Indian J. Plant Genet. Resour. 30(1): 5-12 (2017)
DOI 10.5958/0976-1926.2017.00014.6

Changing Paradigms in Managing Agrobiodiversity through Use: An Appraisal

RS Paroda*[1] and Anuradha Agrawal[2]
[1] *Chairman, Trust for Advancement of Agricultural Sciences and President, Indian Society for Plant Genetic Resources, Pusa Campus, New Delhi-110012, India*
Former Secretary, DARE and Director General, ICAR, Government of India
[2] *National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi-110012, India*

The scientific and conscious management, use and conservation of agrobiodiversity has undergone several paradigm shifts in the past few centuries. In my own career, I did witness these changes occurring many times. Hence, I take this opportunity to delve upon some of the changes in the past and offer some suggestions that are required for needed action to ensure effective and long-term management of agrobiodiversity.

Biodiversity under Domestication

In nature, all organisms have been living in harmony for millions of years; humans (nomadic and forest tribes) were greatly dependent on the endless diversity among and within species, along with that of their habitats and ecosystems. When humans transited from nomadic hunter-gatherer to a more settled lifestyle due to adoption of agriculture some 12,000 years ago, they started to look for such bioresources which could provide them food, feed, fodder, fibre and improved livelihood. The intervention of humans by way of domestication and farming affected the pattern of evolution, diverting the selection from 'fitness' to that of 'human preference'. The available diversity of domesticated species, which provides the basis for the quality, range and extent of choices available to the humankind, is an outcome of such evolution influenced by frequent human interventions, especially by the farm women, over the millennia.

In this context, first we must recognize the difference between biodiversity and agrobiodiversity. Crops, wild species, animal breeds, fish, pollinators and several micro-organisms, which are constituents of agrobiodiversity, directly and indirectly help the humans. Had we not judiciously used agrobiodiversity, possibly our food basket would not have been what it is today. Yet we need to diversify it further to meet our increasing demands for food and nutrition.

By 2050, we would need 70% additional food grains. To ensure that, we must re-emphasize the need for using available genetic resources more effectively and efficiently. We have also seen that if these genetic resources were not protected properly by the tribal people living at subsistence level, possibly these resources would not have been saved. We are also aware that the number of species existing on the earth is enormous and research conducted so far is rather limited. We thus need to explore the unexplored having many valuable traits. Unfortunately, in the past we have been researching mainly on those crops which are of direct use to us. So far, the whole world is dependent on 60% of its energy and food requirement just mainly on three crops: wheat, rice and maize.

Origin and Ownership of Genetic Resources

As a student of genetics and plant breeding, we were taught two commonly held principles for the development of genetic resources and their use. These had been: i) genetic resources were a common heritage of human kind, and ii) they were freely exchanged. How true. If this would have not happened, many of the daily food staples like maize, potato, tomato etc., having their centres of origin in South America, would not have come to India and many crops like sugarcane, pulses, egg plant etc. would have not gone to other countries. We know it very well that rice in the South-East Asia, wheat in West Asia and North Africa, maize in the Central America, and potato in the Latin America and parts of Europe emerged as staple foods that proliferated and subsequently dominated the world food bowl along with millets, pulses, oilseeds, *Saccharum*, cucurbits, citrus,

---

**Author for Correspondence: Email- raj.paroda@gmail.com; taasiari@gmail.com*

Based on Plenary Lecture delivered during Ist International Agrobiodiversity Congress, New Delhi, India, November 6-9, 2016. See extended summary in Indian J. Plant Genet. Resour. 29(3): 225-229.

forage crops and many other species. Among the non-food crops, cotton, jute and bamboo are worth mentioning that have originated from the Indian sub-continent. Thanks to the great efforts of Vavilov, who had single handedly travelled the whole world when communication was so difficult and collected a large number of seeds and plants that enabled him to understand and suggest the concept of centres of origin of crop plants. Today, we fondly call these as Vavilovian centres of origin.

The collection, evaluation, exchange and utilisation of genetic resources in exotic areas accelerated during the second half of the 20th century. This enabled the whole world in boosting food production while keeping pace with the ever increasing world population. Today, when we look back at the degree of dependence on genetic diversity that came from outside the country, one would be amazed that many of those countries who today have gained/capitalised on agrobiodiversity resources did not have a single plant that originated in their country! This dependence is predicted to increase more in future, given the current trends of climate change, emerging needs for expanding our food basket and changing consumer preferences for more healthy and nutritious foods.

As stated earlier, till the late-twentieth century, genetic resources were exchanged freely, not only amongst farmers, but also between plant breeders and researchers within and outside the country. In the late 1980s, this perception got changed; with biodiversity being regarded as a treasure under the national sovereignty system. The paradigm shift from free flow of genetic resources to a restricted exchange emerged as a reality soon after the Convention on Biological Diversity (CBD) came into force in December 1993. Thus, germplasm exchange became operational under the legal instruments or *sui-generis syst*em as per guidelines of international treaties. The underlying idea was that if genetic resources are used to develop commercial products such as new plant varieties, then the subsequent benefits must be shared with the provider(s) of the genetic resources. Hence, the concept of free exchange of agrobiodiversity, has now been changed to protect the right of those who own the germplasm. Thus, the new legal issues that have now emerged prominently are restricting the flow of germplasm. This is an obvious challenge in the present context which has to be addressed jointly by all of us.

Humans–The Catalysts of Change

The obvious change in public perception towards genetic resources has been also due to an alarming rise in world population: since for thousands of years, population grew rather slowly, but in the last century it jumped dramatically. Between 1900 and 2000 the increase in world population was three times greater than the entire previous history of humanity– an increase from 1.5 to 6.1 billion in just 100 years. There are more than 7.4 billion humans living on earth today, whereas 200 years ago, this number was even less than 1 billion! It is expected that at this rate, the world would have around 9.7 billion humans by 2050. Hence, the balance in nature has enormously been disturbed. Mahatma Gandhi, the Father of Nation had said that 'nature has provided for everyone's need but not for everyone's greed'.

Unfortunately, the human greed has disturbed the entire equilibrium. Geologists have started predicting that almost 12,000 years of Holocene has come to an end. Why? Because it is the human beings who have adopted a path of complete destruction of life support systems. This new epoch is being said to have begun from 1950, when radioactive elements from nuclear testing were spread all over the globe and characterized by mass extinctions, plastic pollution, and spike in carbon emissions in the atmosphere. It is now said that we are entering into an era called 'Anthropocene', wherein anthropogenic activities have re-shaped the earth's land, oceans, air and biodiversity to an enormous extent. Consequently, biological diversity has significantly reduced, the earth has become warmer and all over the world we are facing greater incidence of natural catastrophic events.

A recent study shows that about 58 per cent of the world's land surface, and 9 out of 14 of the world's terrestrial biomes, have fallen below 'safe threshold' of biodiversity, impacting a wide range of services provided by biodiversity, including crop pollination, waste decomposition, regulation of the global carbon cycle, and socio-cultural services that are critical to human well-being. Another study has shown that over the past 500 years, rate of extinction of vertebrates, is a clear signal of elevated species loss which has markedly accelerated over the past hundreds of years. In fact, these rates are so high that life on Earth is embarking on its sixth greatest extinction event in its 3.5 billion years of history. In the Anthropocene, humanity faces the imperative question of how to transform agriculture enabling it to feed the world, contribute to eradicate poverty, and contribute to a stable planet. Most importantly, it has been said that averting a dramatic decay of biodiversity and the subsequent loss of ecosystem services is still possible through intensified conservation efforts, but that window of opportunity is rapidly closing. This we should not be allowed to happen and must ensure that this trend is reversed.

Global Outlook Towards Agrobiodiversity

Global thinking and inter-governmental approach to handle the management of genetic resources to improve food and nutrition security under the changing scenario witnessed many developments since the late 20th century. It started with the United Nations Conference on Human Environment held in Stockholm in 1972, with emphasis on population, agriculture and environment. Later the World Leaders congregated at the United Nation's Conference on Environment and Development (UNCED), also known as the 'Earth Summit' at Rio de Janeiro in 1992. One of the major outcomes of this was the adoption of Convention on Biological Diversity (CBD) in 1993, which directly addressed the ways to protect biological resources being are our life support system, from getting extinct. A major shift caused by the CBD was to place these resources under territorial sovereignty of individual nations where they are found or got originated, with legal rights to the nations to determine their access benefit sharing (ABS) system. For addressing trade related concerns, the World Trade Organization (WTO) was established which helped in enacting the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), including those related to agriculture (UPOV and patents).

Almost a decade later, the discussions surrounding the International Undertaking for Plant Genetic Resources (IUPGR) of the FAO culminated in the adoption of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) in 2001. The overall objectives of the ITPGRFA was to ensure conservation and sustainable use of PGRFA and to have both fair and equitable sharing of benefits derived from their use, in harmony with the CBD, for sustainable agriculture and food security. It also recognised for the first time the farmers' right on GRFA. The central piece of the treaty is the Multilateral System (MS) of facilitated access of PGRFA through a Standard Material Transfer Agreement (SMTA) that are freely accessible for breeders and researchers of member countries. The Treaty covers a series of crops listed in Annex 1, which includes 35 food crops and 29 forages. It also covers *ex situ* collection of those crops held by the CG genebanks. Though these crops, account for about 80 per cent of the world's food calories from plants, they do not represent all the 100 food crops of importance to food security and 18,000 forages of value to food and agriculture. Soybean, groundnut, sugarcane, oil palm etc. are among those crops that are still not included in Annex 1 even after 16 years of the Treaty implementation.

This treaty, while in harmony with the CBD, created an alternative multilateral ABS regime for the agricultural sector in order to facilitate access to, and the international transfer of, those plant genetic resources that are 'the raw material indispensable for crop genetic improvement' and thus important for global food security. More recently (2010), the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation (Nagoya Protocol) has been developed as a bilateral mechanism for ABS under CBD. It calls upon nations to develop effective legislative, administrative or policy measures to provide bilaterally those genetic resources that are within its jurisdiction and have been accessed in accordance with prior informed consent and on mutually agreed terms between the two parties.

India's Response to Changing Paradigms

India has been one of the first countries to develop and enact laws related to biodiversity, in response to the new regimes in international law concerning access, conservation and property rights on genetic resources. Obviously, these processes had not been easy. A formidable task was to maintain a balance between the new and traditional rights. Accordingly, three Acts were passed by the Indian Parliament in the beginning of current century in an attempt to protect the nation's biological diversity, IPRs and the interests of researchers, be those plant breeders or the farmers/farming communities. These relevant Acts are: i) the Protection of Plant Varieties and Farmers' Rights Act (PPVFRA), 2001; ii) the Biological Diversity Act (BDA), 2002; and iii) the Geographical Indication of Goods (Registration and Protection) Act, 2000. These legislative measures, in addition to providing enhanced intellectual property protection, emphasise the importance given to the rights of the farmers, the traditional knowledge, and the biological resources of the country. Having been associated with the framing and facilitating the process, it was highly satisfying to see that both laws got approved by the Parliament in a record time. The PPVFRA is a unique act, being the first in the world, that provides rights to the farmers to produce, sell and use their own seeds, besides the typical rights to them equivalent to those of breeders and researchers for the valuable genetic resources conserved by them. Hence, the law aims to protect the plant varieties developed through public and private sector research as well as those developed and conserved by the farmers and farming communities. Accordingly, under the provisions of this Act, a PPVFRA Authority has been established that not only registers the new varieties developed by the breeders and farmers but also ensures fair and equitable benefit sharing through the provision of a national Gene Fund.

The primary objective of the Biological Diversity Act, 2002, is to protect India's rich biodiversity and associated traditional knowledge against their use by others without sharing the benefits arising out of such use. It provides for the establishment of a National Biological Authority (NBA), State Biodiversity Boards and Biodiversity Management Committees with extensive powers to promote conservation, sustainable use and documentation of biological resources. Foreign organisations do require NBA approval in order to access biological resources. Provisions have also been made to set up biodiversity funds and management committees at the national, state and local levels.

The Geographical Indication of Goods (Registration and Protection) Act, 2000 aims to provide a comprehensive framework to facilitate the registration, conservation and protection of goods with a unique geographical identity. The Act provides for the establishment of a Geographical Indication Registry and an Appellate Board to take necessary action against infringement, if any.

Germplasm Flow under the New Regimes

In the pre-CBD era, all biodiversity was considered, managed and used as global public good, with easy access, and exchanged freely in the absence of ownership issues. In the present context, it would have been almost difficult for NI Vavilov to carry out his historical collection expeditions. India was importing more than 60-70 thousand accessions per year prior to CBD which has significantly gone down. India was also exporting around 20-25 thousand accessions per year, which has also declined significantly. Imagine, what would have been the food options for us had these regulations been in place prior to CBD when seeds of food crops like corn, potato, tomato, pepper, soybean etc. were shared to become our major food crops.

As a consequence of enacting legislative measures, the process of germplasm exchange invariably got declined globally. In retrospect, we have slowed down the whole process of germplasm exchange and use. Fortunately, many countries did share the germplasm with CG Centres, which is a major resource presently for multilateral exchange of crops listed under Annex I of the Treaty (ITPGRFA). Having been associated with the negotiations of the Treaty, it was decided then that a call would be taken later to include more crops but more than 20 years have passed and not a single species has been added to the Annex 1 list of 64 crops. Under the CBD, germplasm beyond the multilateral system (under the FAO umbrella of the CG system) can possibly be exchanged, under bilateral agreements and collaborative research projects. For bilateral exchange, the Nagoya Protocol has been developed, which now needs to be understood and followed by all the parties to the CBD for access to and benefit sharing derived from germplasm. So what has happened? Exchange of genetic resources, which was earlier decided by the scientists, has after the CBD, ITPGRFA and Nagoya Protocol, been taken care of by the bureaucrats and lawyers. Obviously, this is one of the major paradigm shifts that have occurred in GR management.

In India, there is still unsettled debate concerning exchange of germplasm both for the public and private seed sectors engaged in plant breeding. Even SMTA has not yet been put into practice for want of procedural clearances and lack of proper understanding. During mid-eighties, Indian Council of Agricultural Research (ICAR), as a policy, allowed free access to the parental lines of hybrids bred by the public system recognising well that seeds of these hybrids would otherwise not reach the end users i.e., the smallholder farmers. This very policy decision not only accelerated the coverage under hybrid seeds, resulting in increased crop productivity, but also strengthened existing private seed sector in India. On the contrary, there is an obvious hesitation to share the germplasm, either for the fear of loss of ownership or for biopiracy. Hence, there is an obvious need for trust-building and partnership. This would demand an enabling policy environment and clear understanding for sharing the germplasm as well as information between public and private sectors engaged in plant breeding.

Think Globally and Act Locally

In the present scenario, it is necessary that we think globally but take concrete measures to act locally. Action at the national/regional level is so critical today to research, document and conserve the available germplasm before it is lost forever. Despite the year 2016 being an International Year of Pulses, there was greater realisation that research on pulse crops had been quite inadequate. Charity begins at home. India is a gene rich centre. As one of the 8 mega gene centres of the world, it also has a strong national research and institutional system in place with adequate human resource. India also has a strong national agricultural research system (NARS). With respect to genetic resources, there are five bureaux dealing separately with plants, animals, fish, insects and microbes. Scientific and economic value of genetic materials are difficult to assess, as future problems and needs cannot be precisely anticipated. Moreover, feeding the ever-increasing world population would require either intensification of existing agricultural systems or by expansion into new lands. This means that optimal management of agricultural ecosystems and diversity of GR would be an essential part of any overall strategy for achieving this goal. In the past, national agricultural research systems, including that of India, had strong national breeding programs for developing improved varieties and hybrids. However, subsequently there became greater dependence on pre-breeding materials provided by the CG Centers. Unfortunately, over the years, efforts on pre-breeding also got declined at these Centers due to resource constraint. On the contrary, a paradigm shift from household food security to that of household nutritional security, demands much higher investments towards intensified scientific understanding of agriculturally important species (be those of crops, animals, insects, aquatic and microbial) as future genetic resource of considerable potential.

Conservation through a Continuum

During the second half of the 20th century, *ex situ* methods of germplasm conservation, especially the seed genebanks, were considered to be the panacea in the management of genetic resources. Everybody thought that because there was danger of extinction of diversity of plant genetic resources, their seeds be collected and conserved in the genebanks–irrespective of whether they are useful or otherwise. In most cases, once collected, seeds were retained in these genebanks for long term storage with not much efforts on their evaluation for the useful traits and documentation for use by the researchers. Hence, often these genebanks were considered as Black Box. On the contrary, less emphasis was given to protect vegetatively propagated plants or those which were considered recalcitrant. As a consequence, in many cases, useful variability got lost for want of alternative scientific storage systems such as tissue culture banks or cryobanks.

In retrospect, we now need those conservation measures that are low cost and more sustainable at varying eco-system level involving communities that are known to be the gene saviours. Also there is an urgency to develop a ‘conservation continuum’, encompassing *in situ*, on-farm, *ex situ*, permafrost and other conservation methods with adequate funding support.

Further, it is of prime importance that the farmers, livestock keepers, aquaculture practitioners or foresters, engaged in conserving useful varieties, breeds and species, derive direct (financial) or indirect (livelihood security) benefits for remaining engaged in such conservation activities. There must be a compensation mechanism for these unique conservation practices by the farming communities. We cannot expect them to continue serving the society while living at sub-sustenance level. Hence, national leaders/policy makers do have a responsibility towards ensuring that the process of natural evolution remains well supported in the best interest of future generations.

The first and second reports on the ‘State of the World’s Plant Genetic Resources’, brought out by the United Nations Food and Agriculture Organisation (FAO) provided authentic assessment of various conservation methods and the state of germplasm collections of plant genetic resources. It has documented more than 1,750 individual genebanks worldwide, of which about 130 hold more than 10,000 accessions each. Currently, about 7.4 million accessions are maintained globally. Analyses suggest that between 25–30% of the total holdings (or 1.9–2.2 million accessions) are quite distinct, with the remainder being duplicates held either in the same or, more frequently, a different collection. Crop wild relatives (CWR) do comprise 10% of these collections, but not much of them have been used so far. Around the globe, genetic resources are maintained in the genebanks at the local and national level by governments, universities, botanical gardens, NGOs, companies, farmers and others in the private and public sectors. They do house a wide range of different types of collections: national collections maintained for the long-term, working collections maintained for the medium- or short-term, collections of genetic stocks and others. When we look at the national genebanks around the world, to begin with, the N.I. Vavilov Genebank in Russia (VIR) was the largest in the past. But now, the Genebank in the USA is number one followed by those of India, China, Russia, Brazil, Japan and Korea. On the contrary, in some countries of the Central Asia and Caucus like Armenia, Georgia, Kazakhstan, Turkmenistan and Kyrgyzstan, where I had the privilege to work with their NARS, not even 2-3 scientists were deployed to work on their valuable genetic resources with practically no infrastructure for the national genebanks. Such national systems do need support, both in terms of infrastructure and capacity building. It is satisfying to note that in last more than a decade, each one of them have established their functional genebanks.

Programmes on *in situ* and on-farm conservation have recently gained tremendous impetus as these protect germplasm in their natural habitat and take into account social and cultural factors such as farmer's perceptions and knowledge. On-farm conservation entails the active participation of local communities in the documentation and description of local species and varieties in a catalogue or register, establishment of nurseries for multiplication and distribution of unique plant or seed material, the promotion of nutritional values and traditional recipes, the development of enterprises and market linkages for the sales of products or services based on local unique crop diversity, and safeguarding of unique species and varieties found on their farms. Thus, *in situ* and on-farm conservation efforts remain ineffective without participation of the local community. Traditionally, local farmers are known to maintain several indigenous crops on their farms, especially fruit species or varieties. Such farmers have been designated as 'Custodian Farmers', identified for actively maintaining and promoting agrobiodiversity and related indigenous technical knowledge, at farm and community level. Linking such farmers to the research institutions and genebanks for characterization and evaluation of the elite genotypes, providing technology for rapid multiplication and distribution of plants is the need of the hour. Documentation of traditional knowledge is another activity that not only ensures its protection against theft but also ensures financial benefits to the knowledge holder when commercial sectors exploit the knowledge. Scientific validation of such traditional knowledge is also essential for improved understanding of the ecological functions of agrobiodiversity especially in the context of physical environment and the socio-economic factors. There is urgent need to promote use of more nutritious species such as millets, indigenous fruits, vegetables, roots and tubers, as compared to major emphasis that we gave in the past to only few selected staples. We now need to ensure up-scaling and out-scaling of innovations to achieve dietary diversity and improved nutrition at household levels. Information systems are still weak and capacity building is urgently required.

It is indeed satisfying that permafrost conservation for plant genetic resources has now been put in place. The Svalbard Global Seed Vault (SGSV), established in 2008 inside a mountain on a remote Island in Svalbard archipelago, located half way between mainland Norway and 1000 km from North pole, provides a great safety as duplicate storage facility for all seeded PGRFA. It is a state-of-the-art seed storage facility built to withstand natural and man-made disasters. The Seed Vault is managed by Norway government. The seed samples are stored in a reinforced concrete tunnel drilled 70 m into a mountain, stored in foil packets at -18°C, and are expected to remain viable for thousands of years. Unlike the hundreds of existing seed banks, the vault does not rely solely on artificial refrigeration systems but even if the power fails, the temperature are expected to never rise above freezing. The SGSV is built to store a massive 4.5 million varieties of crops, with each variety containing around 500 seeds. The Global Crop Diversity Trust works in conjunction with the Norway government to manage the seeds in the vault. The vault currently holds 880,837 seed samples of 5,403 species belonging to 71 institutes. These seeds were donated by almost every country in the world, so there is a massive variety of seeds represented. All germplasm from CGIAR genebanks has been safely duplicated here. If a crop is lost through natural disaster or war and a seed bank is destroyed, a government could request replacement seeds from the vault. A recent example of this was witnessed when ICARDA retrieved part of its seed collection that from the SGSV to fulfil requests for germplasm use. ICARDA's original Gene Bank in Aleppo, Syria was forced to be shifted, after the war in the area. ICARDA had replicated over 80% of its collection in the SGSV, prior to the conflict. The seeds in ICARDA are globally sought due to unique landraces and wild relatives of cereals, legumes and forages collected from the Fertile Crescent of Western Asia. A total of 38,073 seed samples were sent to Lebanon and Morocco, ICARDA's new sites for genebank facilities, in the cropping seasons 2016 and 2017. Of these 15,000 accessions (including bread and durum wheat, lentil, faba bean, chickpea and grass pea) multiplied in 2016 have been sent back for safe duplication to SGSV on February 22, 2017. This proves to be a classical demonstration of the collective wisdom of policy makers, scientists and farmers who have contributed in the genetic resources movement in the past few centuries!

Genetic Diversity–Use it or Lose it!

What we now know is that there is less use of genetic diversity today than yesteryears which led to attaining the Green Revolution. The Food and Agriculture Organization of the United Nations (FAO) has, therefore, initiated with the support of Bill and Melinda Gates Foundation (BMGF), a project to strengthen plant breeding capacity and research on global scale, so that use of genetic resources is enhanced globally. This project, known as the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB), is a multi-partner platform with an aim to improve the institutional capacity for effective crop variety development and their distribution through seed systems. More details are available at: http://www.fao.org/in-action/plant-breeding/en/.

It is well documented that the use of PGR has globally declined. Many countries are not laying enough emphasis on pre- breeding and generation of genetic variability for crop improvement. They are largely dependent on import of pre-breeding materials mainly from the CG centres. In view of this, plant breeding must be brought back in the forefront.

Many stalwarts like Drs Norman Borlaug, GS Khush and SK Vasal had achieved great strides in varietal improvement and adaptation, mainly due to extensive use of genes from landraces and wild relatives. No doubt, working with wild relatives and species is more difficult and require good infrastructure facilities, yet they are very important in the current context of climate change.

Of course, there are several other reasons for the decline in use of germplasm. As already mentioned, access to useful germplasm is becoming more difficult due to existing new regulatory regimes. In addition, the research on traits of interest and the partnership in sharing germplasm is badly lacking. Over all, efforts on pre-breeding are declining due to lack of funding to the National Agricultural Research Systems (NARS) and CG Centers. On the other hand, the requests for germplasm by the breeders has also declined due to lack of digitization, proper evaluation for useful traits, germplasm characterisation and the existing regulatory systems.

Advances in New Science for Agrobiodiversity Management

We are currently in an exciting scientific era, were genome decoding of organisms is becoming almost a routine activity and the possibility to precisely tailor structure and function of organisms is becoming a reality with new tools of biotechnology, especially gene editing using Crisper-Cas technology, advances in omics, space technology and bioinformatics unraveling deeper mysteries of life. New technologies pervading agriculture in terms of smart-phones, satellite imaging, phenotyping using drones, IPM, automated farm practices, decision support systems for NUE etc. are helping farmers to grow more food on their land while reducing cost on water, fertilizer, pesticides etc.

However, the availability of appropriate planting material/breeds remains the most critical factor for enhancing productivity, adaptability and resilience of agro-ecosystems. Developments in science and technology in the areas of genetic engineering, genomics, biotechnology, nanotechnology, bioinformatics, synthetic biology etc. have increased the speed, scale and efficiency in research outputs. These technologies are the game changers that will dictate how genetic resources are researched in future and used effectively. Nonetheless, existing agrobiodiversity would remain the "hardware and software codes of nature" requiring systematic deciphering for designing agricultural crops and breeds for their use through new science. Before the emergence of modern era of use of 'gene guns' by the biotechnologists or plant breeders to transfer the desirable new genes into designer crops, the farming households assessed in their fields and courtyards the semi-wild and semi-cultivated plants for their existing strengths and weaknesses, and selected desirable traits while minimising the undesirable. Nevertheless, the products of biotechnology will also have to be field-tested besides undergoing biosafety tests before their identification and release as superior varieties for commercial cultivation. An important aspect with application of new technologies for agricultural production would be to generate awareness and dispel fears in the minds of general public about the use of new products (*e.g.* golden rice) that are outcomes of cutting-edge technologies as international public goods. With new advances for gene editing, the opportunities to accelerate crop breeding and use of germplasm have increased significantly.

Conclusions

Paradigm changes in agrobiodiversity management in the scientific, social, legislative/regulatory and governance realms have been inevitable, and will continue to happen in the future. That's because human needs and expectations do keep on changing from time to time. To ensure synergy among agrobiodiversity management and agricultural development, the role of stakeholders is crucial, especially in the developing countries that are considered gene-rich. Also a main paradigm shift in agriculture is needed to move from sustained food security to that of household nutritional security. For this, there is an urgent need for higher research investments and more intensified scientific investigations of agriculturally important species (be those of crops, animal, aquatic and microbial). Ecosystem services must ensure synergies between conservation, sustainable agricultural production and sustainable livelihoods.

As transboundary problems continue to rise (e.g. Ug 99 and blast in wheat, Fusarium wilt race 4 in banana etc.), it becomes imperative to carry out research in partnership mode, across national boundaries. To do so, there is great need to understand, adopt and practice access and benefit sharing (ABS) mechanisms, through enabling policy environment, proper public awareness and capacity building. Also the NARS need to build their Gene Funds to sustain activities around agrobiodiversity conservation and management while broadening the genetic base to diversify the current food basket.

Further, for an effective management of genetic resources a paradigm shift from conservation to that of conservation through use is necessary. This would require a holistic approach around *ex situ*, *in situ* and on-farm conservation involving all the stakeholders (farmers, breeders, researchers etc.). Most importantly, emphasis should now be on livelihood perspective, where genetic resources form important asset for much needed livelihood security, going beyond their direct contribution to food and income to more dynamic and less visible ways in which they enable rural households to manage various forms of uncertainty and risk, maximise use of other productive assets, and facilitate both diverse and sustainable livelihood strategies. Time is now for action and not just talk in order to ensure better future for coming generations.