per hectare cultivation of sucker and tissue culture-raised plantlets in India.

State	Commonly cultivated banana varieties	Area of cultivation (million ha)	No. of plants produced (in millions)	No of Suckers (in million)	TC-raised plants (in millions)
Andhra Pradesh	Amritpani, Chakrakeli, Dwarf Cavendish, Grand Naine, Monthan, Karpooravalli, Poovan, Robusta, Rasthali, Thellachakrakeli, Yenagu Bontha	0.08	240	216	24
Arunachal Pradesh	Chini Champa, Malbhog,, Bhimkol	0.0054	16	14	2
Assam	Bharat Moni, Bhimkol, Borjahaji (Robusta), Chini Champa, Chinia (Manohar), Digjowa, Honda, Jahaji (Dwarf Cavendish), Jatikol, Kanchkol, Kulpait, Malbhog, Manjahaji	0.05	150	135	15
Bihar	Alpon, Basrai, Chinia, Chini Champa, FHIA-17, Gauria, Grand Naine, Kothia, Malbhog, Muthia, Singapuri	0.03	90	81	9
Chhattisgarh	Basrai, Grand Naine	0.01	30	27	3
Goa	Myndoli (Horn Plantain), Saldatti (Saba), Savarboni (Bluggoe), Sugandhi (Pisang awak), Velchi (Ney poovan)	0.002	6	5	1
Gujrat	Basrai, Grand Naine, Lacatan, Harichal (Lokhandi), Gandevi Selection, Robusta, Shrimati	0.06	180	162	18
Karnataka	Dwarf Cavendish, Elakkibale, Grand Naine, Monthan, Poovan,, Rasthali, Robusta	0.11	330	297	33
Kerala	Karpurvalli, Monthan, Nendran (Plantain), Palayankodan (Poovan), Rasthali, Red Banana, Robusta	0.06	180	162	18
Madhya Pradesh	Basrai, Grand Naine	0.04	120	108	12
Maharashtra	Basrai, Grand Naine,, Lal Velchi, Robusta, Safed Velchi, Shreemanti	0.08	240	216	24
Orissa	Champa, Dwarf Cavendish, Patkapura (Rasthali), Robusta	0.03	90	81	9
Tamil Naidu	Grand Naine, Karpuravalli, Matti, Monthan, Pachanadan, Peyan, Poovan, Rasthali, Red Banana, Robusta, Nendran, Sakkai, Virupakshi	0.13	390	351	39
Uttar Pradesh	Grand Naine	0.03	90	81	9
West Bengal	Champa, Dwarf Cavendish, Giant Governor, Kanthali, Mortman, Singapuri	0.04	120	108	12
Total		0.7574	2272	2045	227

Source APAARI 2019, FAO 2020 and NHB 2022

Table 2. Production of banana plants from recognized tissue culture laboratories in India

State	Name of recognized commercial tissue culture lab*		Major plant(s) produced by the company	Production of Banana** (in Millions)
Andhra Pradesh	1	Elite Biotechnology. Anantapur	Banana	10
	2	Micco Laboratories Pvt. Ltd. Chittor	Banana	
	3	Sri Soma Biotech. Guntur	Banana	
Bihar	1	Hecure Agro Plants Pvt. Ltd. Muzaffarpur	Teak, turmeric	0
	2	Magadh Sugar and Energy Ltd. Samastipur.	Banana, sugarcane	0
Chhattisgarh	1	Narmada Phosphate Limited. Bilaspur	Banana, bamboo.	12
	2	Yash Biotech. Raipur	Banana	
	3	AKF Plant sciences Pvt. Ltd. Durg	Banana	
	4	COE AIB Tissue Culture Lab., IGKV. Raipur	Banana	
	5	Devleela Biotechs. Raipur	Banana, bamboo	
	6	Aastha Nursery, Raipur	Banana, bamboo	
Gujarat	1	ABC Agro biotechnology Pvt. Ltd. Mahemdabad	Banana, pomegranate Date palm, lemon, fig.	24
	2	Greenfield Biotech. Gandhinagar	Banana	
	3	GSFC Agrotech Ltd.-New Lab. Vadodara	Banana, sugarcane	
	4	IRM Enterprises Pvt. Ltd. (Formerly Cadila Pharmaceuticals Ltd.-Agro Division) Ahmedabad	Banana, pomegranate Lemon, teak, pointed guord, spineguard	
	5	Kalptaru Agro Biotech. Nadiad	Banana, pomegranate Potato minituber, bamboo, lemon, guava, mango	
	6	Kutch Crop Services Ltd. Mundra	Date palm, barhee	
	7	Maltbio Agrifood Pvt. Ltd. Bharuch	Date palm, banana	
	8	Metrogen Biotech. Gandhinagar	Banana, strawberry	
	9	Natural Life Science. Anand	Banana, tindora, pointed guord, pineapple	
	10	MANU"s Labs, Ganghinagar	Banana	

		Mandli Ltd. Bharuch		
	15	Siddhi Plantek. Anand	Bamboo, banana Sugarcane	
	16	Sri Ratnam Biotech LLP, Ta. Nadiad	Bamboo, banana	
	17	National Agri Biotech, Anand	Banana, pomegranate lemon	
	18	Vitrigold Biotech Pvt. Ltd. Anand	Banana, pomegranate, kagzi lime	
	19	Numics Biotech, Anand	Banana, pomegranate, lemon	
Haryana	1	Sheel Biotech Ltd., Gurugram	Banana, pomegranate, lemon, pineapple, gerbera, anthurium, lilium, bamboo, eucalyptus.	4
	2	The Energy And Resources Institute (TERI), Gurugram	Banana, strawberry Potato microtuber, lemon	
	3	Desson Tissue Culture Lab, Natwal	Banana, bamboo.	
Himachal Pradesh	1	Nishant Biotech. Bilaspur	Apple, cherry, pear	0
	2	Sharma Biotech Agrigold Pvt. Ltd. Samoh.	Apple, cherry, pear	
	3	Technico Agri Sciences Ltd. Solan	Apple, cherry, pear	
Jharkhand	1	Sashanka Agro Tech Private Ltd. Ranchi	Teak	0
Karnataka	1	Florance Flora Farm, Bangalore	Banana	17
	2	Meristem Biotech, Bengaluru.	Banana, pineapple	
	3	Green Leaf Plant Technology. Bangalore	Banana, pomegranate	
	4	HU Gugle Biotech Pvt. Ltd. Bangalore	Banana, pomegranate, lemon, teak, pineapple, strawberry	
	5	Jagadamba Bio Plants. Bangalore	Banana, pomegranate Strawberry, date palm, gerbera , anthurium	
	6	K.F. Biotech Pvt. Ltd. Bangalore	Banana, potato mini tuber	
	7	Mysore Organic Farms Pvt. Ltd. Mysore	Banana, Anthurium, Aglaonema, Alpinia, Orchids, Gerbera, Strawberry, Syngonium, Tea, Vanilla, Xanadu	
	8	Novel Biotech. Bangalore	Banana	
	9	Shaanthi Agrotech. Bengaluru	Banana	
	10	Sree Adithya Biotech. Bangalore	Banana	
	11	SLR Greentech Pvt. Ltd. Bengaluru	Banana	
	12	V2 plants Inc. Bengaluru	Banana	
Madhya Pradesh	1	Celgen Biotech India. Vidisha	Banana, Pomegranate, Guava, Teak, Bamboo	7
	2	Reva Flora Culture. Barwani	Bamboo. Orchid, Pomegranate, Banana	
	3	Sachdev Nursery. Damoh	Banana, Pomegranate, Guava, Bamboo	
	4	Shri Mukund Biotech. Jabalpur	Banana, Pomegranate, Guava, Bamboo, Teak, Stevia, Orchids, Sugarcane	

	5	Tirupati Fresh Agro Crop Science Pvt. Ltd. Khargone	Banana	
	6	Arihanth Biotech, Jabalpur.	Teak, banana.	
Maharashtra	1	Ajeet Seeds Ltd., Aurangabad	Banana	55
	2	Almaq Biotech LLP, Latur	Bamboo	
	3	Advent Plantech LLP, Nashik	Banana	
	4	Biosis Plants Pvt. Ltd. Nashik	Banana, gerbera, orchids, strawberry	
	5	Futura Bioplants Pvt. Ltd. Pune	Gypsophila, gerbera, carnations, banana.	
	6	HU Gugle Agro Biotech Co. Ahmednagar	Banana,pomegranate, banana	
	7	Ishved Biotech Pvt Ltd, Buldana	Banana, bamboo, date palm, pomegranate lemon	
	8	Jain Irrigation Systems Ltd. Jalgaon	Banana	
	9	Janani Biotech and Tissue Culture Lab. Kolhapur	Banana	
	10	K.F. Bioplants Pvt. Ltd. Pune	Gerbera, carnation, dendrobium, strawberry	
	11	Kimya Biotech Pvt. Ltd. Sangli	Gerbera, carnation	
	12	Kshitij Biotech Corporatio. Satara	Banana, strawberry	
	13	Mahabeej Biotechnology Centre. Nagpur	Banana, strawberry	
	14	Namo Bioplants, Nashik	Banana, strawberry	
	15	Ram Biotech. Jalgaon	Banana	
	16	Rise ‘n’ Shine Biotech Pvt. Ltd. Pune	Banana, gerbera, carnation, lilium, pomegranate, teak, paulownia	
	17	Ruddhi Biotech Pvt. Ltd. Kolhapur	Banana	
	18	Seema Biotech. Kolhapur	Banana, teak, bamboo	
	19	Seven Star Fruits Pvt. Ltd. Jalna	Apple ,cherry, banana	
	20	Callus Biotech Pvt. Ltd. Kolhapur	Banana, pineapple	
Orissa	1	Excel Plant Link Pvt. Ltd. (Unit-2) Dhenkanal	Banana, pineapple, geranium.	2
	2	Regional Plant Resource Centre, Bhubaneswar	Banana, pineapple	
Punjab	1	Bhatti Tissue Tech. Jalandhar	Potato	0
	2	Mahindra Hzpc Pvt. Ltd. Mohali	Potato microtuber	
	3	PepsiCo India Holdings Pvt. Ltd. Hoshiarpur	Potato	
	4	Technico Agri Sciences Ltd. Chandigarh	Potato	
Rajasthan	1	Atul Rajasthan Date Palms Ltd. Jodhpur	Datepalm	0
Tamil Nadu	1	HiFi Biotech India Ltd. Salem	Banana	22
	2	Genewin Biotech. Hosur	Bamboo, Dendrocalamus, banana, ginger	
	3	Growmore Biotech Ltd. Hosur	Bamboo	
	4	Hosur Hortitech. Hosur	Banana	
	5	Jayasree Biotech. Hosur	Banana	
	6	SPIC Agro Biotech Centre. Coimbatore	Banana	

	7	Sree Bairava Nursery. Hosur	Banana, bamboo.	
Telangana	1	ACE Agro Technologies. Secunderabad	Banana	30
	2	Agri Vitro Tech Laboratories. Hyderabad	Strawberry, banana	
	3	Microsun Bioplants (I) Pvt. Ltd. Secunderabad	Banana	
	4	Vitroplant. Hyderabad	Banana	
Uttar Pradesh	1	Merino Industries Ltd. Hapur	Banana	2
	2	GRS Bioplants, Pvt. Ltd. Firozabad	Banana, Potato tuber, Syngonium.	
	3	Sagar Agrisciences Pvt. Ltd., (Unit-II). Barabanki	Strawberry, Banana, Sugarcane.	
West Bengal	1	Elegant Flower Company Pvt. Ltd. Kolkata	Banana, Potato micrtuber.	2
	2	Pallishree Ltd. Arambagh	Banana, Pomegranate, Orchid, gerbera, syngonium	

* List of recognized commercial Tissue Culture Production Units by the Department of Biotechnology (DBT), Govt. of India under the "National Certification System for Tissue Culture Raised Plants (NCS-TCP)".

** Production per year has been calculated on the basis of the information available on individual company production data.

superior varieties, along with integrated nutrient and water management, high-density planting, and other good agricultural practices[17,20]. While specific varieties such as Rasthali (Silk), Poovan (Mysore), Ney Poovan, Thella Chakkarakeli, Karpuravalli (Pisang Awak), Nendran (French Plantain), Hill Banana (Pome-AAB), and Monthan (Cooking banana) are grown extensively in different regions, the Indian banana trade predominantly relies on Cavendish clones[25]. These clones are known by various names across regions, including Robusta, Grand Naine, Basrai, Harichal, Shrimanthi, Bhusaval, and Pedda Pacha Arati. Cavendish clones account for 52% of the total area under banana cultivation and contribute 64% of the total banana production[19].

The demand for bananas is projected to continually increase, with an estimated requirement of 50 million tons to meet domestic demand by 2050[26]. Additionally, there is a significant potential for export of banana and its products, further boosting demand. To achieve the production target of 50 million tons by 2050, several major constraints must be addressed, including the need for high-quality planting material, rising input costs of fertilizers, irrigation and management of insect pests and diseases[27,16,28].

Role of TC Bananas in India

Tissue culture-raised plantlets are crucial in overcoming the production challenges in bananas as they offer numerous advantages over conventional suckers. They exhibit higher field establishment rate, uniform growth, synchronized harvesting, early maturity, superior fruit quality, increased production, and other favorable yield-related parameters. Tissue culture-derived plantlets have demonstrated a yield of 63.44 t/ha, representing a remarkable 39.43 per cent increase compared to the conventional sucker grown crop (45.50 t/ha). Consequently, crop cultivated with tissue culture plantlets exhibited a higher benefit-cost ratio of 2.25 compared to 1.65 for crops grown with conventional suckers[9,18,19,24,24,29,30,31].

In India 0.7574 million ha land is utilized by farmers for banana cultivation across 15 States. Among these, Tamil Nadu ranks first with 0.13 million hectares, followed by Karnataka with 0.11 million hectares, and Andhra Pradesh and Maharashtra with 0.08 million hectares each. Goa contributes the smallest area, with only 0.002

million hectares (Table 1). Cultivation of bananas is not profitable in 14 states of the country, including the North-eastern states, due to geographical barriers. With the recommended planting density of 3,000 banana plants per ha, it has been estimated that approximately 2,272 million plants are grown annually[32,19,33]. As the present majority Indian farmer uses 70-90% conventional planting materials such as sucker and 10-30% tissue culture raised plantlets in various states across the country (Table1). It indicates clearly that the use of tissue-cultured plantlets is lower than the banana sucker. For instance, banana cultivation can be impeded by manifesting suitable protocol for micropropagation using appropriate plant-growth hormones concentration, suitable concentration of explant sterilization[13,14]. This will not only surpass the pathogen invasion issues but also enhance the banana production.

India ventured into field of commercial tissue culture in 1987, with the establishment of a modern export oriented commercial plant tissue culture by A.V. Thomas and Co, a well-known plantation company of Kerala, located in Cochin[9]. Currently, the Government of India has recognized 99 tissue culture units, with a combined capacity of 187 million banana plants per annum (Table 2). In addition to these recognized labs, 100 smaller units are also operational to meet the huge demands for production[34].

In India, some 14 varieties exhibit marketing potential for tissue culture and can be made accessible to farmers. Nevertheless, a notable concern is the predominant focus of the majority of companies on the Grand Naine (also known as G9) variety. Despite the vast potential of more than 2,000 million of tissue culture grown plants of banana in India, there is a need to encourage Indian farmers to adopt this technology. This, in turn, depends on sufficient well-equipped tissue culture industry and a certification program to ensure the availability of healthy planting material[35,36].

Impediments in TC Banana Production

The majority of the tissue culture units in the country catering to both the domestic and interstate market are confined to only four states: Maharashtra, Gujarat, Telangana and Karnataka. Other states remain untapped for the potential of TC banana due to challenges such as climatic disadvantage, lack of infrastructure and non-conducive policies[35,24]. States such as Bihar, Assam, and Goa, where banana production relies on traditional farming methods, face a lack of well-developed infrastructural support for tissue culture-based industries, creates a significant gap between farmers and the industry (Fig. 1)

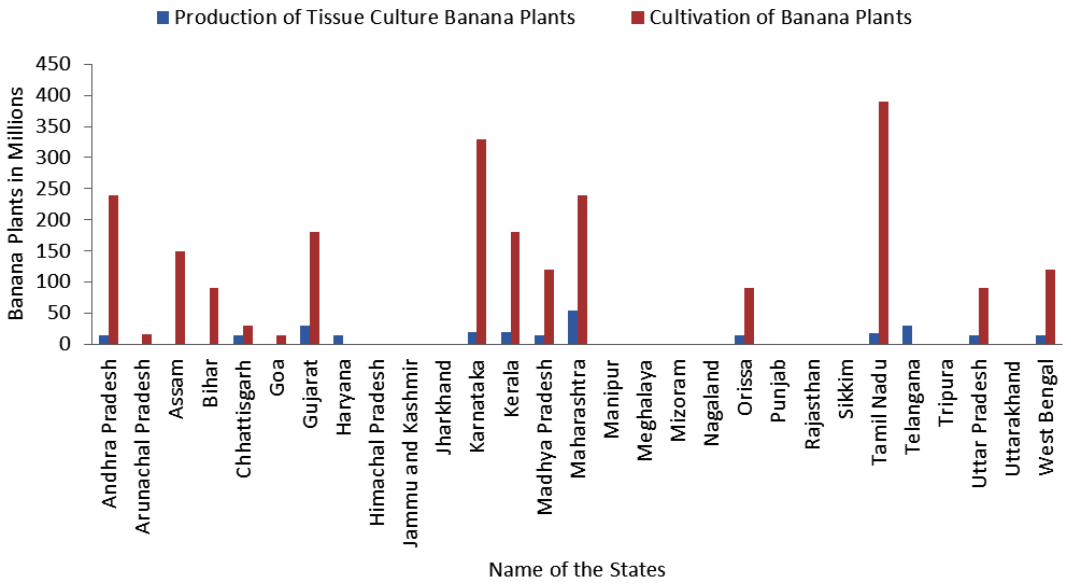

Fig. 1. State wise cultivation of banana plants and production of tissue culture banana plantlets

Indian industries currently lack sufficient access to primary markets. It has been observed that market estimation exercises conducted before establishing business lose relevance when plantlets are ready after post-harvesting, transportation, and storage. In the market, farmers do not place long-term orders, leading to uncertainty in production planning for the industry. Post-hardening loss is another major constraint in the sector, which could be minimized by establishing tissue culture industries uniformly according to the demands of various states across the country (Fig.1). States such as Assam, Bihar, and Goa, have untapped market potential and should be targeted in a more planned manner (Fig.1). The rigidity and illiteracy among Indian farmers pose additional challenges for the industry in convincing them of the economic advantages and genetic fidelity of tissue culture-raised plants[37].

Another significant challenge faced by the industry is the presence of middlemen who primarily benefit from the marketing of the plants[38,39,40]. To tap into the vast potential market size of more than 2,200 million of plant per annum, extensive networking of channels, market development and improved post-harvest handling, storage, transport and certification are essential throughout the country[27]. In efforts to promote tissue culture and distribute plant materials to farmers, state and district horticulture boards have established partnerships with industries. However, due to a lack of proper planning, they have been unable to supply the plants to farmers effectively. Concurrently, small-scale farmers, due to a lack of adequate information, are not receiving tissue culture planting materials and are unable to purchase or prebook plants well in advance

It is crucial to note that secondary hardened plants, being living materials, cannot be stored in the greenhouse for extended periods due to limited nutrients in pots and space. Consequently, the plants may suffer from nutrient deficiencies, leading to adverse consequences such as stunted growth and eventual death. Furthermore, individuals functioning as middleman between the government and industries become key beneficiaries of such collaborations, exploiting existing policy gaps for monetary gain. This situation underscores the need for a more comprehensive and transparent policy framework to ensure fair and equitable benefits for all stakeholders involved in the tissue culture industry.

The study also reveals that the horticulture department procures greenhouses from the company to sustain plant life; however, farmers do not get benefit from this initiative due to inadequate extension services, resulting in the deterioration of the greenhouse and plant spoilage due to a lack of maintenance. In India, tissue culture industry, represents, to a certain extent, the transformation of the traditional economy into a modern one. Therefore, there is a need to educate Indian farmers through extension activities to optimize the utilization of their available land for banana cultivation. This includes obtaining the best possible rates through government subsidies, promoting overall prosperity of the farmer through the adoption modern technology[39,40,41,42,43,44 45.]

CONCLUSION AND FUTURE PERSPECTIVE

Based on present study, it can be concluded that there is a need to motivate the Indian farmers across the country regarding the diversity, quality and economic significance of tissue culture raised plants to adopt method from traditional modes of farming to the modern technology. Furthermore, it is proposed that the establishment of regional translational collaborative centers to conduct pre-production target analysis, aim to minimize the post-harvest losses of Indian tissue culture industries should be promoted to address the challenges faced in lab - to - land programs.

In addition, microbial-pathogen attacks drastically reduce crop yield and production. Global food security and the rising food demands to meet for the augmenting populations are critical concerns in agricultural sector, which can be significantly minimized by using micropropagation. However, it is essential to develop a rapid and cost-effective protocol that selectively eliminates the tissue hardening and destructive pathogen invasion during banana cultivation. These efforts will also reduce the banana import from other countries that will further helpful for economic growth and encourage farmers to cultivate banana.

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Conflict of interest

The authors do not have any conflict of interest.

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Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Authors contribution

Rajeev Kumar : Conceived the idea, Designed investigation and Wrote the manuscript.; Anshuman Shah : Analyzed results and Contributed to writing the manuscript, Ravi Kant Singh, Abhinav Kumar Srivastava and Udai Pratap Singh : Data curation, Anuradha Agarwal: Analyzed results and Contributed in providing constructive feedback. All authors have reviewed and approved the manuscript.

REFERENCES

1. Boretti A, Rosa L. Reassessing the projections of the world water development report. *NPJ Clean Water.* 2019: 2(1):15.
2. Serraj R, Krishnan L, Pingali P. Agriculture and food systems to 2050: a synthesis. *Agriculture & Food Systems* . 2019;2050:3-45.
3. Govil S, Gupta SC. Commercialization of plant tissue culture in India. *Plant cell, tissue and organ culture.* 1997 :51:65-73.
4. Bhatt D. Commercial Micropropagation of Some Economically Important Crops. InAgricultural Biotechnology: *Latest Research and Trends* 2022 Jan 8 (pp. 1-36). Singapore: Springer Nature Singapore.
5. Singh S, Thangjam R, Harish GD, Singh H, Kumar R, Meena DP, Agrawal A. Conservation protocols for Ensete glaucum, a crop wild relative of banana, using plant tissue culture and cryopreservation techniques on seeds and zygotic embryos. *Plant Cell, Tissue and Organ Culture (PCTOC).* 2021:144:195-209.
6. Singh S, Agrawal A, Kumar R, Thangjam R, John KJ. Seed storage behavior of Musa balbisiana Colla, a wild progenitor of bananas and plantains-implications for ex situ germplasm conservation. *Scientia Horticulturae*. 2021: 5;280:109926.
7. Verma G, Ravichandran S. Evolution of biotechnology as a million dollar market: The Management and commerce of a biotech start-up. *Biotechnology Business-Concept to Delivery.* 2020:161-78.
8. Salunkhe P, Mahajan M, Sharma V, Trivedi D. Commercialisation of Plant Tissue Culture in India: A Review. *Asian Biotechnology & Development Review*. 2022 :24(2).
9. Patil SM, Kumari VC, Sumana K, Sujay S, Tejaswini M, Shirahatti PS, Ramu R. Sustainable development of plant tissue culture industry: The Indian scenario. *J. Appl. Biol. Biotechnol.* 2021: 9(2):18-27.
10. Sharma N, Kumar N, James J, Kalia S, Joshi S. Strategies for successful acclimatization and hardening of in vitro regenerated plants: Challenges and innovations in micropropagation techniques. *Plant Science Today*. 2023:10(sp2):90-7.
11. Justine AK, Kaur N, Pati PK. Biotechnological interventions in banana: current knowledge and future prospects. *Heliyon*. 2022: 8(11).
12. Erol MH, Dönmez D, Biçen B, ªimºek Ö, Kaçar YA. Modern approaches to in vitro clonal banana production: Next-generation tissue culture systems. *Horticulturae.* 2023: 9(10):1154.
13. Kadam MS, Ghodake BD, Chinche AV, Chopade SJ, Gond PP, Tattapure VM. Effect of Growth Regulators, Sterilization Treatments, and Potting Mixtures on in vitro Micropropagation of Red Banana (*Musa acuminata*). *Biological Forum – An International Journal*. 2023;15(12):181-188.
14. Kumar D, Chakradhar P, Ranganna G, Vimal VK, Raj R, Anusha C, Patra S, Nagaraju V. Tissue Culture in Banana Cultivation: A Review of its Impact on Disease Management, Yield Improvement, and Sustainable Production. Journal of Advances in Biology & Biotechnology. 2024:27(9):628-44.
15. Evans EA, Ballen FH, Siddiq M. Banana production, global trade, consumption trends, postharvest handling, and processing. Handbook of banana production, postharvest science, processing technology, and nutrition. 2020: 31:1-8.
16. Singh HP, Singh B. Banana research and development in India-a review. *International Journal of Innovative Horticulture.* 2020;9(2):71-6.

17. Uma S, Saraswathi MS, Backiyarani S, Durai P, Agrawal A. Unravelling the potential of Musa genetic resources for benefit of global banana community. Banana & Plantains: *Leading-Edge Research and Developments*. 2020;1:1-44.
18. FAO. 2020. FAOSTAT [Internet]. Available from: http://www.fao.org/faostat/en/#data/QC.
19. Uma S, Kumar PS. Banana research and development in India-challenges and opportunities. *Progressive Horticulture*. 2020;52(1):1-1.
20. Kumar PS, Shiva KN, Saraswathi MS, Uma S, Selvarajan R. Export of GI and Traditional Bananas: Present Scenario. Trade Opportunities and Way Forward, ICAR-National Research Centre for Banana, Tiruchirappalli, Tamil Nadu. 2022.
21. Agrawal A, Tyagi RK. In vitro conservation and cryopreservation of genetic resources of Musa spp.—A review of the recent developments with special reference to India. *International Journal of Innovative Horticulture*. 2014;3(2):115-33.
22. Uma S, Saraswathi MS, Backiyarani S, Durai P, Agrawal A. Unravelling the potential of Musa genetic resources for benefit of global banana community. Banana & Plantains: Leading-Edge Research and Developments. 2020;1:1-44.
23. Vision 2050. National Research Centre for Banana. Tiruchirappalli: Indian Council of Agricultural Research. 2015.
24. APAARI. *Banana Tissue Culture in India – A Success Story*, 43 p. Asia Pacific Association of Agricultural Research Institutions. 2019.
25. Singh S, Agrawal A, Kumar R, Thangjam R, John KJ. Seed storage behavior of Musa balbisiana Colla, a wild progenitor of bananas and plantains-implications for ex situ germplasm conservation. *Scientia Horticulturae*. 2021: 280:109926.
26. Raman M S and Umanath M. Production and marketing of banana in Tiruchirapalli district of Tamil Nadu: an economic analysis. *International Research Journal of Agricultural Economics and Statistics.* 2016.7: 67-75.
27. Rani SP, Mani K. Impact of credit on investment in tissue culture banana cultivating farms. *International Research Journal of Agricultural Economics and Statistics*. 2016. 7: 7-14
28. Sachan BS, Yadav B, Verma AK, Bhardwaj VV. Economic Study of Banana Marketing in District Fatehpur, Uttar Pradesh. *Economic Affairs.* 2021. 66(2): 343-47.
29. Bairwa KC, Singh A, Jhajaria A, Singh H, Goyam BK, Lata M, Singh N. Conventional sucker with tissue culture banana production in Central India-A case study. *African Journal of Agricultural Research.* 2015:10(14):1751-5.
30. Bhanusree MR, Kumar KR, Suresh CP, Shukla G, Chakravarty S. Comparative studies on tissue culture plantlet versus conventional sucker var. Grand Naine banana. 2015. *Plant Archives* 15(2): 785-88.
31. Poonam, Jhariya MK. Knowledge, adoption and managerial perspectives of banana growing communities in Durg, Chhattisgarh, India. *Journal of Human Ecology*. 2017:59(1):10-9.
32. Hassan SN. A Study on Technological Gap in Banana Cultivation Technologies in Southern District of Tamil Nadu. *International Journal of Scientific and Research Publication*. 2016;6(7):388-94.
33. Kumar R, Sinha K, Kumar S. Micropropagation of banana cv Malbhog through meristem tip culture in consort with thermotherapy. *Phytomorphology.* 2005. 55: 17-22.
34. Shukla SK. National Certification System for Tissue Culture Raised Plants (NCS-TCP) as the unique quality management system for plant tissue culture sector: its inception, evolution, impact and way forward.2017.
35. Avvaru S. Plant tissue culture of Banana in laboratory. Research and Reviews: *Journal of Botanical Sciences.* 2016. 5: 54-62.
36. Saxena M and Gandhi C P. Indian Horticulture Database. National Horticulture Board, Ministry of Agriculture, Government of India. 2014.
37. Sirisha B, Kishore Babu M, Gowthami V. A study on impact of literacy of farmers during the purchase of agricultural inputs. *International Business Management*. 2016;10(6):726-31.
38. Bapat SA, Iqbal SH. The plant tissue culture scene in India: I. Identification of grey areas in communication (research and industry). *Journal of Scientific and Industrial Research.* 1998. 57: 357-64.
39. Bapat SA, Iqbal SH. The plant tissue culture scene in India:[II] financial considerations for technology sustainability. *Journal of Scientific and Industrial Research.*1999 58: 89-95.
40. Bapat SA, Iqbal SH. The plant tissue culture scene in India:[III] technology acceptance and popularisation. *Journal of Scientific and Industrial Research*. 1999. 57: 357-64.
41. FAO. Banana Market Review – Preliminary Results 2023. Rome: Food and Agriculture Organization of the United Nations.2023.
42. Manchanda P, Kaur A, Singh Gosal S. Micropropagation of banana (Musa acuminata) through proliferation of axillary shoots. *Indian Journal of Agricultural Sciences*. 2012 May 1;82(5):451.
43. NHB. 2021-22. Indian production of banana. National Horticultural Board. Available

from:https://agriexchange.apeda.gov.in/India%20Production/India_Productions.aspx?cat=fruit&hscode=1042 (accessed July 21, 2024).

44. Suman S. Plant tissue culture: A promising tool of quality material production with special reference to micropropagation of banana. *Biochemical & Cellular Archives*. 2017:17(1).

45. Voora V, Larrea C, Bermudez S. Global market report: bananas. Winnipeg: International Institute for Sustainable Development. 2020.