International Journal of Horticultural Science and Technology (2025) Vol. 12, No. 3, pp. 847-862 doi.org/10.22059/ijhst.2024.378619.872

International Journal of Horticultural Science and Technology
Journal homepage: https://ijhst.ut.ac.ir

Qualitative Characteristics of Indigenous *Musa* Varieties: A Step for Conserving Biodiversity and Promoting Sustainable Use

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ARTICLE INFO

Article history:

Received: 27 June 2024,
Received in revised form: 4 October 2024,
Accepted: 4 November 2024,

Article type:

Review paper

Keywords:

Asian countries,
Banana,
In vitro plant regeneration,
Nutrient requirements

ABSTRACT

The process of *in vitro* cultivation depends on various parameters, such as plant genetics, composition of the culture media, stage and age of the tissue, mode of introduction, sample size, and hormonal influences. Ranked as the fourth most essential global food crop and the fourth most important crop in India, after wheat, rice, and maize, bananas provide considerable benefits through *in vitro* propagation. This technique improves the number of plantlets, maintains physiological consistency, and guarantees continuous production of plants that are free from diseases throughout the year. The Southeast Asian region is known for cultivating a wide array of banana types, including pisang in Malaysia/Indonesia and kluai in Thailand. In India, there are three main banana-producing regions: Southern, Western, and Eastern India. Nevertheless, the demand for banana production remains substantial. Only a limited number of native cultivars, such as red banana and poovan, are commercially reproduced, while others like jatikhol, honda, and bhimkol remain unexplored. These indigenous *Musa* varieties possess considerable nutritional and therapeutic worth, containing a wide range of both macro and micro-nutrients, making them a vital source of energy. Nevertheless, there is a limited availability of techniques for cultivating disease-free plants of these indigenous kinds by *in vitro* regeneration. This article emphasizes the significance of in vitro regeneration, preservation, and development of disease-resistant banana plants..

Introduction

The banana (*Musa spp.*) is a worldwide important fruit crop, with major cultivation in India. Bananas have a substantial impact in guaranteeing the food security of several individuals in impoverished nations. The fruit in question is widely acknowledged and consumed worldwide in many preparations, such as fresh, cooked, and processed food products (Govindaraju et al., 2012). Presently, the banana production in India stands at 29163 million t, grown in an area of 858 ha (NHB, India 2018). As to the findings of Kwa and Ganry (1989), banana plants cultivated in a regulated environment offer numerous benefits. These factors encompass enhanced cluster weight, a greater quantity of digits, and less variability in fruit dimensions and form. Although there is a wealth of information on the micro-propagation of banana cultivars in

India and other countries (Dore Swamy et al., 1983), there is a lack of data on the micro-propagation of specific native varieties such as Giant Grover, Singapuri, Patkapura, Honda, Manjahaji, etc. that are found in our country. *Musa* cultivars have evolved from the wild species *Musa acuminata* (AA) and *Musa balbisiana* (BB). There are various categories of *M. acuminata* bananas are coated in sugar and classified as dessert varieties, whereas the types of *M. Balbisiana* bananas possess a greater concentration of starch. There are two types of suckers: sword suckers, characterized by a strong base, pointed tip, and thin leaf blades resembling a sword, and water suckers, which are smaller, less vigorous, and have wide leaves that grow in clusters (Scot et al., 2006). The traditional approach to banana cultivation is propagating through suckers, a time-consuming process hindered by the hormone-induced apical dominance of the parent plant. According to Aman et al. (2018), a banana plant produces a finite number of 5-20 suckers over its whole lifecycle. The genome of *Musa balbisiana* confers specific drought and disease tolerance characteristics to hybrid clones. The domestication of bananas is recorded in Kautilya's Arthasastra (250-300 BC) and is depicted in artworks at Ajantha and Ellora (300-400 BC) (Subbaraya U et al., 2016, FAO). Preserving germplasm is of utmost importance in order to safeguard *Musa balbisiana*, a wild banana genotype that exhibits vital traits like as drought tolerance and disease resistance, rendering it extremely beneficial for local banana farming. Continual scientific investigation is currently underway to improve the resilience of transgenic bananas in the face of agricultural challenges. The main objective of this review study is to understand the importance of the nutritional and industrial value of indigenous *Musa* cultivars, as well as the need for their regeneration and preservation using *in vitro* methods.

Distribution

India is the foremost global producer of bananas, although its export rate is significantly lower compared to other nations. India's production of 26.2 million t represents 27.43% of the global total, whereas the Philippines produces 9.01 million t. China, Brazil, and Ecuador collectively have a manufacturing output of approximately 7 to 8 million t. According to FAO STAT, the current worldwide production of dessert bananas (*M. acuminata*) is approximately 67 million t year^{-1}. The year is 2011. India boasts a great genetic variety of bananas, encompassing over 90 different types.

Distinct and individual duplicates may be found in bananas. Plantains predominantly pertain to the ABB classification and trace their primary origins to India, namely in southern India, as a result of somatic mutation (Behera et al., 2018). Table 1 exhibits the occurrence of numerous native banana cultivars, such as Dwarf Cavendish, Robusta, Malbhog, and Harichal, in various regions of India.

Dietary properties

Bananas are highly energizing as they contain 128 kilocalories 100 g^{-1}. According to Chandler S and Gowen (1995), bananas are a valuable source of vitamin A. Srinivasa et al. (2006) showed that bananas contain significant amounts of potassium and sodium. Bananas are a rich and plentiful source of potassium (Fig. 1) and also provide healthy amounts of protein and dietary fibers (Fig. 2). A single banana provides 23% of the potassium required for a daily dietary intake. Potassium is required for muscular function as it facilitates the maintenance of their optimal performance and prevents muscle spasms. Potassium additionally reduces the likelihood of experiencing a stroke. The inclusion of vitamins in bananas has a significant role in preserving general physical well-being through several means. According to Figure 3, bananas supply 41% of the required daily amount of vitamin B. Moreover, the consumption of bananas improves focus and cognitive acuity. Kumar et al. (2012) found that bananas have beneficial impacts on both mental and physical well-being. Table 2 presents various native banana cultivars together with their nutritional components.

Therapeutic attributes

Bananas have shown effectiveness in the treatment of colorectal cancer (Deneo-Pellegrini et al., 1996), breast cancer (Zhang, 2009), and renal cell cancer (Rashidkhani et al., 2005). *M. acuminata* is employed in the treatment of several ailments including fever, cough, bronchitis, diarrhea, allergic infections, and non-communicable diseases. The well-defined pharmacological properties of *M. acuminata* demonstrates antioxidant, antidiabetic, immunomodulatory, hypolipidemic, anticancer, and antibacterial characteristics (Sarah Mathew and Singh Negi, 2016). Consuming *Musa sapientum* fruits has been discovered to possess a prophylactic impact on several diseases. According to a study conducted by Best et al. (1984), it was shown that consuming unripe green *Musa sapientum* (a type of banana) can

help avoid damage to the lining of the digestive system in rats. The ulcer's healing process is affected by it (Dunji et al., 1993).

Table 1. Some indigenous banana varieties growing in different regions of India with their scientific name, genome, and cultivar local names.

States	Scientific Name	Genome Group	Cultivars Local Names
Andhra Pradesh	*Musa acuminata* *Musa paradisiaca*	AAA AAB	Dwarf Cavendish (AAA), Robusta (AAA), Amritpani (Rasthali, AAB), Thella Chakkrakeli (AAA), KarpooraChakrakeli (Poovan, AAB)
Assam	*Musa acuminata* *Musa paradisiaca* *Musa balbisiana* *Musa paradisiaca*	AAA AAB ABB AB	Jahaji (AAA), Dwarf Cavendish, Bor-Jahaji (AAA, Robusta), Malbhog (AAB), Chinia (AAB), Manohar (ABB), Kanchol (AAB), ChiniChampa (AB), Bhimkol (AAB)
Bihar	*Musa paradisiaca* *Musa balbisiana*	AAB ABB	Dwarf Cavendish, Alpan (AAB), ChiniChampa, Malbhog, Muthia (ABB), Kothia (ABB), Monthan (ABB)
Gujarat	*Musa acuminata*	AAA	Dwarf Cavendish, Lacatan (AAA), Harichal (Lokhandi, AAA)
Karnataka	*Musa acuminata* *Musa paradisiaca* *Musa paradisiaca*	AAA AAB AB	Dwarf Cavendish, Robusta (AAA), Poovan (AAB), Rasabale (AAB, Rasthali), Hill Banana (AAB), Monthan, Elakki Bale (AB)
Kerala	*Musa paradisiaca* *Musa acuminata*	AAB AAA	Nendran (AAB Plantain), Palayakodan (Rasthali), Dwarf Cavendish, Robusta, Monthan, Red Banana (AAA)
Maharashtra	*Musa paradisiaca* *Musa paradisiaca*	AAB AB	Basrai (Dwarf Cavendish), Robusta, Lal Velchi (AAB), Safed Velchi (AB), Rajeli (AAB, Nendran), Clones of Basrai
Tamil Nadu	*Musa paradisiaca*	AAB	Virupakshi (AAB), Robusta, Dwarf Cavendish, Red Banana, Poovan, Rasthali, Nendran, Monthan
West Bengal And Orissa	*Musa paradisiaca* *Musa acuminata* *Musa balbisiana*	AAB AAA ABB	Champa (AAB), Morthaban (AAB, Rasthali), AmritSagar (AAB), Giant Grover (AAA), Lacatan (AAA), Monthan (ABB)

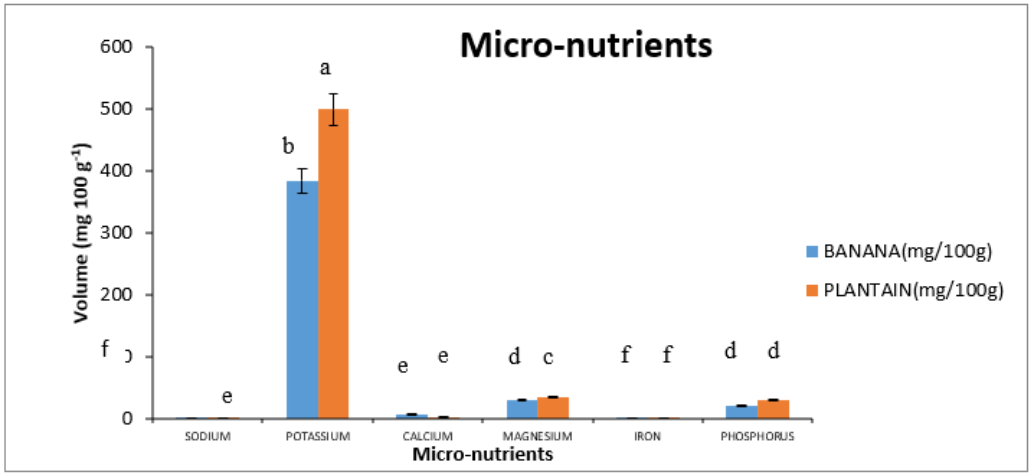

Fig. 1. Micro-nutrients present in banana and plantain such as sodium, potassium, calcium, magnesium, iron, phosphorus (Mean ± SEM). Each experiment was repeated thrice ($P < 0.5$; a, b, c, d, e, f represents the standard error in respective data with a is the highest and f lowest).

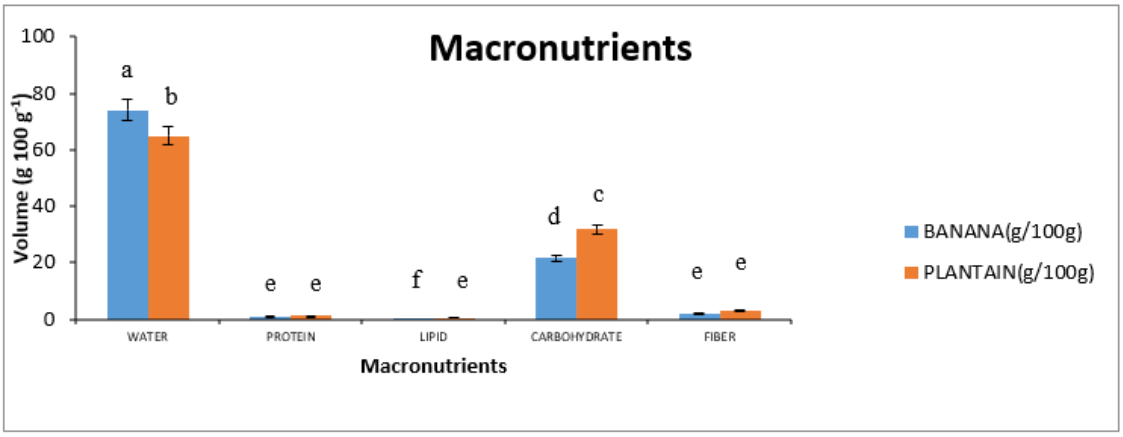

Fig. 2. Macronutrients present in banana and plantain such as water, protein, lipid, carbohydrate, fiber. (Mean ± SEM). Each experiment was repeated thrice ($P < 0.5$; a, b, c, d, e, f represents the standard error in respective data with a is the highest and f lowest).

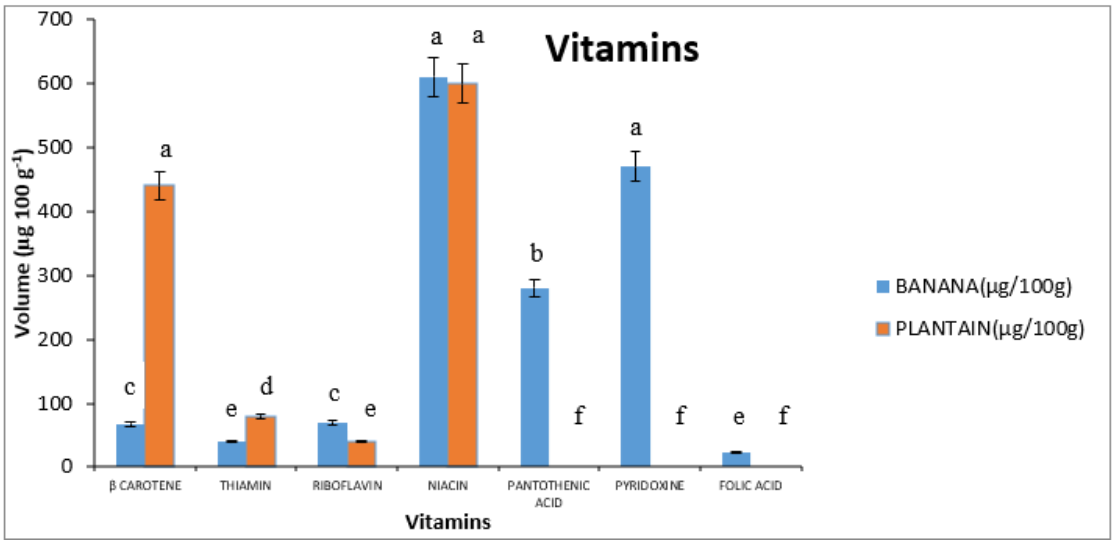

Fig. 3. Vitamins present in banana and plantain such as βcarotene, thiamin, riboflavin, niacin, pantothenic acid, pyridoxine, folic acid (Mean ± SEM). Each experiment was repeated thrice ($P < 0.5$; a, b, c, d, e, f represents the standard error in respective data with a is the highest and f lowest).

Table 2. Nutritional components found in different Indigenous varieties of banana (*Mean ± SEM). Each experiment was repeated thrice ($P < 0.5$).

Banana Varieties	Carbohydrate (g 100 g^{-1})	Protein (g 100 g^{-1})	Minerals (mg 100 g^{-1})	Calcium (mg 100 g^{-1})	Sodium (mg 100 g^{-1})	Potassium (mg 100 g^{-1})
Palayamkodan(AAB)	31.1	1.14	0.182	1.35	220	350
Rasakadali (AB)	30.73	0.91	0.58	0.79	250	400
Robusta (AAA)	22.63	1.33	0.17	0.85	230	400
Poovan (AAB)	38.77	1.37	0.48	0.80	210	280
Nendran (AAB)	41.33	1.11	0.68	0.62	180	500
Kadali (AA)	32.13	1.37	0.33	0.48	180	400
Red Banana (AAA)	21.70	1.34	0.70	0.35	200	400
Padatti (AAB)	26.66	1.28	0.30	0.85	210	400

Leucocyanidin, a flavonoid, has been found as a significant constituent of the liquid extract obtained from unripe banana pulp. The extract has demonstrated noteworthy anti-ulcerogenic efficacy, as documented by Lewis et al. (1999). Various flavonoids, specifically leucocyanidin analogues, possess considerable medicinal potential for treating gastrointestinal disorders. The correlation between the composition and function of flavonoids indicates that their capacity to impede, eliminate free radicals, and bind metals is linked to their characteristics (Heim et al., 2002). The primary medicinal benefits obtained from flavonoids are mostly related to their inhibitory and chelating actions. Flavonoids possess mutagenic and anti-tumoral properties (Rasool et al., 2010) as a result of their distinctive characteristics. Flavonoids can inhibit some proteins, like oxygenases (prostaglandin synthase), that are essential for the synthesis of eicosanoids. Flavonoids hinder the mobility of hyaluronidase and facilitate the preservation of proteoglycans in connective tissues. According to Havsteen (2002), this could impede the growth of germs or the dissemination of malignant tumors. Flavonoids have been found to inhibit the oxidation process of the body's endogenous antioxidants, such as vitamin C (Korkina and Afanas'ev, 1997). Table 3 mentions several bioactive chemicals discovered in bananas that possess health advantages, including gallic acid, ferulic acid, and gallocatechin gallate.

Table 3. Different health benefits from different bioactive compounds found in bananas.

Bio-Active Compound	Health Benefits
Gallic Acid	Antioxidant Properties
P-Coumaric Acid	Reduce The Risk of Stomach Cancer
Gallocatechin Gallate	Cholesterol Reduction
Quercetin	Promotes Cardiovascular Health
Ferulic Acid	Anti-Microbial, Anti-Inflammatory
Trans α Carotene	Precursor To Vitamin A
Trans β Carotene	Reduce Risk of Cancer

Germplasm preservation

Shoot or meristem tip cultures are appropriate for both the efficient production of uniform and actively growing propagules for field application, as well as the conservation of germplasm. *In vitro* methods are employed to preserve banana species that are predominantly propagated by vegetative means. Banana species can be stored at a temperature of 28 °C under ideal growth conditions. Nevertheless, it is important to relocate each culture at intervals of 2-4 months. The utilization of slow growth media conservation offers the benefit of minimizing the need for sub-cultures, leading to substantial reductions in labor requirements. The germplasm is easily obtainable for retrieval, duplication, and distribution (Houwe IV et al., 2004). The concealment of development is often accomplished by making various alterations to the physical and chemical conditions of the tissue-culture environment. The primary and widely associated factor that inhibits the growth of bananas is low temperature. This approach has consistently been utilized for numerous years to protect the International *Musa* Germplasm collection at the INIBAP (International Network for the Improvement of banana and Plantain) Transit Centre at K.U.Leuven. Banana shoots are cultivated at a temperature of 16 ± 1 °C. A cluster of 20 replicates of shoot culture cultivated on MS medium, supplemented with 30 g L^{-1} sucrose, 2.25 mg L^{-1} BA, and 0.175 mg L^{-1} IAA, represents each incremental growth in the population. The duration of sub-culture intervals often spans from one to several years, although there are notable differences across various genotypes. According to a study by Houwe et al. (1995), some genotypes can be sustained for a period of 20 months, but others need to be sub-cultured every few months. The lack of genetic diversity has led to the demise of several indigenous wild varieties of banana. Therefore, it is crucial to give priority to the preservation of our biodiversity (Fig. 4).

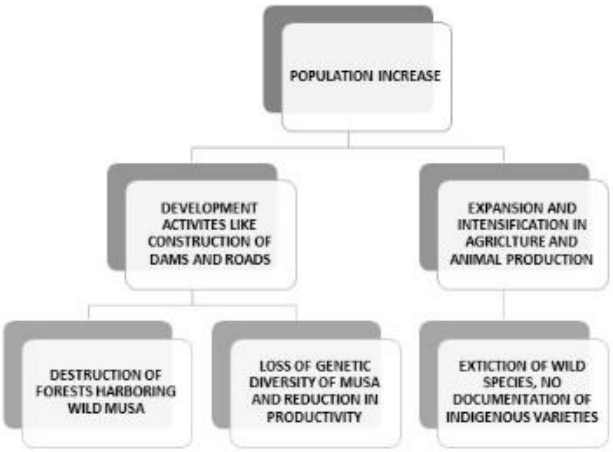

Fig. 4. Conservation is important to protect the plant variety as this flowchart showing as the population increases the loss of diversity increase.

Techniques for preserving biological samples in a controlled laboratory environment

The conservation of seed structure is not feasible or has limitations for species that do not produce seeds or mostly reproduce by vegetative means, such as banana and plantain (*Musa spp.*). Other crops, such as potato (*Solanum tuberosum*), yam (*Dioscorea spp.*), cassava (*Manihot spp.*), sweet potato (*Ipomea batatasi*), or sugar cane (*Saccharum spp.*), either possess infertile genetic makeup or produce seeds that are not useful for conserving specific quality traits. Cultivating these plants as field crops is the most commonly acknowledged approach for conserving their genetic resources. Prioritizing the gene pool should be the first step in formulating a conservation strategy, rather than focusing on progress. Merely establishing plantations in the field will not suffice to fulfill the needs of preserving native plant species. It is improbable that a single preservation technology will meet the criteria of a gene pool. While there may be exceptions, it is commonly acknowledged that employing a combination of *in situ* and *ex situ* conservation methods is generally considered to be rational. The image outlines many conservation tactics, such as slow growth storage, cryomoderate preservation, continuous sub-culturing gene-bank storage, *in situ* conservation, seed storage, and *in vitro* conservation of DNA clones, pollens, shoot tips, and other similar methods. The utilization of the number 5 can be employed for the conservation of these crops. Biotechnology is employed to harness plant genetic resources through large-scale asexual reproduction in a regulated setting, to change genetic characteristics, to tackle problems related to plant diseases, and to securely transmit germplasm. Moreover, it is employed to characterize and conserve germplasm in a controlled laboratory environment in order to amplify the advantages of diverse applications. *In vitro* protection is crucial for crops that display seed dormancy and those that reproduce through clonal methods. Storing them in the field gene-bank in the traditional manner involves some dangers. *In vitro* preservation involves a sequence of developments that starts with the collection and identification of diseases, followed by their elimination and storage, and ultimately culminating in their distribution and utilization. The utilization of *in vitro* collection offers significant benefits in addressing issues associated with the accessibility, state, and movement of germplasm that needs to be gathered in the field. *In vitro* capacity refers to the process of creating cultures, preferably of a type that has a low chance of somaclonal modification, and then transferring them to slow growth storage or cryopreservation. To ensure the long-term integrity of DNA, it is advisable to employ cryopreservation, a technique that entails keeping it in liquid nitrogen. Different cultures have been well preserved using cryopreservation, with cell cultures being the easiest to handle and shoot-tips being the most difficult. Vitrification, an alternate cryopreservation technique, offers the potential to overcome difficulties associated with preserving highly organized materials like shoot-tips. Another fascinating method of preservation involves the application of artificial seed technologies. The degree of progress in *in vitro* conservation differs across different crops, with banana being the most advanced crop in

which this strategy demonstrates its benefits. The following are some of the *in vitro* procedures that have been mentioned:

Sub-culturing involves the constant transfer of plant material to fresh tissue culture conditions in order to accomplish *in vitro* preservation. Nevertheless, this approach is unsuitable for the extended or intermediate preservation of germplasm because to the potential hazards of microbial contamination, equipment failure, and the accompanying labor and costs. Furthermore, widely experienced problems include somaclonal fluctuation and the loss of morphogenic ability. Two potential methods to address these issues are the implementation of a slow growing culture and the utilization of cryopreservation techniques. CryoModerate development strategies pertain to methods employed for the preservation of materials over a moderate duration. Standard freezing techniques are used to preserve isolated substances like apices, whereas extended-term preservation is accomplished by utilizing liquid nitrogen at a temperature of -196 °C. This novel method enables the storage of plant material without the necessity of adjustment or rotation, safeguards it against contamination, and necessitates minimal maintenance. Multiple cryopreservation procedures are accessible, such as freezing, ultra-rapid freezing, vitrification, encapsulation/dehydration, and encapsulation/vitrification. More investigation is required to examine the utilization of current cryopreservation techniques on a significant scale within a gene-bank environment, as well as to establish procedures for conserving more species.

Slow growth storage is a technique used in plant tissue culture to preserve *in vitro* cultures for a period of time ranging from two weeks to one year or longer without affecting their viability and potential for regeneration. The objective of this approach is to achieve the maximum duration of sub-culture while minimizing any harmful impact on the plant tissues. Slow growth can be attained by employing any or all of the following methods: lowering temperature, incorporating growth inhibitors, decreasing oxygen concentration, reducing light intensity, diminishing the nutrient content of tissue culture media, selecting small explants, utilizing a small tissue culture vessel, and introducing chemicals with osmotic properties. The most commonly used method for reducing growth in slow growth storage is the 'cold storage' of shoot cultures. The incubation at a temperature lower than that required for optimum growth will reduce the metabolic activities, such as respiration, water loss, wilting, and ethylene production. Reduced metabolic activities, in turn, will ensure the secure preservation of shoot cultures, resulting in the restricted growth of the plantlets. Slow growth storage is a valid *in vitro* approach to preserve several vegetative-propagated species by controlling the growth and development of plantlets, economizing storage space and labor, and reducing costs. It prolongs the timing between sub-cultures, lowers the risk of losing germplasm through handling errors, such as contamination problems, and decreases the risk of genetic instability due to the reduction in the number of sub-cultures. Slow growth storage is a short-to-medium-term storage option, while cryopreservation is a long-term storage option.

Cryopreservation refers to the process of preserving live organic material at extremely low temperatures, typically at or near the temperature of liquid nitrogen (-196 °C). At this temperature, all cellular division and metabolic processes are suspended. The plant material can be stored in this manner without alteration for many periods, with minimal maintenance. In addition to universal seeds, dormant buds, and certain dust, higher plant structures are unable to withstand temperature changes without protection. Before freezing, tests undergo cryoprotective treatment, which typically involves the application of chemicals such as dimethylsulphoxide (DMSO), sorbitol, mannitol, sucrose, and polyethylene glycol. The material's endurance can be influenced by its physiological condition. Cell suspensions exhibit resilience to freezing when employed during their exponential growth phase (cells are small and possess relatively low water content). A conventional method is available for the cryopreservation of cell culture (Fig. 5).

Cryopreservation is the optimal technique for the extended preservation of bananas, whilst slow growth storage is appropriate for shorter to medium-term conservation. Nevertheless, the utilization of slow growth media conservation emerges as the most beneficial and noteworthy method for the *in vitro* preservation of *Musa* species. This is because of its exceptional capacity for regeneration, which exceeds that of other conservation strategies. *In vitro* propagation, also known as tissue culture, involves the cultivation and proliferation of plants in a carefully regulated laboratory setting, apart from their original ecological surroundings. Bananas are often propagated asexually using suckers. The conventional approach is persistent, boring, and not particularly efficient in terms of generating uniform plants (Banaerjee and De Langhe, 1985). Typically, a plant yields just 5 to 10 offshoots

year^{-1} using traditional methods. In addition, the cultivation of bananas is largely affected by a wide range of diseases (Rahman et al., 2004). Consequently, the effectiveness of bananas decreases and the crop yield becomes extremely low. In order to overcome this limitation, the use of *in vitro* culture systems for the production of banana seedlings can be an efficient method for generating planting materials. A large number of genetically diverse and disease-free plants are regularly produced by the delivery of plant parts (explants) with high genetic potential (Martin et al., 2006). Plant replication is commonly carried out in this process. A range of drugs was administered using a diluted concentration of MS medium (Murashige and Skoog media), along with different concentrations of growth regulator to promote successful root adoption. Tissue culture plants exhibit vigorous growth, proliferate more rapidly, and require less time to establish and harvest. The tissue culture approach produces a greater yield compared to standard sword suckers (Vasil et al., 1982). The tissue culture process involves establishing different cells or tissues under suitable culture conditions, followed by *in vitro* cell proliferation and subsequent plant regeneration (Johri, 1982). A lack of proper procedures and insufficient knowledge about nutrient media and optimal physical and chemical conditions are the main reasons why most plant cells or tissues fail to develop into complete plants *in vitro*. These factors are crucial for the proper growth of cells, tissues, and organs (Mendes et al., 1999). In banana, the most common method of propagation is to use actively growing parts, such as the meristem portion of stems, known as micro-cuttings. This is done through *in vitro* micro-propagation, where different concentrations of cytokinins and auxins, such as BAP (6-Benzylaminopurine), NAA (1-Naphthaleneacetic acid), and TDZ (Thidiazuron), are used (Molina et al., 2008; Wojtania and Gabryszweska, 2001). Several *Musa* types have been successfully cultivated in a standardized regenerated media.

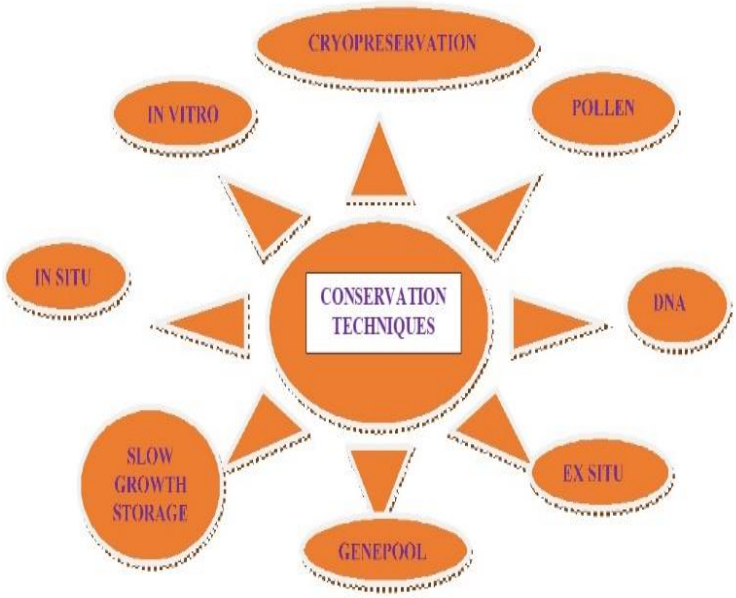

Fig. 5. Different type of conservation technique which can be used to save the biodiversity in many ways for our future generations.

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Diseases of bananas

Diseases continue to be a major challenge for banana cultivation globally. The most destructive disease is Fusarium wilt, tropical race four (TR4), which can destroy more than 50% of the world's bananas. This disease, transmitted through soil, poses a significant threat to the Cavendish banana trade and is widespread in several countries. Other significant diseases include Sigatoka, banana bunchy top virus, and Banana Xanthomonas Wilt. Sigatoka, caused by *Mycosphaerella fijiensis*, is typically controlled by the application of fungicides, which can result in ecological damage and financial burdens for farmers. Banana bunchy top virus is prevalent in Asia and Africa and is primarily transmitted by aphids and contaminated planting material. Banana Xanthomonas Wilt, caused by the bacterium Xanthomonas campestris pv. *Musa*cearum, has caused significant outbreaks in East Africa over the past decade. Control measures for banana Xanthomonas Wilt include purifying work equipment, eliminating diseased plants, and remedying contaminated soil. However, maintaining the necessary degree of disease control in smallholder and subsistence farming situations is encountering difficulties (Buddenhagen, 2009; Eden-Green, 2004) is the most destructive disease. TR4 differs from the illness that devastated Gros Michel a century ago; in this case, it infects and kills Cavendish, as well as other varieties of the same species. TR4 has the ability to destroy more than 500th of the bananas now grown worldwide. The disease closely resembles race one and is transmitted through soil. There are no effective controls for this disease. Once the soil becomes infected, the pathogen can survive for an extended period of time (Butler, 2013; García-Bastidas et al., 2013). The transmission of the disease occurs through contaminated plants, dirt carried on footwear and clothing, mechanical assembly, and water, including irrigation systems and flooding. Originally believed to have originated in Thailand (Ordonez et al., 2015), it is now widespread in southeast Asia, including China, Taiwan, and the Philippines (Queensland Government Department of Agriculture and Fisheries, 2015). It poses a threat to both the Cavendish banana trade and the local Lakatan variety (Ploetz, 2015; Ploetz, 2015; Queensland Government Department of Agriculture and Fisheries, 2015). Recent records indicate the presence of this phenomenon in Pakistan, along the Indian border (Blomme et al., 2013), Lebanon (Syed et al., 2015), Jordan in the Middle East (Stover, 1990), and Mozambique in Africa (Arango Isaza et al., 2016). The study by Molina et al. (2008) reports that Cavendish bananas have been found to exhibit some level of tolerance but are still susceptible to Dark Sigatoka, a fungal disease caused by *Mycosphaerella fijiensis* (Morelet), which has a significant impact on banana crops in several countries (Stover, 1990). It is typically limited by the application of fungicides, but often requires spraying more than once week^{-1}. This has the potential to result in significant future ecological damage. Splashing is often limited to mechanical manufacturing activities, where the cost of management can account for up to 33% of the production expenses. Subsistence farmers

may not utilize those fungicides and should contend with the resulting losses, including reduced food production and financial income. Bunchy top, caused by the banana bunchy top virus, is prevalent in Asia and Africa, but currently absent in the Americas (Adegbola et al., 2013; Dale, 1987). The disease is already spreading rapidly throughout Africa, primarily transmitted by aphids and contaminated planting material. It has already caused significant damage to the smallholder-based Cavendish industry in Malawi and has also become established in Nigerian plantains (Harding et al., 1991; Hwang, 2004). Banana Xanthomonas Wilt is a disease that is caused by the bacterium Xanthomonas campestris pv. *Musa cearum*, a fungal pathogen, has been responsible for significant outbreaks in East Africa over the past ten years, spreading throughout Ethiopia, Uganda, Rwanda, Burundi, the Democratic Republic of Congo, Tanzania, and Kenya (Kumar et al., 2011). The micro-organisms are transferred through the soil and on decaying organisms (Molina et al., 2008). Control can be achieved by decontaminating work equipment, eliminating diseased plants, and remedying contaminated soil. However, maintaining the necessary degree of disease control in smallholder and subsistence farming situations is encountering difficulties.

Transgenic banana

The development of disease-resistant banana and plantain varieties by genetic modification is the foundation upon which practical advancements in yield production can be achieved. While there are some natural sources of protection against common diseases and pests in both landrace and wild banana species, developing disease-resistant bananas through traditional breeding is challenging due to factors such as long generation times, varying levels of ploidy, sterility of most edible cultivars, and limited genetic variability (Tripathi et al., 2005). Furthermore, there are certain illnesses for which the sources of blockage are unknown, with a notable example being the banana bunchy top virus and banana bacterial wilt. Biotechnology is increasingly being used globally to aid and increase the management and enhancement of banana and plantain crops, complementing the results produced through conventional breeding methods. Tissue culture has been employed to generate pathogen-free plant material, therefore reducing the transmission of diseases that may occur through the use of conventional suckers in propagation. Genetic transformation is a method used to generate disease-resistant bananas. The current endeavors to develop resistance against bacterial wilt in bananas using Recombinant DNA technology are founded on the assumption that there are no well-established sources of resistance to this disease in banana germplasm, thus necessitating the use of alternative methods such as classical breeding for improvement. There is an increasing need for enhanced varieties, especially those that provide resistance to the bacterial disease Xanthomonas wilt, as controlling bacterial diseases can be challenging. The utilization of pesticides for disease control is causing significant concern among ecologically conscious consumers. Developing resistant cultivars is often the optimal and cost-effective approach to controlling microbial infections. Attempts to create disease-resistant kinds of micro-organisms by conventional breeding have had limited results, as there is a scarcity of genetic variation that exhibits resistance to Banana Xanthomonas Wilt. Additionally, new strains of the pathogen continue to emerge. While there are known sources of germplasm that are resistant, it is anticipated that the production of improved banana germplasm by traditional breeding will likewise take 6-20 years (Balint-Kurti et al., 2001). Hence, the utilization of genetic transformation technologies could provide an alternative method for acquiring disease-resistant banana and plantain cultivars. The banana is genetically modified using the process of micro projectile bombardment of embryogenic cell suspensions or by utilizing Agrobacterium. The Agrobacterium system employs either embryogenic cell suspensions or top shoot meristems. Utilizing transformation techniques could expedite the creation of disease resistant banana plants, in a significantly faster time frame compared to traditional breeding, especially when introducing multiple genes simultaneously. The objective of transgenic banana is to confer resistance against nematodes, fungi, bacteria, and viruses. Efforts should be made to add optional characteristics such as drought tolerance into banana and plantain production. This would expand the geographical range of cultivation and significantly contribute to ensuring food security and improving the economic conditions in Africa. The transformation of sterile triploid dessert banana cultivars could potentially have a significant commercial impact. Currently, there are no genetically modified bananas available for purchase. However, there is great potential for genetic manipulation of banana species to enhance disease and pest resistance using existing modification techniques. The current transgenic bananas are either in greenhouse conditions or undergoing field experiments, and are therefore not yet available for commercial

use. Several transgenic banana lines have been subjected to greenhouse or field investigation, including those that provide resistance to nematodes, black and yellow Sigatoka (Balint-Kurti et al., 2001), as well as those that express the hepatitis B surface antigen.

Nanotechnology

Plant tissue cultures play a vital role in plant science, as they are important for conservation, large-scale propagation, genetic manipulation, generation of bioactive compounds, and plant enhancement. Currently, nanoparticles (NPs) have been successfully utilized to eliminate microbial impurities from explants in tissue culture experiments. Additionally, NPs have demonstrated their beneficial role in organogenesis, physical embryogenesis, somaclonal variation, genetic modification, and secondary metabolite production. The integration of nanotechnology into plant tissue culture has led to numerous achievements, highlighting the benefits of using nanoparticles (NPs) in this field. The discussion and presentation cover both the beneficial and adverse effects of using NPs in the environment. The need for further investigation in pursuit of specific answers to unresolved questions regarding systems is emphasized as the key to actual progress in plant nano-biotechnology. Recent research has been conducted on the revival of cryopreserved artificial seeds using gold nanoparticles, which has the potential to revolutionize preservation methods. Aggregation of nanoparticles in plant tissues during the initial phase of a cryopreservation technique, known as pre-culture, has the potential to significantly accelerate the thermodynamic processes that occur throughout the freezing and rewarming of biological material. Nanotechnology is regarded as a significant breakthrough in the twenty-first century that promises to enhance traditional agricultural practices and promote economic development by improving the management and conservation strategies while reducing the wastage of agricultural resources (Kulus et al., 2021). These technologies can also be used to preserve indigenous *Musa* types in a controlled environment. Plant tissue culture is a significant innovation being utilized in agronomy to facilitate plant development. Nanoparticles are also employed for the generation of secondary metabolites and the preservation of germplasm in plant tissue culture. They serve as disinfectants and supplements in this context. The preservation of germplasm is currently a matter of great concern. The application of nanotechnology in safeguarding plant germplasm has spurred the development of another beneficial aspect of nanotechnology.

Conclusions

India possesses a diverse range of indigenous banana species. Many producers of the tissue culture plants are still continuing to import banana stock cultures, which could potentially have a negative impact on Indian biodiversity. Utilizing the plant tissue culture technology is crucial for the propagation and preservation of indigenous plant species. Therefore, it is possible to implement effective conservation measures, particularly through *ex situ* conservation methods, to successfully protect and enhance the existing germplasm database using micro-propagation technology. The declining soil fertility leads to reduced production as a result of excessive use of inorganic fertilizers, which has resulted in alterations in the physical qualities of the soil, leading to a consistent decrease in the weight of bunches in all cultivars. Due to the reduction in available land for agriculture and the depletion of water resources, it is necessary to make intentional efforts to increase the efficiency of banana production while minimizing input costs. In order to fulfill the growing demand for bananas, the banana industry aims to achieve a production target of 60 million t by 2050. To do this, the industry must adopt a competitive approach, prioritize quality, and utilize the plant tissue culture process. Consequently, the research area of Indigenous banana is acknowledged for its requirements in terms of research, methodologies, and novel initiatives. The necessity for *in vitro* regeneration and protection of native banana species is highly significant in the present period.

Author Contributions

RB has drafted the article, data collection and analysis, articulation of graph, tables and figures for the article. SS have made a substantial contribution starting from concept and design of the article, interpretation of data for the article. TR revised it critically for important intellectual content, approved the version. SKS contributed in Formal Analysis and provided industrial inputs.

Acknowledgements

The authors are grateful to the Amity Institute of Biotechnology, Amity University, Noida for the invaluable support for providing platform rendered during the article preparation.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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