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Managing Agrobiodiversity through Use: Changing Paradigms

Scientific and conscious management, use and conservation of agrobiodiversity have undergone many paradigm shifts in the past few centuries. Management of agrobiodiversity, including its conservation and use, is extremely important for the welfare of society at large. Some suggestions are given below to ensure its effective and long-term management.

Biodiversity under Domestication

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

First, a clear understanding between biodiversity and agrobiodiversity needs to be grasped. Biodiversity is essential for food security and nutrition. Thousands of interconnected species make up a vital web of biodiversity within the ecosystems upon which global food production depends. With the erosion of biodiversity, humankind loses the potential to adapt ecosystems to new challenges such as population growth and climate change. Achieving food security for all is intrinsically linked to the maintenance of biodiversity. Agrobiodiversity is the result of the interaction between the environment, genetic resources and management systems and practices used by culturally diverse people, and therefore land and water resources are used for production in different ways. Thus, agrobiodiversity encompasses the variety and variability of animals, plants and micro-organisms that are necessary for sustaining key functions of the agro-ecosystem, including its structure and processes for, and in support of, food production and food security (FAO, 1997). Local knowledge and culture can, therefore, be considered as integral parts of agrobiodiversity, because it is the human activity of agriculture that shapes and conserves this biodiversity. Many people's food and livelihood security depends on the sustained management of various biological resources that are important for food and agriculture. Agricultural biodiversity, also known as agrobiodiversity, or the genetic resources for food and agriculture, includes: harvested crop varieties, livestock breeds, fish species and non-domesticated (wild) resources within field, forest and rangeland including: tree products; wild animals hunted for food and in aquatic ecosystems (e.g. wild fish); non-harvested species in production ecosystems that support food provision, including soil micro-biota, pollinators and other insects such as bees, butterflies, earthworms and greenflies; and non-harvested species in the wider environment that support food production ecosystems (agricultural, pastoral, forest and aquatic ecosystems). Had we not judiciously used agrobiodiversity, our food basket may not have been what it is today. Yet there is a need to diversify it further to meet increasing demands for food and nutrition (Paroda and Agrawal, 2017).

By 2050, we will be requiring 70% additional foodgrains. To ensure this happens, use of available genetic resources needs to be more effective and efficient. If these resources had not been protected properly by tribals living at subsistence level, vital resources would possibly not have been saved. Further, the number of species existing on the earth is enormous, but research conducted on them so far has been limited. Unfortunately, in the past, research was mainly on crops that were of direct use to humans. The whole world is dependent for 60% of its energy and food requirements on three crops – wheat, rice and maize (Swaminathan, 2011; 2016).

Origin and Ownership of Genetic Resources

Earlier, two common principles were posited for the development of genetic resources and their use – genetic resources were considered a common heritage of humankind; and they were freely exchanged. If this were not to have happened, many of the daily food staples like maize, potato and tomato, having their centres of origin in South America, would not have come to India, and many crops like sugarcane, pulses and eggplant would not have reached other countries. It is well known that rice in south-east Asia, wheat in west Asia and north Africa, maize in central America and potato in Latin America and parts of Europe, emerging as staple foods, proliferated and subsequently dominated the world food bowl along with millets, pulses, oilseeds, saccharum, cucurbits, citrus, forage crops and many other species. Among non-food crops, cotton, jute and bamboo are worth mentioning, having originated from the Indian sub-continent. Vavilov travelled the whole world and collected a large number of seeds and plants, which enabled him to understand and suggest the concept of centres of origin of crop plants. Today, these are fondly called Vavilovian centres of origin (FAO, 1999; Frison *et al.*, 2011; Paroda and Agrawal, 2017).

The collection, evaluation, exchange and utilization of genetic resources in exotic areas accelerated during the second half of the 20th century. This enabled the whole world to boost food production while keeping pace with an ever-increasing population. India looks back with amazement at its degree of dependency on the genetic diversity that came from outside. India, and many other countries, capitalized on agrobiodiversity resources, though there was not a single plant that originated from within the country. This dependency is predicted to increase more in future, given the current trends of climate change, an expanding food basket and changing consumer preferences towards healthy and nutritious food (Mohapatra, 2016; Upadhyay, 2016).

As stated earlier, until the late 20th century, genetic resources were exchanged freely, not only among farmers but also between plant breeders and researchers within and outside the country. In the late 1980s, this perception changed, with biodiversity being regarded as a treasure and the subject of national sovereignty. This 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 instrument or *sui generis* system, as per the 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 resource. Hence, the concept of free exchange of agrobiodiversity was changed to protect the rights of the owners of the germplasm. Thus, new legal issues, which prominently emerged, restricted the flow of germplasm. This is an obvious challenge that must be addressed jointly by all (Paroda and Agrawal, 2017).

Humans – the Catalysts of Change

The obvious change in public perception towards genetic resources has also been due to an alarming rise in the world's population. For thousands of years, the population grew rather slowly, but in the last century it jumped dramatically. Between 1900 and 2000, the increase in the world's population was three times greater than in the entire history of humanity – an increase from 1.5 billion to 6.1 billion. There are more than 7.5 billion humans living on earth today, whereas 200 years ago, this number was less than a billion. It is expected that at this rate the world will have around 9.7 billion people by 2050 (Swaminathan, 2016). Hence, the balance of nature has been massively disturbed. Mahatma Gandhi, the Father of the Nation, had said that 'nature has provided for everyone's need but not for everyone's greed'.

Unfortunately, human greed has disturbed the equilibrium. Geologists have begun to predict that almost 12,000 years of the Holocene have come to an end. Why? Because it is human beings that have adopted a path of destruction of the life-support system. A new epoch is said to have begun around 1950, when radioactive elements from nuclear testing were spread over the globe, and has been characterized by extinctions, plastic pollution and a spike in carbon emissions in the atmosphere. It is now said that we are entering an era called 'Anthropocene', wherein anthropogenic activities are reshaping the earth's land, oceans, air and biodiversity. Consequently, biological diversity has significantly reduced, the earth has become warmer, and all over the world we are facing greater incidences of natural catastrophic events (Paroda and Agrawal, 2017).

A recent study has shown that about 58% of the world's land surface, and 9 out of 14 of the world's terrestrial biomes, have fallen below the '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 sociocultural services critical for human well-being. Another study has shown that over the past 500 years, the rate of extinction of vertebrates is a clear signal of elevated species loss, which has markedly accelerated over the past hundred years or so. In fact, these rates are so high that life on the earth is embarking on its sixth greatest extinction event in its 3.5 billion-year history. In the Anthropocene, humanity faces the question of how to transform agriculture to enable it to feed its population, eradicate poverty and contribute to a stable planet. Most importantly, it has been said that averting a dramatic decay in biodiversity and subsequent loss of ecosystem services is still possible through intensified conservation efforts, but this window of opportunity is rapidly closing. This cannot be allowed to happen, and strenuous efforts need to be made to ensure that it does not.

Global Outlook towards Agrobiodiversity

Global thinking and intergovernmental approaches to managing genetic resources to improve food and nutritional security within this changing scenario have witnessed many developments since the late 20th century. They started with the UN Conference on Human Environment held in Stockholm in 1972, with its emphasis on population, agriculture and environment (Philippe, 1972). Later, world leaders congregated at the UN 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 the Convention on Biological Diversity (CBD) in 1993, which directly addressed ways to protect biological resources, being our life-support system, from becoming extinct. A major shift caused by the CBD was to place these resources under the territorial sovereignty of individual nations where they are found or where they originated, with legal rights of the nations to determine their own system of access and benefit sharing (ABS). For addressing trade-related concerns, the World Trade Organization was established, which helped to enact the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), including those related to agriculture (International Union for the Protection of New Varieties of Plants (UPOV) and patents) (FAO, 1999; Frison *et al.*, 2011; Kotschi and Lossau, 2011; Paroda and Agrawal, 2017).

Almost a decade later, discussions around 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 objective 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 recognized for the first time farmers' rights on GRFA. The centrepiece of the treaty was the multilateral system (MLS) of facilitated access of PGRFA through a Standard Material Transfer Agreement (SMTA), which was freely accessible for breeders and researchers of member countries. The treaty covered a series of crops listed in Annex 1, which included 35 food crops and 29 forages. It also covered *ex situ* collections of those crops held by the CG gene banks. Though these crops accounted for about 80% of the world's food calories from plants, they did not represent all 100 food crops of importance to food security and 18,000 forages of value to food and agriculture. Soybean, groundnut, sugarcane and oil palm were among those that were still not included in Annex 1 even 16 years after the implementation of the treaty.

This treaty, while in harmony with the CBD, created an alternative multilateral ABS regime for the agriculture sector to gain access to, and transfer, those plant genetic resources that were 'the raw material indispensable for crop genetic improvement', and thus were important for global food security. In 2010, the Nagoya Protocol on Access to Genetic Resources, and the fair and equitable sharing of benefits arising from their utilization, was developed as a bilateral mechanism for ABS under CBD. It called upon nations to develop effective legislative, administrative and policy measures to provide, bilaterally, those genetic resources that were within their jurisdiction and which were accessed in accordance with prior informed consent and on mutually agreed terms between two parties (FAO, 2011; Hodgkin *et al*., 2016).

India's Response to Changing Paradigms

India has been one of the first countries to develop and enact laws relating to biodiversity, in response to new regimes in international law concerning access, conservation and property rights on genetic resources. These processes have not been easy. A formidable task was to maintain a balance between new and traditional rights. Accordingly, three Acts were passed by the Indian Parliament at the beginning of the current century in an attempt to protect the nation's biological diversity, IPR and the interests of researchers, be they plant breeders or farmers/farming communities (Batur and Dedeurwaerdere, 2014). The three Acts were: (i) the Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA) 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, emphasized the importance given to rights of farmers, the traditional knowledge and the biological resources of the country. The PPV&FRA is a unique Act, being the first in the world to provide rights to farmers to produce, sell and use their own seeds, equivalent to those of breeders and researchers over the valuable genetic resources conserved by them. Hence, the law aims to protect plant varieties developed through public and private sector research as well as those developed and conserved by farmers and farming communities. Accordingly, under the provisions of this Act, a PPV&FRA authority has been established that not only registers new varieties developed by breeders and farmers but also ensures fair and equitable benefit sharing through the provision of a national gene fund (Paroda and Agrawal, 2017).

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 organizations require NBA approval to access biological resources. Provisions have also been made to set up biodiversity funds and management committees at the national, state and local level.

The Geographical Indication of Goods (Registration and Protection) Act 2000 aims to provide a comprehensive framework to facilitate 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 any necessary action against infringement.

Germplasm Flow under New Regimes

In the pre-CBD era, all biodiversity was considered, managed and used as a global public good, with easy access, and was exchanged freely. In the present context, it would have been difficult for N.I. Vavilov to carry out his historical collection expeditions. India imported 60–70,000 accessions p.a. prior to CBD, which reduced significantly. India also exported around 20–25,000 accessions p.a., which also declined. 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 and became our major food crops.

As a consequence of enacting legislative measures, invariably the process of germplasm exchange declined globally. In retrospect, the whole process of germplasm exchange and use has slowed down. Fortunately, many countries did share the germplasm with CG centres, which are a major resource for multilateral exchange of crops listed under Annex I of the treaty (ITPGRFA). During the treaty negotiations, it was decided 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 list of 64 crops. Under the CBD, germplasm beyond the multilateral system (under the FAO umbrella of the CG system) can 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. But not much progress has been made. Exchange of genetic resources, which was earlier decided by scientists, after the CBD, the ITPGRFA and the Nagoya Protocol, has been taken care of by bureaucrats and lawyers. Obviously, this is one of the major paradigm shifts that has occurred in GR management. It has halted exchange of germplasm, affecting agriculture a great deal (Batur and Dedeurwaerdere, 2014; Paroda and Agrawal, 2017).

In India, there is still debate concerning exchange of germplasm, both for 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 the mid-1980s, the ICAR, as a policy, allowed free access to parental lines of hybrids bred by the public system, understanding well that seeds of these hybrids would otherwise not reach end-users, i.e. the smallholder farmers. This very policy decision not only accelerated coverage with hybrid seeds, resulting in increased crop productivity, but also strengthened the existing private seed sector in India. Nevertheless, there is an obvious hesitation to share germplasm, out of fear of either biopiracy or loss of ownership. Hence there is a need for much-needed trust building and partnership. This demands an enabling policy environment and a clear understanding for sharing germplasm as well as information between public and private parties engaged in plant breeding.

Think Globally, 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 extremely critical for research, documentation and conservation of the available germplasm before it is lost for ever. Despite 2016 being the International Year of Pulses, there is greater realization that research on pulse crops has been inadequate. India is a gene-rich centre. As one of the eight mega-gene centres of the world, it also has a strong NARS with adequate human resources. 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 is difficult to assess, as future problems and needs cannot be precisely anticipated. Moreover, feeding the ever-increasing population would require either intensification of existing agricultural systems or expansion into new areas. This means that optimal management of agricultural ecosystems and diversity of genetic resources would be an essential part of any overall strategy for achieving this goal. In the past, NARS had strong national breeding programmes for developing improved varieties and hybrids. However, subsequently, there was greater dependence on pre-breeding materials provided by the CG centres (Khush, 2016; Paroda and Agrawal, 2017). Unfortunately, over the years, efforts on pre-breeding materials have also declined at these centres due to resource constraints. A paradigm shift from household food security to that of household nutritional security demands much higher investment in intensified scientific understanding of agriculturally important species (be they crops, animals, insects, aquatic species or microbes) as future genetic resources of great potential.

Conservation through Continuum

During the second half of the 20th century, *ex situ* methods of germplasm conservation, especially seed gene banks, were considered a panacea in the management of genetic resources. Everybody thought that because there was a danger of extinction of diversity of plant genetic resources, their seeds should be collected and conserved in gene banks, irrespective of whether they were useful. In most cases, once collected, seeds were retained in these banks for long periods with not much effort given to their evaluation for useful traits or documentation for use by researchers. These gene banks were often considered as 'black boxes'; but unless you know the useful traits of the germplasm collections, how can these be utilized for crop improvement? Also, less emphasis was given to protect vegetatively propagated plants or those that were considered recalcitrant. As a consequence, in many cases, useful variability was lost for want of alternative scientific storage systems such as tissue culture banks or cryobanks.

There is a need to establish a clonal bank repository at the national level along the lines of a national seed gene bank, where, in one place, or its designated regional centres in the country's various agro-ecological zones, most of the vegetatively propagated plants can be maintained, researched and conserved for present and future use. In retrospect, there is now a need for conservation measures that are low-cost and more sustainable at various ecosystem levels, involving communities known to be '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 (Paroda and Agrawal, 2017).

Further, it is of prime importance that farmers, livestock keepers, aquaculture practitioners and foresters engaged in conserving useful varieties, breeds and species derive direct (financial) or indirect (livelihood security) benefits in order to remain occupied in such conservation activities. There must be a compensation mechanism for farming communities employing their unique conservation practices to serve society continuously. Hence, national leaders/policy makers have a responsibility to ensure that the process of natural evolution remains well supported in the best interests of future generations.

The first and second reports on the State of the World's Plant Genetic Resources, brought out by the FAO, provided an authentic assessment of various conservation methods and the state of germplasm collections of plant genetic resources. It documented more than 1750 individual gene banks worldwide, of which about 130 hold more than 10,000 accessions each. Currently, about 7.4 million accessions are maintained in gene banks globally. Analyses suggest that 25–30% of the total holdings (1.9–2.2 million accessions) are unique, the remainder are duplicates held either in the same or, more often, at a different collection. Crop wild relatives (CWR) comprise 10% of these collections, but not many of them have been used so far. Around the globe, genetic resources are maintained in the gene banks at local and national level by governments, universities, botanical gardens, NGOs, companies, farmers and others in the private and public sectors. They 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 gene banks around the world, the N.I. Vavilov Genebank in Russia (VIR) was the largest. Lately, the gene bank in the USA is the biggest, followed by those in India, China, Russia, Brazil, Japan and South Korea. In some countries of central Asia and the Caucacus, such as Armenia, Georgia, Kazakhstan, Turkmenistan and Kyrgyzstan, not even two to three scientists were deployed to work on their valuable genetic resources, and there was practically no infrastructure for the gene banks. Such national systems need support, both in terms of infrastructure and capacity building. It is satisfying to note that in the past decade or so, each of these countries has established functional gene banks (Padulosi *et al.*, 2002).

Programmes on *in situ* and on-farm conservation have recently gained tremendous impetus as these protect germplasm in the natural habitat and take into account social and cultural factors such as farmers' perceptions and knowledge. On-farm conservation entails 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, promotion of nutritional values and traditional recipes, development of enterprises and market linkages for sale of products or services based on the local unique crop diversity, and safeguarding of unique species and varieties found on farms. Thus, *in situ* and on-farm conservation efforts remain ineffective without the 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 'custodian farmers', identified for actively maintaining and promoting agrobiodiversity and related indigenous technical knowledge at the farm and community level. Linking such farmers to research institutions and gene banks for characterization and evaluation of elite genotypes, and providing technology for rapid multiplication and distribution of plants is the need of the hour. Documentation of traditional knowledge is another activity that ensures its protection against theft and ensures financial benefits to knowledge holders when commercial sectors exploit that knowledge. Scientific validation of such traditional knowledge is also essential for improved understanding of the ecological functions of agrobiodiversity, especially in the context of the physical environment and socio-economic factors. There is an urgent need to promote the use of more nutritious species such as millets, indigenous fruits, vegetables, roots and tubers, compared with the past when major emphasis was given to only a select few staple varieties. We now need to ensure upscaling and outscaling of innovations to achieve dietary diversity and improved nutrition at household level. Information systems are still weak, and capacity-building is urgently required (Paroda and Agrawal, 2017).

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 the Svalbard archipelago, half-way between mainland Norway and the North Pole, provides a 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 the government of Norway. 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; even if the power fails, the temperature is expected to never rise above freezing. The SGSV has been 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 government of Norway to manage seeds in the vault. The vault currently holds 880,837 seed samples of 5403 species belonging to 71 institutes. These seeds were donated by almost every country in the world, so there is a massive variety of represented seeds. All germplasm from CGIAR gene banks has been safely duplicated here. If a crop is lost through a natural disaster or a war, and a seed bank is destroyed, the government can request replacement seeds from the vault. A recent example of this was when the International Center for Agricultural Research in the Dry Areas (ICARDA) retrieved part of its seed collection 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 held 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 ICARDA's new sites for gene bank facilities in the cropping seasons 2016 and 2017 in Lebanon and Morocco. Of these, 15,000 accessions (including bread and durum wheat, lentil, faba bean, chickpea and grasspea), multiplied in 2016, were sent back for safe duplication to SGSV on 22 February 2017. This proved to be a classic demonstration of collective wisdom of policy makers, scientists and farmers.

Genetic Diversity – Use It or Lose It!

It is a well-established fact that there is less use of genetic diversity today than in the past, which led to ushering in the Green Revolution. The FAO has, therefore, initiated, with the support of the Bill and Melinda Gates Foundation (BMGF), a project to strengthen plant breeding capacity and research on a global scale, so that use of genetic resources is enhanced globally. This project, known as the Global Partnership Initiative for Plant Breeding (GIPB), is a multi-partner platform with an aim to improve 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/ (Paroda and Agrawal, 2017).

It is well documented that the use of PGR has declined globally. 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 CG centres. In view of this, plant breeding must be brought to the forefront. Many stalwarts like Drs Norman Borlaug, G.S. Khush and S.K. Vasal 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 requires good infrastructural facilities, yet they are very important in the current context of climate change.

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

Advances in New Science for Agrobiodiversity Management

We are currently in an exciting scientific era where genome decoding of organisms is becoming almost a routine activity and the possibility of precisely tailoring structure and function of an organism is becoming a reality with new tools of biotechnology, especially gene editing using Crisper-Cas technology, advances in omics, space technology and bioinformatics. New technologies pervading agriculture in terms of smartphones, satellite imaging, phenotyping using drones, IPM, automated farm practices and decision support systems for nitrogen use efficiency (NUE) are helping farmers to grow more food on their land while reducing cost of water, fertilizer, pesticides, etc. (Paroda and Agrawal, 2017).

However, the availability of appropriate seed and planting material/breeds remains the most critical factor for enhancing productivity, adaptability and resilience of agro-ecosystems. Developments in science and technology in genetic engineering, genomics, biotechnology, nanotechnology, bioinformatics and synthetic biology 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 the modern era of use of 'gene guns' by biotechnologists or plant breeders to transfer desirable new genes into designer crops, farming households could assess in their fields and courtyards the semi-wild and semi-cultivated plants for their existing strengths and weaknesses, and select desirable traits while minimizing undesirable ones.

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 the application of new technologies for agricultural production would be to generate awareness and dispel fears in the minds of the general public about the use of new products (e.g. golden rice) that are the outcome of cutting-edge technologies as international public goods. With new advances in gene editing, the opportunities to accelerate crop breeding and use of germplasm will increase significantly.

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