

Indian Journal of Plant Genetic Resources

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Reflecting on 25 Years of Indian Journal of Plant Genetic Resources

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It's with great pride and pleasure that we publish this special issue of the 25th volume of the Indian Journal of Plant Genetic Resources (IJPGR), the official journal of the Indian Society of Plant Genetic Resources (ISPGR). The occasion provides an opportunity to briefly reflect on the things that have changed as well as those which have remained the same, in respect of plant genetic resources (PGR) management.

Genesis of ISPGR and IJPGR

A 'National Symposium on Plant Genetic Resources' was organized by the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, on March 3-6, 1987 to commemorate completion of a decade of NBPGR's establishment. The symposium was attended by 300 scientists from India and 20 from abroad, including those from International Centres like International Rice Research Institute (IRRI), Philippines, International Maize and Wheat Improvement Centre (CIMMYT), Mexico and International Centre for Research in Semi-arid Tropics (ICRISAT), India. During the symposium, Dr RS Paroda, the then Director of NBPGR proposed the creation of ISPGR, which was also welcomed by all the delegates of the symposium. The primary objective of the Society was to provide a forum to various workers in the field of PGR to express their views, publish their findings and interact with different stakeholders. The society was formally registered under the Indian Societies Act (1860) on November 3, 1987 with the Registrar of Societies, Delhi (Registration No. S/18336 of 1987). The Constitution of ISPGR was drafted under which the General Body (GB) comprising all members of the Society was designated the supreme authority and elected an Executive Council (EC) biannually for management of all the activities. The Constitution was revised in 2007 and since then EC tenure has been changed to three years.

The EC of ISPGR is headed by a President. Dr RS Paroda became the Founder President for two consecutive tenures (1987-88 and 1989-92) and later for another tenure

during 1996-98. During 1993-95, Dr RS Rana, the then Director of NBPGR was the President, whilst in 1999-2000, Dr Mangala Rai, the then DDG (Crop Science), Indian Council of Agricultural Research (ICAR), New Delhi, became President. Dr PL Gautam took charge as President in 2001-2002, when he was National Coordinator, National Agricultural Technology Project (NATP), ICAR. In the subsequent two tenures (2003-04 and 2005-06), Dr BS Dhillon, the then Director, NBPGR, served as President. During 2007-09, Dr Bhag Mal from International Plant Genetic Resources Institute (IPGRI, later rechristened as Bioversity International), Sub-regional Office for South Asia was the President. Thus, over the years the Society has greatly benefitted by being led by scientists who have contributed immensely in the areas related to PGR. Further, it has been blessed by patronage from luminaries like Dr MS Swaminathan and the late Dr AB Joshi, two doyens of Indian Agriculture.

The need to have a separate journal exclusively dealing with different facets of PGR to encourage publication and dissemination of information was also strongly advocated during the 'National Symposium on Plant Genetic Resources'. Thus, IJPGR was conceived. The first volume of IJPGR was published in 1988. To begin with, issues of IJPGR were biannual, but from 1999 onwards (Volume 12), 3 issues per volume are being published.

Linking the Past with Present

The first volume of IJPGR published in 1988 carried invited articles from many stalwarts of PGR (see Box 1). Dr MS Swaminathan, in his capacity as DG, IRRI, Philippines, contributed two papers - the first on "100th Birth Anniversary of Academician NI Vavilov" was an apt beginning to a journal dedicated to the science of PGR. The second article entitled "Genetic Conservation: Man to Microbes" dealt with a wider and holistic perspective on genetic conservation in which he rightly visualized development of a "global germplasm ethic for PGR conservation, exchange and use". We have

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seen this vision becoming a reality under the legally binding International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) which came into force in 2004, with its objectives of conservation and sustainable use of PGR for food and agriculture and the fair and equitable sharing of the benefits arising out of their use, for sustainable agriculture and food security. Contemporary views on the issue have been lucidly dealt in the first article of the present issue entitled “The Suwon Agro-biodiversity Framework: The Way Forward for Managing Agrobiodiversity for Sustainable Agriculture in the Asia-Pacific region” (pp. 1-8) by Dr RS Paroda, who now is the Executive Secretary, Asia-Pacific Association of Agricultural Research Institutions (APAARI), Bangkok, Thailand, besides other important portfolios like Chairman, Commission for Farmers’ Right, Haryana. Interestingly, Dr Paroda had contributed an article on “PGR Network in India” in the first issue of IJPGR, in which while giving an overview of PGR activities in India at that time, laid emphasis on capacity building at a national level. In the article in the present volume he has broadened the horizons to include agro-biodiversity management not only at national but also at regional level (Asia-Pacific).

Issues related to intellectual property rights and ownership of PGR were mentioned briefly by Dr Swaminathan and Dr Paroda in the inaugural volume of IJPGR. With many important national and international developments pertinent to these issues in the past 25 years, it was considered appropriate to dedicate full papers on these aspects. Dr PL Gautam, Chairman, Protection of Plant Varieties and Farmers’ Right Authority, New Delhi, and co-authors have provided a lucid overview about development of legal instruments related the enactment of Protection of Plant Varieties and Farmers’ Right Act in various countries, including India, as well as other relevant acts applicable to PGR (pp. 9-30). In another paper, Dr RS Rana, Member, National Biodiversity Authority, India has ably provided a detailed account on the issue of access and benefit sharing in PGR in the article entitled “Accessing PGR and Sharing the Benefits : Experiences in India” (pp. 31-51).

Global perspectives on *in situ* conservation were discussed in the inaugural issue of IJPGR by Dr JT Williams, International Board for Plant Genetic Resources (now known as Bioversity International), Rome, Italy. He advocated development of *in situ* conservation methods, especially in case of crop wild relatives and agro-forest/tree species (such as rubber, cacao and fruit trees), through

ecosystem conservation. The article by Dr Bhuwan Sthapit and co-authors, Bioversity International, in the current issue entitled “Community Based Approach to On-Farm Conservation and Sustainable Use of Agricultural Biodiversity in Asia” (pp. 97-110), describes the challenges of implementation of on-farm conservation based on three case studies in India, Nepal and South East Asia. Their studies have shown the importance of role of communities in biodiversity management (landscape, species and genetic diversity) and strongly advocate the Community Biodiversity Management (CBM) model for on-farm conservation. Another article by Dr CA Bonham and associates, Bioversity International, entitled “The Patterns of Use and Determinants of Crop Diversity by Pearl Millet Farmers in Rajasthan” (pp. 85-96) also discusses the determinants of on-farm diversity of pearl millet in Rajasthan. They found that irrigation and income are key factors which effect patterns of on-farm diversity and affluent farmers maintain greater varietal diversity than poorer farmers. The article by Dr KR Shivanna, from Ashoka Trust for Research in Ecology and Environment, Bengaluru, on “Reproductive Ecology and Conservation of Plant Genetic Resources of the Wild” (pp. 75-84), describes how understanding reproductive ecology, including pollination, breeding system, seed dispersal and seedling establishment mechanisms of wild PGR is absolutely essential for their effective conservation.

Today, PGR utilization has become a buzz word in the PGR management systems. Dr RS Rana, working then at the Central Soil Salinity Research Institute, Karnal, contributed an article on “Evaluation and Utilization of PGR for Salt Affected Soils” in the first issue of IJPGR. Salt effected soils were a major challenge, especially for small and marginal farmers. He advocated the collection, conservation, assessment and utilization of salt-tolerant PGR to address the problem. Dr Rana’s vision has become a reality today. ICAR launched a network mega-project on ‘National Initiative on Climate Resilient Agriculture’ (NICRA) in February, 2011, with the objective to enhance resilience of Indian agriculture to climate change and vulnerability, through strategic research and technology demonstration, including developing salt tolerant varieties. Further, in the current issue of IJPGR, Dr BS Dhillon and co-workers from the Punjab Agricultural University, Ludhiana, have demonstrated how a broad genetic base (including crop wild relatives), handled through precise and fast breeding technology (marker assisted gene tagging and transfer) is the approach to be followed in utilization

Box 1. Cover page of the first volume of IJPGR published in 1988

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100th Birth Anniversary of Academician N. I. Vavilov	<i>M. S. Swaminathan</i>	1
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Biochemical Approaches in Crop Plant Evaluation	<i>S. P. Singh, N. C. Singhal and S. L. Mehta</i>	111
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of PGR in the current context of narrow genetic base of crops. Their article entitled “Enhanced Utilization of PGR in Crop Improvement Programmes” (pp. 52-62) is highly illustrative on these aspects.

In the inaugural issue, Dr MH Mengesha, ICRISAT, Hyderabad, in his article entitled “Genetic Resources Activities at ICRISAT” gave an overview on germplasm collection, evaluation, maintenance, conservation and utilization of the five mandated crops (sorghum, pearl millet, chickpea, pigeonpea and groundnut). The emphasis was on amassing germplasm and developing appropriate short and long-term conservation strategies. In

the current issue, Dr HD Upadhyaya and associates from ICRISAT describe “Mini Core Collections for Enhanced Utilization of Genetic Resources” (pp. 111-124), wherein mini cores have been shown to be efficient option for studies on genetic diversity, population structure, association mapping and targeted allele mining for agronomically important traits, including biotic and abiotic stress tolerance/resistance. These two articles clearly show the paradigm shift in PGR management, over the years.

The first issue of IJPGR had a few papers describing survey, collection and evaluation of PGR (see Box 1). In the present issue, Dr V Ramanathan Rao, Bioversity

International, discusses the “Valuation of PGR” (pp. 63-74). The paper delves into the issues of cost involved in PGR management and the tangible economic benefits that can be demonstrated for justifying these costs. These are contentious but very important issues, which require more research and debate.

To conclude, in this issue of IJPGR, we have tried to draw together a reflection on the current ‘state-of-the-art’ in main areas of concern of PGR – conserving diversity, understanding that diversity, using genetic diversity in crop breeding, and managing diversity for more sustainable production and impact of climate change. Unprecedented

and rapid strides are currently taking place in the field of genomics and bioinformatics. This coupled with the art and science of biotechnology has opened many avenues to tailor crops suitable for a foreseeable future. But most importantly its the canvas of PGR, on which new masterpieces can be created by using the modern tools. By forging harmonious links, at human and institutional levels, we will evolve successfully toward the creation of a dynamic PGR network. We sincerely thank all the authors who have spared their valuable time and contributed in weaving together this issue of the journal.

The Suwon Agrobiodiversity Framework: The Way Forward for Managing Agrobiodiversity for Sustainable Agriculture in the Asia-Pacific Region

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The Asia-Pacific region is the largest supplier of the world's food and agricultural products. It houses about 58% of the world's population but has only 38% of the world's agricultural land. Attainment of Millennium Development Goals (MDGs), particularly alleviating poverty, assuring food and nutritional security and environmental sustainability, presents a major challenge to development in this region. Fortunately, the region is the centre of diversity of many important species of crops, livestock and forest tree species. Furthermore, resource poor farmers in the region are largely dependent on agrobiodiversity of minor crops, wild food and medicinal plants and animals for their food security and livelihood.

Agricultural biodiversity has important role in achieving the food and nutritional security. It is key resource for crop improvement and imparting greater resilience, stability and sustainability to farming systems. It also contributes to better nutrition and health, and is a source of increased incomes and improved livelihoods.

Despite the obvious importance of agrobiodiversity for food and agriculture in the region, there is a continuing loss of this important resource, due to human interventions and natural events. The large scale adoption of a few improved varieties of a limited number of crop species has resulted in displacement of many traditional varieties and the loss of traditional knowledge associated with them. Recognizing these concerns, efforts have been ongoing by various international and regional organizations and the national governments towards collecting, documenting and conserving agricultural genetic resources. This has culminated in the establishment of genebanks in some international centers and countries.

In view of the need for further strengthening agricultural biodiversity conservation and use, particularly at the regional level, an International Symposium on "Sustainable Agricultural Development and Use of Agrobiodiversity in the Asia-Pacific Region" was jointly organized by the Asia-Pacific Association of Agricultural Research Institutions (APAARI), Bioversity International and the Rural Development Administration (RDA) of

the Republic of Korea at Suwon, Republic of Korea, on 13-15 October, 2010. The symposium provided an opportunity to review, identify and redefine the role and direction of agricultural R&D for the conservation and use of agrobiodiversity for development. It was attended by 84 participants from 32 countries.

The participants at the international symposium adopted the Suwon Agrobiodiversity Framework that shows the way forward for access and benefit sharing of genetic resources and evoking required awareness concerning genetic resource management. The Suwon Agrobiodiversity Framework embodies the rationale, challenges and opportunities, integrated approach, focus of research and development, and the areas of collaboration.

Rationale

The Asia-Pacific region is the center of diversity of many important species of crops and livestock. Resource poor farmers in the region are largely dependent on the agrobiodiversity of minor crops, their wild relatives and other species of plants and animals for their food security and livelihood. The rich mosaic of people and cultures found in the region have contributed to the enormous diversity of cultivated plants and domesticated animals. Population migration and trade enabled introduction of new species and varieties. Additionally, the genetic diversity in both indigenous and introduced species has been enhanced through extensive exchange of germplasm within the region.

Agrobiodiversity is the foundation of sustainable agricultural development. Plant Genetic Resources for Food and Agriculture (PGRFA), that constitute a major part of current agrobiodiversity, are an essential resource to meet our food security. However, while the threats to these resources are growing, the efforts to conserve and use genetic diversity are still insufficient. This has been further confounded by the large scale adoption of few improved varieties resulting in displacing some of the landraces on farmers' fields. Also, the traditional knowledge, associated

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with the use of old varieties/landraces, has somehow remained undocumented and is rapidly disappearing. Reduction of agricultural biodiversity on the farm can significantly increase the vulnerability of farmers and existing agro-ecosystems. In recognition of the value of genetic diversity for the society, and also in view of the concerns of their loss, concerted efforts have been made by various international/regional organizations and national governments in the conservation and promotion of sustainable use of available crop and animal genetic resources. The sustainable conservation of agrobiodiversity can help in achieving the Millennium Development Goals (MDGs) since use of PGRFA is central to food security. However, this can only be possible through easy access and benefit sharing (ABS) of PGRFA and Animal Genetic Resources (AnGR).

The 9th session of the Commission on Genetic Resources for Food and Agriculture, held in 2002, emphasized “the importance of promoting the sustainable use of PGRFA and AnGR, through germplasm characterization, evaluation, genetic enhancement through plant breeding, seed production and distribution; and its contribution to food security”. Promoting sustainable use of biodiversity is also one of the seven 2010 Biodiversity Targets of Convention on Biological Diversity (CBD) (Decision VII/ 30). Furthermore, the CBD at its 8th Conference of the Parties (COP 8) held in Curitiba, Brazil in 2006 adopted a ‘Cross-cutting Initiative on Biodiversity for Food and Nutrition’, to be developed under the leadership of the Food and Agriculture Organization of the United Nations (FAO) and Bioversity International. These priorities have also been endorsed by the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)-Article 6: Sustainable Use of Plant Genetic Resources. “Genetic Resources Partnership” is also identified as one of the four areas for elaboration under the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB), being implemented by FAO. It is now increasingly accepted that future crop productivity increases can only be achieved through an increased use of PGRFA, including wild relatives and exotic materials. It is for this reason, the United Nations General Assembly has declared 2010 as an International Year of Biodiversity (Resolution 61/204 dated 20 December 2006) to bring greater awareness and promote new initiatives that can reduce the current loss occurring globally and enhance activities aiming mainly at conservation through use.

APAARI, in collaboration with its stakeholders, especially Bioversity International and other CGIAR Centers, viz., CIMMYT, IRRI, ICRISAT, ICARDA, ILRI, ARIs, FAO, GFAR, CFF, AVRDC and other Regional Fora, and the National Agricultural Research Systems (NARS) continue to review the role and direction of agricultural R&D to efficiently address above challenges. Several stakeholders have also initiated programmes to promote conservation and use of agrobiodiversity for sustainable agricultural production in the Asia-Pacific region. Four sub-regional networks have been organized to promote regional collaboration for strengthening PGRFA conservation and use. These are: (i) South Asia Network on Plant Genetic Resources (SANPGR), (ii) the East Asia PGR Network (EA-PGR), (iii) Regional Cooperation for Plant Genetic Resources in Southeast Asia (RECSEA-PGR) and (iv) The Pacific Plant Genetic Resources Network (PAPGREN). In addition, there are also several commodity focused PGR networks like the Banana Asia Pacific Network (BAPNET), the International Coconut Genetic Resources Network (COGENT), Cereals and Legumes Asia Network (CLAN), and the International Network for the Genetic Evaluation of Rice (INGER). These sub-regional networks are operated mostly by the CGIAR Centers in close partnership with APAARI.

As a part of these ongoing efforts, and in recognition of 2010 as an International Year of Biodiversity, APAARI had organized an International Symposium on “Sustainable Agricultural Development and Use of Agrobiodiversity in the Asia-Pacific Region”, in partnership with Rural Development Administration (RDA), Republic of Korea; Global Forum for Agricultural Research (GFAR); Bioversity International; FAO and other International Centers such as CIMMYT, ICARDA, ICRISAT, IRRI, ILRI and AVRDC.

Challenges and Opportunities

The attainment of MDGs, as reviewed recently by the world leaders (September, 2010) particularly on alleviating poverty, assuring food and nutrition security and environmental sustainability, against the background of declining natural resources, together with changing climate scenario, remains a daunting task.

Therefore, initiatives through conservation and use of agrobiodiversity must respond to these challenges. It is also evident that the contribution of agrobiodiversity in ensuring sustainable and productive agriculture remains vital to food security. The reservoir of genetic resources

remains a main resource for food security, and equally important for improving nutrition, product quality, product diversification and food safety.

Responding to the emerging challenge of climate change, greater access to a range of varieties that can help farmers deal with drought or flood, will be required. Exploring the genetic resources available will require new tools (Genomics, GIS, ICT), technologies and innovative approaches for their conservation and use.

All these challenges are compounded by the continuing loss of genetic diversity of plants, livestock and aquatic resources. At the same time, available agrobiodiversity can contribute significantly towards addressing the concerns of food security, poverty, environmental degradation, urbanization, climate change, etc. Hence, effective conservation and sustainable use of available genetic resources becomes a major priority in the region.

Integrated Approach

The proposed integrated approach seeks to ensure the continued availability of critical genetic resources not only for the improvement of agricultural productivity and resilience of the production systems but also to improve the quality of the supply chains through effective collaboration of different stakeholders working on a broad range of genetic resources for food and agriculture. It also builds on current partnerships and eco-regional experiences involving national and international organizations and for integrating partnerships across the different sectors of genetic resources.

The vision of the proposed approach draws lessons from existing collaboration between different CGIAR centres, NARS, Regional Fora and all the stakeholders in the region – a collaboration that now needs to be strengthened to a higher level of performance and accountability.

An integrated systems approach would intrinsically be more useful in the long run since it brings together work on microbes, crop plants, forest trees, livestock and fish genetic resources. It should also combine research on genetic, biological, agronomical, socio-cultural, market and economic aspects. It will encourage development of national plans that will focus not only on major commodities that are important for our food security but also on other crops, livestock and aquatic resources. Finally, it encourages the different organizations and local communities to work in partnership for collective actions. This approach will maximize the resources

and opportunities to have an agile response to new, yet unforeseen developments in understanding diversity and promoting use through research, conservation, evaluation and documentation.

Focus of Research and Development

1. *Studies to enhance use of genetic resources through subset approaches:*

There are many methods/approaches to sample germplasm collections to create subsets that are manageable in size by the researchers to quickly evaluate/characterize (phenotypic/genotypic) genetic resources to select useful accessions for use in pre-breeding. These approaches include core, mini core, Focus Identification of Germplasm Strategy (FIGS), composite and reference collections and trait-specific subsets. Enhancing research efforts on certain underutilized crops and their wild relatives may also be necessary to cover gaps in existing knowledge concerning their benefits to the society.

2. *Pre-breeding and participatory plant breeding to enhance utilization of genetic resources in crop improvement programmes:*

There is a need to encourage the use of genetic resources [especially underutilized species, their relatives and other useful species such as non-timber forest products (NTFPs), medicinal plants, etc.] to exploit untapped genes, broaden the genetic base of existing cultivated varieties and develop the new ones. This will be essential for coping better with the challenges of increasing productivity, improving quality, managing new pests and diseases, and adapting to climate change and abiotic stresses. It will also be important to develop partnership with farmers and other stakeholders to explore alternative approaches for genetic improvement such as participatory plant breeding and community based conservation activities.

3. *Strategies and technologies to enhance in situ and ex situ conservation through use:*

The aim must be to generate and synthesize coherent messages with appropriate information and knowledge, evidence and tools which can contribute to the understanding of genetic diversity and its effective use, especially

- The incorporation of information/knowledge and new technologies (genomics) into integrated approaches can promote the understanding of the

diversity distribution and identification of useful traits for adaptation to climate change, and other abiotic and biotic stresses.

- Research should explore the potential of consumer preferences, certification strategies, geographic indication, community and farmers' rights or payment systems for ecosystem services to secure agrobiodiversity for the future and exploit its direct values and uses. A market oriented approach is very important in enhancing the economic status of farmers involved in conservation and use of genetic resources.
- Efforts need to be made to empower traditional custodians of biodiversity in the region for in situ conservation on-farm to enhance conservation of landraces and wild relatives of cultivated crops and livestock, both in situ and on-farm together with its associated knowledge.
- Apply proven modalities for community based biodiversity conservation with partners especially the civil societies, such as supporting communities to sustainably use local genetic diversity to reduce vulnerability and crop loss and to sustain the resilience and ecosystem services of their production systems.
- Promote cost-effective complementary *ex situ* and *in situ* strategies for conservation of genetic resources.

4. ***Assessment of the agrobiodiversity richness and the status relative to economic, social and cultural (traditional knowledge) factors:***

- Support studies related to the assessment of genetic erosion and restoration of lost diversity across the region jointly with various national and international partners including advance research organizations (to access new methodologies).
- Assessing the relationship of poverty and other socio-economic factors that affect the genetic diversity for developing various livelihood options or for the payment for ecosystems services associated with conservation and use.
- Greater emphasis on documenting traditional knowledge (TK) and linking its use in both conservation and utilization of PGR in the context of benefit sharing as well as exchange of knowledge among communities.

5. ***Interdisciplinary studies on the invaluable ecosystem services for agriculture that agricultural landscapes, forests and other mainly wild ecosystems provide (following CBD-COP 5 Ecosystems Approach):***

Degradation of wild ecosystems in the landscape has important implications to agriculture and food production. Compensating the lost ecosystem services with artificial irrigation systems, growth media, fertilizers or pesticides is potentially not only costly but probably not even viable in many resource-poor areas. There is a need to better understand the relationships between society and nature in the socio-ecological landscape (as those envisioned in the CBD-COP 10 Satoyama Initiative). It is, therefore, worth looking into the following aspects:

- The role of wild ecosystems in providing services for forest and other agricultural systems, the processes and interactions which maintain these services, and the threats that they are facing.
- Planning rehabilitation and maintenance of diverse landscape mosaics of agricultural lands and viable wild ecosystems including policies that support their creation and maintenance.
- Adaptation of wild ecosystems to changing environment as a prerequisite for the continued provision of the services as their demand increases.

6. ***Information systems and tools for data exchange:***

The aim is to develop or adapt an information facility for online access to a wide range of datasets on genetic resources. The rapidly changing ICTs open up new opportunities to collect, store and analyze genetic resource information, and facilitate its exchange among researchers, local communities and countries. The integration of geo-references as the primary key for all forms of data, capitalizing on social media, data-interchange protocols, electronic germplasm catalogues and directories, GENESYS, GRIN Global and others. Common descriptors with guidelines for recording and reporting information should be extended to increase comparability and usability among datasets.

7. ***Supportive policies, laws and strategies to enable enhanced PGR exchange and use:***

There is need to focus on assessing the impacts of international laws and policies on the use and

conservation of genetic resources. Support is needed to assist countries that have signed the ITPGRFA to have the necessary regulatory/legislative mechanisms to implement the Treaty effectively. A well developed ABS framework must also be developed to provide legal mechanisms necessary to accelerate sharing of genetic resources.

Areas of Regional Collaboration

1. *Developing national agrobiodiversity plans and integrating them into regional and global collaborative frameworks:*

The development of national plans and integrating them into regional collaborative frameworks are important to enhance both food security and sustainable agricultural development. In the absence of such national agrobiodiversity plans and regional collaborative frameworks, it is difficult to advocate the importance of agrobiodiversity to the policy makers and other stakeholders. This will require assessment of national and regional priorities for agrobiodiversity in view of the emerging challenges. To achieve this, the facilitation role of regional fora such as APAARI, CGIAR centres, FAO, etc. is necessary and must be promoted.

2. *Increasing R&D collaboration on agrobiodiversity conservation and use in the region:*

Agrobiodiversity cuts across national boundaries and there are many common issues and concerns that need multi-country partnerships and sharing of experiences. Collaboration and support are very much needed in collecting, understanding and maintaining endangered crop, livestock and fisheries genetic resources. More R&D collaboration for underutilized crops in the region such as: small millets (finger millet, kodo millet, barnyard millet, foxtail millet, and little millet), minor but locally important legumes (black gram, rice bean, lablab bean, horsegram, etc.), cultivated minor and wild tropical fruits, and indigenous vegetables will ensure needed progress in improving these crops through plant breeding efforts.

3. *Increased sharing of information and data on genebank collections:*

To further improve access and sharing of genetic resources in the region, the sharing of information on national genebank collections is a prerequisite. This could be on the model similar to that of CGIAR's SINGER or the European countries' EURISCO where

data and information from different genebanks are available from a common searchable database. These databases are needed to accelerate the access to the collections held by the different genebanks. The national and international centers must ensure sharing of information being critical for enhanced use of genetic resources (i.e. GENESYS) following an open source system. The sustained use and maintenance of the GPA-NISM in many Asia-Pacific countries that have this database and its development in other countries should also be supported. The GPA-NISM provides the big picture of PGRFA in different countries beyond the genebanks.

4. *Strengthening agrobiodiversity capacity, education and public awareness:*

Capacity development needs to be addressed at the individual, systemic and institutional levels. Continuing capacity development in national systems is needed since often well-trained staff are either promoted or transferred. This can be in the form of short-term as well as formal degree courses. The capacity of indigenous and local communities to assess, inventorize and monitor genetic resources and related TK will also have to be developed. At the institutional level, emphasis is needed for the administrative framework; funding and resource management; mechanisms for follow-up, monitoring and assessment; in addition to strengthening policy analysis and capacity. Public awareness and education on agrobiodiversity should start at an early age with focus on the basic appreciation of genetic resources from their own locations, knowing their value for food, nutrition, health and to humanity. Other points to consider are as follows:

- Several universities in the region currently provide degree courses in plant and animal genetic resources but suffer from low enrolment. There is a need to make the curriculum more innovative and interesting (agrobiodiversity in food, nutrition, health and humanity) to young people and also make it relevant to supporting the extension workers. There is also a need to increase awareness and support through scholarship programs to these genetic resources related degrees and courses.
- The more advanced organizations in the region are currently offering short-term courses on PGR and AnGR management (e.g. RDA, South Korea;

Japan NIAS Genebank, Japan; NBPGR, India; CAAS, China) to enhance the capacity of different genebanks in the region. Such courses should be expanded and be made more specialized to cover new tools (e.g. DNA fingerprinting, information technology), approaches (complementary and integrated approach) and strategies. Specific courses that will improve the access of researcher to donors and grant information including better skills to grant writing and producing effective publications are also needed.

- There is a need to lay greater emphasis on public awareness on agrobiodiversity targeting policy makers and consumers, especially in the context of importance of conservation. The importance of underutilized tropical fruit species, crops, vegetables, forages and medicinal plants for food security, nutrition and income generation also needs to be emphasized. The participation of rural communities, the private sector and CSOs in conservation can help in ensuring financial support for national genebanks.
- There is also an urgent need for policy advocacy on agrobiodiversity for the officials involved in developing national policies and international treaties and conventions such as ITPGRFA and CBD.

5. *Enhancing exchange and use of genetic resources:*

- Through available options for the multilateral system for PGR exchange using SMTA, especially in those countries that have signed ITPGRFA.
- Empowering the farmers' organizations to participate in decision making related to implementation of farmers' rights as stipulated in the ITPGRFA.
- Enhanced cooperation on plant quarantine issues, including pest risk analysis (PRA) for safe movement and exchange of germplasm.
- Promoting the implementation of the GPA through specific actions at the national and regional levels through policy advocacy, strengthened R&D programmes and the use of NISM-GPA.
- More active facilitating role of APAARI on communications between the Treaty Secretariat

and the NARS, and between NARS and policy makers.

6. *Role of stakeholders in strengthening agrobiodiversity conservation and use:*

In view of limited funding resources in the region, enhanced collaboration between international and regional agencies, CSOs, the private sector, and regional networks will help in promoting genetic resource conservation and use.

- The proposed emphasis on research relating to genetic resources in the different Consortium Research Programmes should ensure better integration with national plans and regional and global strategies/collaborative frameworks.
- The sub-regional networks on genetic resources will have better sustainability if linked with regional/global organizations such as APAARI, GFAR and FAO with adequate financial support and active facilitation roles of CGIAR centres.
- Regional PGR and crop networks should emphasize on strengthening partnerships for the exchange of genetic resources that benefit users and germplasm providers directly (including wild relatives, neglected and underutilized crops, forest trees and NTFPs).
- Pursue partnership with CSOs and the private sector for more effective public awareness, education and advocacy. Civil society and the private sector can contribute to the development of a more holistic perspective to support agrobiodiversity initiatives in the region. The private sector can also help in generating additional resources, keeping in view corporate social responsibility.

Conclusions

The vast agrobiodiversity in the Asia-Pacific region is a valuable resource to achieve the MDGs, especially food and nutrition security and agricultural sustainability. These resources are to be used and conserved to ensure productivity and quality, adaptation to climate change and sustainable agriculture development. Effective conservation and utilization of this capital would obviously require increased focus and investment both at the national and regional levels, through greater involvement of all stakeholders. Also there is need for greater public awareness and policy advocacy for enhanced support for

AR4D efforts in the region. International and regional agencies, CSOs, private sector, and regional networks have a crucial role to play in strengthening agrobiodiversity conservation and use in the Asia-Pacific. Enhanced collaboration between national and international research institutions and civil society would help in the holistic understanding and importance of agrobiodiversity. The following actions will ensure optimal participation of different stakeholders and the building of new partnership opportunities:

- Benefitting from the new tools and technologies through new alliances among scientists working on plant and animal breeding, molecular biology, bioinformatics and biometrics that integrates genetic resources, genomics and genetic improvement programmes.
- Laying focus on genetic resources in different CGIAR research programmes should be analysed for better integration into national plans and regional and global collaborative frameworks, to avoid gaps and overlaps.
- Enhance regional and crop improvement programmes and PGR networks to ensure capacity development and improved exchange of materials and their use in the Asia-Pacific region. Such networks must be facilitated by the CGIAR centres to identify regional priorities and implement region- wide PGR-related activities. Network activities should also focus more on underutilized crops of the region. The different sub-regional networks will also be more sustainable if linked with regional or global initiatives, such as those of APAARI and GFAR.
- Strengthening partnerships with CSOs and the private sector to contribute more effectively towards public awareness, education and policy advocacy. CSOs and the private sectors can contribute significantly towards development of a more holistic perspective to support agrobiodiversity related initiatives in the region. Private sector can also help in this especially for resource mobilization and use of new tools and innovations in exploiting genetic resources.

Finally, there is a need to form new partnerships involving farmers and other stakeholders who ultimately guard the agrobiodiversity and its associated knowledge. Active collaboration with them will ensure recognition of farmers' needs and concerns, optimal planning and

monitoring of activities, participation in plant and animal breeding activities, adoption of innovations, documentation and use of TK, and usefulness of research for the poor. All above initiatives will contribute to the holistic understanding of agrobiodiversity conservation and use for the settlement of humankind.

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It is our expectation that this Framework will catalyze all the stakeholders in Asia-Pacific region to accelerate activities relating to conservation through use of valuable genetic resources.

ACRONYMS

ABS	Access and Benefit Sharing	ICARDA	International Center for Agricultural Research in the Dry Areas
AnGR	Animal Genetic Resources	ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
APAARI	Asia Pacific Association of Agricultural Research Institutions	ICTs	Information and Communication Technologies
ARI	Agricultural Research Institute	ILRI	International Livestock Research Institute
AVRDC	The World Vegetable Center	INGER	International Network for the Genetic Evaluation of Rice
BAPNET	Banana Asia Pacific Network	IRRI	International Rice Research Institute
CAAS	Chinese Academy of Agricultural Sciences	ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
CBD	Convention on Biological Diversity	MDGs	Millennium Development Goals
CFF	Crops for the Future	NARS	National Agricultural Research Systems
CGIAR	Consultative Group on International Agricultural Research	NBPGR	National Bureau of Plant Genetic Resources
CIMMYT	International Maize and Wheat Improvement Center	NIAS	National Institute of Agrobiological Sciences
CLAN	Cereals and Legumes Asia Network	NTFPs	Non-Timber Forest Products
COGENT	International Coconut Genetic Resources Network	PAPGREN	Pacific Plant Genetic Resources Network
COP	Conference of the Parties	PGR	Plant Genetic Resources
CSOs	Civil Society Organizations	PGRFA	Plant Genetic Resources for Food and Agriculture
EA-PGR	East Asia Plant Genetic Resources Network	PRA	Pest Risk Analysis
EURISCO	European Plant Genetic Resource Catalogue	RDA	Rural Development Administration
FAO	Food and Agriculture Organization of the United Nations	RECSEA	Regional Cooperation for Plant Genetic Resources in Southeast Asia
FIGS	Focus Identification of Germplasm Strategy	SANPGR	South Asia Network on Plant Genetic Resources
GFAR	Global Forum for Agricultural Research	SINGER	System-wide Information Network for Genetic Resources
GIPB:	Global Partnership Initiative for Plant Breeding Capacity Building	SMTA	Standard Material Transfer Agreement
GPA	Global Plan of Action	TK	Traditional Knowledge
GPA-NISM	Global Plan of Action-National Information Sharing Mechanism		

Protection of Plant Varieties and Farmers' Rights: A Review

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Intellectual Property Rights (IPR) and its application and expansion to agriculture has recently attracted global attention. Consequent upon the establishment of international agreements/institutional mechanisms such as the CBD and the WTO, and further, signing of ITPGRFA, the growing importance and the global scope of IPR in agriculture have been well realized and recognized. Most of the countries as members of World Trade Organization (WTO) are required to harmonize their related instruments with the TRIPS Agreement. It required that member countries enact/amend their domestic laws to provide for intellectual property rights (IPRs) in one form or the other in all fields of agricultural technology. Developing countries are currently attempting to fulfill the obligations of these international agreements by evolving new IPR regimes that simultaneously protect the rights of breeders and farmers. India's PPV & FR Act is significant both in the domestic and international context. The paper highlights various conventions/treaties/agreements affecting agricultural innovation systems and legal mechanisms adopted in developed and developing countries for such innovations. It also reviews the achievements / progress made in effective implementation of various provisions of the Indian legislation.

Key Words: Agro-biodiversity, Authority, Convention, Farmers' rights, Gene bank, Gene fund, Hotspots, Intellectual property, Plant variety, PPV & FR Act, Registration, Treaty

Introduction

Intellectual property, very broadly, means the legal rights which result from intellectual activity in the industrial, scientific, literary and artistic fields (WIPO). Two broad philosophical approaches underlie the decision to grant IPRs. The first approach to IPR protection predominates in many civil law / legal systems where the products of the human mind are stamped with the personality of their creator, inventor or author, thus endowing him or her with a moral as well as an economic claim to exploit those products to the exclusion of third parties. The second approach to IPR protection takes as its starting premise an instrumental view of IP. Legal protection for the products of human intellectual effort and ingenuity is granted not because of a moral commitment to compensating creators or innovators, but because the products they create enrich a society's culture and knowledge and thus increase its welfare. New plant varieties are afforded legal protection under this approach to encourage commercial plant breeders to invest the resources, labor and time needed to improve existing plant varieties by ensuring that breeders receive adequate remuneration when they market the propagating material of those improved varieties (Kannaiyan *et al.*, 2008).

IP protection is crucial for a sustainable contribution of plant breeding and seed supply. Breeding new varieties of plants, which are developed after contributing number

of years to the selective inheritance of traits which provide improved yields, higher quality, and better resistance to such plant varieties, requires a substantial investment, in terms of skill, labor, material and economic resources. However, a new variety, once released, could in many cases be readily reproduced by others so as to deprive its breeder of the opportunity to benefit adequately from the investment made. Thus, an effective system of plant variety protection (PVP) is a key enabler for investment in breeding and the development of new varieties of plants or improving existing plant varieties, encourage importation of foreign varieties, promote exportation of plant varieties, provide access to information of the created products and the methodology of creation for the enhancement of social welfare and generally benefit the market place. An international system of IPR protection for plant varieties expands these benefits by facilitating access to new varieties created in other states.

Global Perspective

As early as the 1883 Paris Convention for the Protection of Industrial Property, agriculture was envisaged as an area of enterprise in respect of which property rights could be secured. Given the state of technology in 1883, the inclusion of these agricultural subjects within the Paris Convention, was probably in the context of the protection of trademarks and indications of source. During the next fifty years, different countries in Europe attempted to

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extend IP protection to the field of agriculture. The first attempt to recognize the intellectual property rights of a plant breeder was the enactment of the Plant Patent Act by USA in 1930 which aimed to protect asexually propagated plants by patents leading to a debate regarding the type of protection to be extended to the agriculture. There were two divergent views, either to extend patent protection to plants or to extend the *sui generis* protection, recognizing the plant breeder's rights. It was further debated that plants or animal varieties or essentially biological processes for the production of plants and animals are exception to patentable subject matter. Thus, by 1970s it was well established in the developed world that IP protection will be extended to agriculture. Extensions of IPR to agriculture lead to other issues such as protection of interests and rights of farmers and price rise due to monopoly in agricultural products. The first significant application of intellectual property to agriculture occurred with the evolution on the initiative of associations of horticulturalists and plant breeders of the UPOV Convention for the protection of plant breeder's rights for plant varieties. Secondly, traditional farmers and indigenous people around the world have been seeing their plant genetic resources (PGRs) and traditional knowledge (TK) monopolized by private enterprises under patents and plant breeders' rights and have not been receiving their equitable share of benefits for their contribution. These concerns led to the adoption of two United Nations binding international treaties, Convention of Biological Diversity (CBD), 1992 and The Food and Agriculture Organization (FAO) International Undertaking on Plant Genetic Resources, which was renegotiated and adopted as the International Treaty on Plant Genetic Resources for Food and Agriculture (also known as Seed Treaty) seeking to establish principles for facilitating access to plant genetic resources and establishing fair and equitable mechanisms of benefit sharing. To provide a strong basis for greater legal certainty and transparency for both providers and users of genetic resources Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (2010) has been adopted. By 1995, with the establishment of WTO, the TRIPS Agreement provided that all member countries must implement a system of protecting IP in agriculture. This extended some kind of protection to agriculture by all the developed and developing WTO member countries. The provisions of *sui generis* protection provided the legitimacy to protect the rights of the farmers and balance the rights of the breeder and the farmer.

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These international conventions /treaties /agreements /protocols have comprehensive provisions for conservation and sustainable use of, and access to genetic resources and for sharing of benefits derived from their use. Concurrently, new emerging regimes in protection mechanisms for innovations at the global levels are impacting the access, transfer, and use of biological and /genetic resources and/ or associated technologies for furthering the research and developmental activities in all fields of agriculture.

World Trade Organization (WTO)

As part of creating global universal standards for trade negotiations, the General Agreement on Tariffs and Trade (GATT) was initiated in 1946 and established in 1947. The initial objectives were to promote peace through an interdependent world by removing unnecessary barriers to trade and reduction of tariffs across borders. After several rounds of negotiations, the Uruguay round led to the signing of GATT agreement at Marrakesh in Monaco in April 1994, one of the key elements being the establishment of the WTO in January 1995 in Geneva. India is its founder member of WTO and also that of its predecessor, the GATT. The WTO's scope extended beyond matters of merchandise trade, to agriculture, textiles and clothing, investments, innovation, competition policies, safeguard measures, trade in services, anti-dumping, sanitary and phyto-sanitary measures etc. The WTO aims to help producers of goods and services, exporters, and importers conduct their business and create economic peace and stability in the world through a multilateral system based on consenting member countries (currently there are 153 members and 31 Observer governments) that have ratified the rules of the WTO in their individual countries as well (http://www.wto.org/english/thewto_e/whatis_e/whatis_e.htm).

Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS)

The TRIPS agreement is an international agreement administered by the WTO that sets down minimum standards for many forms of intellectual property (IP) regulation as applied to nationals of other WTO Members. It was negotiated at the end of the Uruguay Round of the GATT in 1994. The TRIPS agreement introduced intellectual property law into the international trading system for the first time and is quoted as one of the comprehensive international agreement on intellectual property to date.

Specifically, TRIPS contains requirements that

nations' laws must meet for copyright rights, including the rights of performers, producers of sound recordings and broadcasting organizations; geographical indication, including appellations of origin; industrial designs; integrated circuit layout-designs; patents; monopolies for the developers of new plant varieties; trademarks and undisclosed or confidential information. TRIPS also specify enforcement procedures, remedies, and dispute resolution procedures. Protection and enforcement of all intellectual property rights shall meet the objectives to contribute to the promotion of technological innovation and to the transfer and dissemination of technology, to the mutual advantage of producers and users of technological knowledge and in a manner conducive to social and economic welfare, and to a balance of rights and obligations. Because ratification of TRIPS is a compulsory requirement of WTO membership, any country seeking to obtain easy access to the numerous international markets opened by the WTO must enact the strict intellectual property laws mandated by TRIPS.

The TRIPS Agreement includes three items related to agriculture: geographical indications (Arts. 22-24); patent protection of agricultural chemical products (Arts. 70.8 and 70.9); and plant variety protection (Art. 27.3 (b)). Under TRIPS Article 27.3(b), member countries may exclude plants, animals other than microorganism and other biological processes from patentability but are obliged to provide intellectual property protection to plant varieties. According to these provisions, countries must provide for plant variety protection either by patents or a '*sui generis*' system or any combination thereof. '*Sui generis*' literally means 'of its own kind or unique'. While countries would have to follow detailed standards set out in the TRIPS agreement for providing patent rights to plant varieties, the only requirement to establish a *sui generis* system is that it should be effective. This gives countries the option of determining the scope and contents of the rights to be granted under a *sui generis* system (http://www.wto.org/english/tratop_e/trips_e/intel2_e.htm).

International Union for the Protection of New Plant Varieties (UPOV)

The International Union for the Protection of New Varieties of Plants (UPOV) is an intergovernmental organization which was established by the International Convention for the Protection of New Varieties of Plants by a Diplomatic Conference in Paris on December 2, 1961. The Convention entered into force on 10 August 1968. The purpose was to ensure that the member states party to the Convention

acknowledges the achievements of breeders of new plant varieties by making available to them an exclusive property right, on the basis of a set of uniform and clearly, defined principles. UPOV mission is 'to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants, for the benefit of the society'.

The Convention was revised in Geneva in 1972, 1978 and 1991. Both the 1978 and the 1991 Acts set out a minimum scope of protection and offer member States the possibility of taking national circumstances into account in their legislation. Under the 1978 Act, the minimum scope of the plant breeder's right requires that the holder's prior authorization is necessary for the production for the purposes of commercial marketing, the offering for sale and the marketing of propagating material of the protected variety. The 1991 Act contains more detailed provisions defining the acts concerning propagating material in relation to which the holder's authorization is required. As on August 08, 2011, 70 countries have become the members of the UPOV out of which 47 countries are party to the 1991 Act, 22 countries are party to 1978 Act and one country (Belgium) is party to the 1961/1972 Act of UPOV (http://www.upov.int/en/about/upov_convention.htm).

Convention on Biological Diversity (CBD)

The CBD was adopted at the Rio de Janeiro Earth Summit, in June 1992. Over 150 governments signed the documents at the Rio conference, and since then 193 countries have ratified the Convention. The Convention has three objectives, 'the conservation of biological diversity, the sustainable use of its components and fair and equitable sharing of the benefits arising out of the utilization of genetic resources. The CBD Preamble reaffirms that States have sovereign rights over their own biological resources, but, at the same time, are responsible for conserving their biological diversity and for using their biological resources in a sustainable manner. The most important parts of the Convention are Articles 15 and 8(j). Article 15 of the Convention recognizes the sovereign rights of States over their natural resources, their authority to determine access to genetic resources, and that access, where granted, shall be on mutually agreed terms or subject to prior informed consent of the provider country. Article 8(j) requires parties to respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional life styles relevant for the conservation and sustainable use of biological diversity

Table 1: Comparison of provisions in UPOV 1978, UPOV 1991 and TRIPS

Provision	UPOV 1978	UPOV 1991 Act	TRIPs compatible Patent Laws
Protection coverage	Varieties of species / genera as listed. Minimum of five on joining. 24 after 8 years	Minimum of fifteen on joining. 10 years later, must protect all plant genera and species	Inventions
Requirement	Novelty (variety must not have been commercialized) Distinctness Sufficient uniformity having regard to the particular features of the variety's propagation Stability	Novelty (variety must not have been commercialized) Distinctness Sufficient uniformity having regard to the particular features of the variety's propagation Stability	Novelty (invention must not have been published) Non-obviousness (Inventiveness) Industrial applicability (usefulness)
Protection term	Minimum 15 years (18 years for trees and vines)	Minimum 20 years (25 years for trees and vines)	Minimum 20 years (TRIPS)
Protection scope	Production for commercial purposes and offering for sale, marketing and repeated use for the commercial production of another variety	Commercial transactions with propagating material. Harvested material protected only if produced from propagating material without breeder's permission and if breeder had no reasonable chance to exploit his right over it.	Making the patented product, using the patented process or using, offering for sale, selling or importing for those purposes the patented product obtained by the patented process
Breeders' exemption	Mandatory. Breeders free to use protected variety to develop new variety	Permissive but Essentially Derived Varieties can only be marketed with the agreement of the breeder	No
Farmers' privilege	Minimum scope of protection allows farmers' privilege Any species eligible for PBR protection cannot be patented	Each member country can define a farmers' privilege suitable for its condition This Act is silent on this question; countries may choose to exclude plant varieties from patent protection	No Many countries exclude plant varieties as such from patent protection

Source: <http://www.fao.org/docrep/007/y5714e/y5714e03.htm>

and promote their wider application with the approval and involvement of the holders of such knowledge, innovation and practices and encourage the equitable sharing of the benefits arising from their utilization. It also promotes *in situ* and *ex situ* conservation of biological diversity. It signals wider international acceptance of both intellectual property rights (IPRs) over biological inventions and the need for multilateral assistance for crop genetic resources preservation (<http://www.cbd.int/convention>).

International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)

Internationally the concept of farmers' rights came up in 1980s as a response to the increased demand for plant breeders' rights, to draw attention to the unremunerated innovations of farmers. It was based on the fact that the farmers have been engaged in the informal breeding process besides conserving and preserving biological and genetic resources for time immemorial. Hence, they deserved to be recognized and rewarded like the contribution of breeders in development of the new varieties was recognized and rewarded through plant breeders' right. The first mention of farmers' rights was made in the meeting of the

Working Group of the FAO Commission on PGR, 1986, in the context of the International Undertaking on Plant Genetic Resources (IUPGR) (Nagarajan and Singh, 2010). The 25th session of the FAO Conference of 1989 was a landmark in the history of recognition of farmers' right. The Conference endorsed the concept of farmers' right, and defined these as right arising from the past, present and future contributions of farmers in conserving, improving, and making available plant genetic resources, particularly those in the centers of origin/diversity. The negotiations at the 27th session of the FAO Conference culminated in the adoption of the ITPGRFA (also known as Seed Treaty), through Resolution 3/2001, in November 2001.

The ITPGRFA is a legally binding instrument that targets the conservation and sustainable use of plant genetic resources for food and agriculture and equitable benefit-sharing, in harmony with the 1992 CBD, for sustainable agriculture and food security. The Treaty was adopted in 2001 and, in accordance with its Article 28, came into force on 29 June, 2004, and currently has 127 parties. The preamble of the Treaty highlights the necessity of promoting farmers' rights at national and international levels. It recognized the enormous contribution that the

local and indigenous communities and farmers have made and will continue the efforts on conservation and development of plant genetic resources (Article 9.1). The main components of the farmers' rights highlighted in the Treaty are: (i) right to save, use, exchange and sell farm-saved seed and other propagating material (Article 9.3), (ii) right to fair and equitable sharing of benefits arising from the use of plant genetic resources for food and agriculture, (iii) right to participate in national decision-making process about plant genetic resources [entrusting national governments with the responsibility for implementing these rights in accordance with their needs and priorities subject to national legislation (Article 9.2)], and (iv) protection of traditional knowledge. The responsibility for implementing these provisions rests with the national governments who are free to choose the measures as they deem appropriate, according to their needs and priorities. The treaty also establishes a Multi Lateral System (MLS) for facilitated access to a specified list of PGRFA including 35 crop genera and 29 forage species essential for food security and interdependence, balanced by benefit-sharing in the areas of information exchange, technology transfer, capacity building and commercial development (<http://www.planttreaty.org>).

Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity

The Protocol was adopted at the tenth meeting of the Conference of the Parties on 29 October 2010, in Nagoya, Japan which significantly advances the Convention's third objective by providing greater legal certainty and transparency for both providers and users of genetic resources. Specific obligations to support compliance with domestic legislation or regulatory requirements of the Party providing genetic resources and contractual obligations reflected in mutually agreed terms are a significant innovation of the Nagoya Protocol. These compliance provisions as well as provisions establishing more predictable conditions for access to genetic resources will contribute to ensuring the sharing of benefits when genetic resources leave a Party providing genetic resources. In addition, the Protocol's provisions on access to traditional knowledge held by indigenous and local communities when it is associated with genetic resources will strengthen the ability of these communities to benefit from the use of their knowledge, innovations and practices. Benefits may be monetary or non-monetary such as royalties and the

sharing of research results. The Protocol lists ten monetary benefits and seventeen forms of non-monetary benefits, but does not limit the scope of benefits and Parties are at liberty to apply any other form of benefit sharing (Earth Negotiation Bulletin, 2011).

Plant Variety Protection in Developed Countries

The general patentability requirements were similar at the basic level in most national patent acts which required inventions to be novel and industrially applicable. The non-obviousness or inventive step requirement was established later on initially by case law in the mid-nineteenth century and subsequently by codification.

i) United States of America

The United States is bound by the TRIPS Agreement and is also a UPOV member since February 22, 1999. The protection of plant varieties may obtain under one of three different systems (Grunberg, 2011). Patents can be obtained under the Plant Patent Act (1930) which applies to asexually reproduced plants (e.g. by tissue culture, cuttings etc. and not including edible tuber propagated plants) for a period of twenty years from the date of filing. The right granted excludes others from making, using, selling, offering for sale and importing the plant, or any of its parts. Plants and plant parts may be covered by Utility Patent where a class of varieties with a specific trait, plant parts and methods of producing or using plant varieties may be protected such as disease, insect or herbicide resistance, drought and salt tolerance, improvement of fruit and flower quality, etc. The term of protection is twenty years from the date of filing. Plant variety protection certificates (PVP) under the U.S. Plant Variety Protection Act (1970) implementing the UPOV Convention and applies only to sexually reproduced and tuber propagated plants which conform to Novelty, Distinctiveness, Uniformity and Stability (here in after referred as NDUS). The Plant Variety Protection Act is administered by the U.S. Department of Agriculture, which issues Plant Variety Protection Certificates (PVPC) for qualifying plant varieties. The term of protection is 20-25 years from the date of grant of protection. Protection cover excludes other from selling, offering for sale, multiplying, conditioning, importing, exporting and stocking the variety. PVP Act (1970) was further amended in 1994 extending statutory protection to F_1 hybrids and tuber propagated plants and generally brought the United States into compliance with the 1991 UPOV Convention.

The U.S. has in its national legislation only a limited farmer's exemption. In the case of farmers, protected seed may be "saved" for replanting on their own individual holdings provided that it is not sold to any third parties who use it for reproductive purposes.

ii) Australia

Australia is both a WTO and UPOV member and has signed the UPOV 1991 Convention in March 1, 1989 for complying with TRIPS. Australia's Plant Breeder's Rights (PBR) scheme is administered under the Plant Breeder's Rights Act 1994 and conforms to the UPOV 1991. Plant Breeder's Rights are a form of Intellectual Property (IP) which grant a limited commercial monopoly to breeders of new plant varieties. All new varieties of plant (including hybrid), fungal, algal species and transgenic plants which meets NDUS are potentially eligible for a PBR. PBR registration (also referred to as a grant or certificate of PBR) gives plant breeders specific and exclusive commercial rights to a new variety: producing or reproducing the material; conditioning the material for the purpose of propagation; offering the material for sale; selling the material; importing the material; exporting the material and stocking the material for any of the purposes described above. PBR allows a breeder the right to exclude others from a range of activities including producing and reproducing a protected variety. PBR also protects the registered name and synonym of the variety from use in relation to other similar plants. PBR is personal property and can be assigned, sold and transferred to other parties. PBRs are exhausted after sale of seed, except when the sold seed is multiplied for commercial purpose. The PBRs are allowed for 25 years in case of trees and vines and for 20 years for any other variety. The Act also allows farmers' privilege and compulsory licensing.

iii) European Union

All countries in Europe have legislation on PVP inspired by the UPOV convention. In addition, the European Union (EU) has created a PVP system which allows PVP over a plant variety in the whole territory of the European Union, through the so called Community Plant Variety Rights (CPVR) which is based on the 1991 UPOV Convention. This Community system withstands with the national PVP systems of the EU countries, which grant protection within the national territories only. Community plant variety rights shall have uniform effect within the territory of the Community and may not be granted, transferred or terminated otherwise than on uniform basis. There is no

double protection system and only plant variety protection is granted. The CPVR confers protection to all varieties of all botanical genera and species, including inter alia, hybrids between genera and species provided that the varieties meet exactly the same requirements as outlined under the UPOV Convention and conform to NDUS parameters. The duration of protection for varieties of vine and tree species shall be 30 years and for rest 25 years from the year of grant of protection. There is no reference to farmers' rights in the EU regulation to safeguard agricultural production; farmers are authorized to plant, on their own holding, the product of the harvest obtained by planting a variety which is covered by a Community plant variety right. However this provision is applicable to some agricultural plant species. Researcher's exemptions for the acts done for experimental purposes and for acts done for experimental purpose and for acts done for the purpose of breeding or discovering and developing other varieties are not extended under the Act. Also there is no benefit sharing mechanism under the Community Plant Variety Regulation (<http://www.cpvo.europa.eu/main/en/home/community-plant-variety-rights/legislation-in-force>).

Plant Variety Protection in Developing Countries

As required under Article 27(3)(b) of TRIPS, countries had three options with reference to protecting plant varieties. UPOV could have been accepted as laying down general norms on a possible *sui generis* law but the liberal norms in the 1978 version of UPOV were revised in 1991 and the norms were tightened in favour of the breeders. Nevertheless, some kind (*sui generis*) of legislation was certainly needed for a variety of reasons, the most important of these reasons being WTO/TRIPS agreement. Developing countries were supposed to have such a system in place by 2000. Least developed countries were allowed a transition period until 2006, which has been extended until 2013 (Soam *et al.*, 2009 and Singh *et al.*, 2011d). A country is not required to be a member of UPOV to meet the TRIPS requirement for a *sui generis* system, but many developing countries have at least modeled their legislation on UPOV 1978 or 1991. A number of other countries are in the process of modifying their IP systems (Tripp *et al.*, 2007).

China: Regulations of the People's Republic of China on the Protection of New Varieties of Plants, issued on March 20, 1997 conform to the 1978 Act of the UPOV convention in principal. It is only a Regulation issued by the state council. Protection is provided through PVP

registration. Protection is extended to new, extant and essentially derived variety of the notified crop species. The criteria of protection are NDUS. The term of protection of variety rights is 20 years for vines, forest trees, fruit trees and woody ornamental plant and 15 years for other plants from the date of grant of certificate. There is no provision of farmers' rights in the legislation, however, use of protected variety for propagating purposes and use of harvest by farmers, on their own holdings shall not require authorization, or payment of royalties to the right holder. Provisions for compulsory/voluntary licensing have been kept but no mechanism on benefit sharing to farmers/communities has been defined under the Act (<http://www.cnpvp.cn/en/index.html>).

Indonesia: The Government of Indonesia approved the legislation entitled "Plant Variety Protection Law" (PVPL) in 1997. Procedural, administrative matters, such as implementation of the convention, finance and final provision are mostly adopted from the Patent Law. Its main features include that PVP shall be granted to all the varieties of all plant species, sexually or asexually propagated as new, extant, farmers' variety and essentially derived variety, which are new, unique, uniform, stable and has a denomination. The duration of protection is 20 years for crops and 25 years for forest trees (www.ppvt.setjen.deptan.go.id).

Kenya: Plant variety protection (plant breeder's rights) in Kenya is governed by the Seeds and Plant Varieties Act was enacted in 1972 which was further revised in 1991. This Act contains two major sections on seed certification and plant breeder's rights. In May 1999 Kenya acceded to the UPOV, 1978. The Act provides protection to new, extant, farmers' and essentially derived varieties in all crops which conforms to NDUS, except algae and bacteria. The duration of protection is 18 years for trees and vines and 15 years for other crops. Apart from breeder's rights, farmer who has bred or developed a new variety is entitled to registration and protection in similar manner to a registered breeder of a variety. Farmers are entitled for compensation in case of non-performance of a registered variety, recognition and reward, to save, use, sow, exchange, share but not sell the seeds as enshrined in the UPOV 1978 Act. Researcher exemption to use of protected variety for experimental purposes for breeding new varieties have also been provided under the Act. Benefit sharing mechanism is also established but under a different Act called the Environmental Management and Coordination Act, 1999 under which individuals and NGOs

can claim for benefit sharing on behalf of any village or local community for a variety registered as essentially derived variety (www.kephis.org).

Malaysia: The Government of Malaysia opted *sui-generis* systems of plant variety protection and approved the Protection of New Plant Varieties Act, 2004 which came into force since 1st January 2007 and Protection of New Plant Varieties Regulations 2008 was enforced on 20th October 2008. All plants excluding microorganisms which fulfill the criteria of NDUS are eligible for protection. The duration of protection of a registered variety which is new, distinct, uniform and stable is 20 years and for variety which is new, distinct and identifiable is 15 years. Apart from breeder's rights, farmers' rights, farmers' exemption (to farmers having less than a total area of 0.2 hectares) and compulsory licensing are also enforced (<http://pvpbkkt.doa.gov.my/Authorized/PVPACT/index.htm>).

Philippines: The Government opted *sui generis* system for protection of new plant varieties and enacted the Plant Variety Protection Act, 2002. Protection is given to new and essentially derived varieties which are new, distinct, uniform and stable through PVP registration. The duration of protection for trees and vines is 25 years and for other type of plants is 20 years from the date of grant of certificate. Apart from breeder's rights, traditional rights have been given to small farmers to save, use, exchange, share or sell their farm produce, sale and exchange of seed among small farmers, including sale and exchange of seeds among small farmers for reproduction and replanting in their own land and researcher exemption for use of protected variety for experimental and non commercial purposes and for breeding other varieties have also been provided under the Act (www.bpi.da.gov.ph).

Thailand: In compliance with TRIPS agreement, Thailand adopted the *sui-generis* system and enacted the Plant Varieties Protection Act, 1999 which was enforced in 2003. The Act is designed to encourage the breeders to breed new plant varieties, promote appropriate mechanism for the enforcement of the rights of local communities and breeders for access to biological resources and maintain genetic diversity in the field. The Act provides protection to new plant varieties, extant varieties, community's varieties and essentially derived varieties of the notified crop species which are novel distinct, uniform and stable. The certificate of registration of new plant variety shall be valid for 12 years for the plants which fruits within the period of not over two years, 17 years for the plants which are capable of giving fruits within the period of

over two years and 27 years for trees which fruits within the period of over two years from the date of grant of certificate. Apart from breeder's rights, farmer is entitled to registration and protection of a variety. A farmer or any person who is traditionally involved in conservation or development of the plant variety which is not registered as a new variety may register himself as a community under the Act. Farmers and researchers can also use the protected variety for experimenting or research for developing plant varieties, for cultivating or propagating a protected variety by him for non-commercial purposes which is declared as promoted plant variety in the quantity not exceeding three times the quantity obtained. Provision of benefit sharing in relation to the profits derived from the use of plants (domestic plant varieties and wild plant varieties) conserved by the community has been made through the PVP Fund created under the Act (www.doa.go.th).

Plant Variety Protection System of India

Agriculture provides for employment and key means of livelihood to two third of India's population and contributes 21% of India's GDP. The rural areas are still home to some 72 percent of the India's 1.21 billion people, a large number of whom are poor. More significantly, about 67 per cent of the total farming population in the country constitutes small and marginal farmers who depend on rain-fed agriculture and fragile forests for their livelihoods (Kochupillai, 2011). Agriculture being an integral component of the national economy and livelihood of millions of people, a balanced approach towards protecting the interests of the plant breeders in the formal sector and the traditional farming communities was required. It was in this background that a different form of protection was felt needed in India in addition to or instead of the existing international models. India took a significant step in this direction by adopting the *sui generis* system for protection of plant varieties and enacting a legislation that explicitly provides for farmers' rights in addition to PBRs. The Act is unique in the world in the sense that it has granted rights to both breeders and farmers simultaneously under one Act and has taken the farmers' rights concept a step forward and genuinely addresses the concerns of farmers as breeders, innovators, conservers, etc. It has tried to incorporate the features of UPOV, CBD and ITPGRFA along with certain distinctive features of its own as per requirement of farmers.

The Protection of Plant Varieties and Farmers' Rights Act, 2001

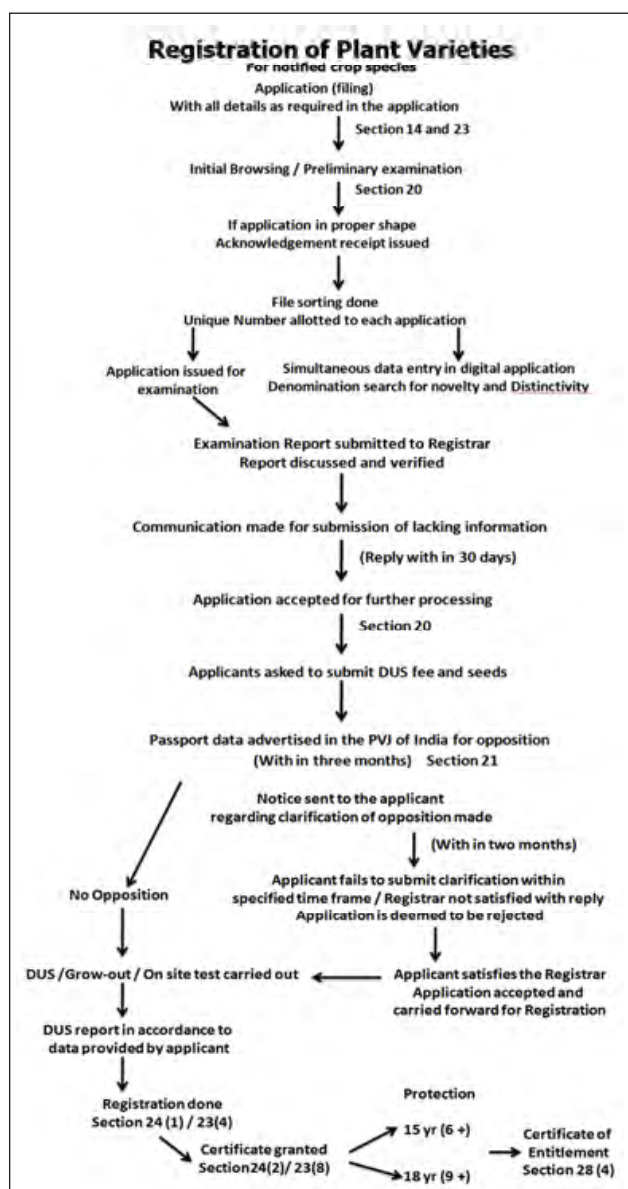
India as a member of WTO and signatory to the TRIPS

enacted the "Protection of Plant Varieties and Farmers' Rights Act, 2001" (herein after referred as Act), for which Rules were notified in 2003 (The Gazette of India Extraordinary, 2001 and The Gazette of India, 2003). For the purpose of this Act, in exercise of the power conferred under sub-section (1) of the Section 3, the Central Government established the "Protection of Plant Varieties and Farmers' Rights Authority" (herein after referred as Authority) on 11th November, 2005 (The Gazette of India, 2005). The PPV&FR Authority is a body corporate under the Ministry of Agriculture with Chairperson as the Chief Executive. Besides the Chairperson, the Authority has 15 members, notified by the Government of India (GOI). The functioning of the Authority is based on the following major objectives of the Act:

- To provide an effective system for protection of Plant varieties and rights of farmers and plant breeders.
- To recognize and protect the rights of farmers in respect of the contribution made at any time in conserving, improving and making available plant genetic resources for the development of new plant varieties.
- To accelerate agricultural development in the country, protect plant breeders' rights, stimulate investment for research and development in public/private sector for development of plant variety and
- To facilitate the growth of seed industry to ensure the availability of high quality seeds and planting material to the farmers.

Specifically so as to promote the encouragement for the development of new varieties of plants and to protect the rights of the farmers and breeders the Authority shall provide for registration of new and extant plant varieties, develop, characterize and document the registered varieties, create compulsory cataloguing facility for all varieties of plants, ensure that seeds of varieties registered under the act are available to farmers and provide for compulsory license, collect statistics with regard to plant varieties, including the contribution of any person at any time in the evolution or development of any plant variety and maintain National Register of plant varieties (Singh *et al.*, 2011c).

To facilitate the registration of plant varieties, Authority has opened two branch offices of the Plant Varieties Registry, one at Birsa Agricultural University, Ranchi and other at Assam Agricultural University, Guwahati. These branch offices will function within its



Source: Gautam et al. (2011a)

territorial limits and will also keep a copy of National Register of plant varieties.

Registration of Plant Varieties

Under Section 29 (2) of the Act, the Central Government by notification in official Gazettes specifies the genera and species eligible for the purpose of registration of varieties. So far, Central Government has notified 54 crop species for the purpose of registration. PPV&FR Authority has developed crop specific “Guidelines for the Conduct of Test for Distinctiveness, Uniformity and Stability” which have been published in various issues of the Plant Variety Journal of India (PVJI) published by the Authority and

can be downloaded from the website of the Authority. The purpose of these Guidelines is to provide detailed practical guidance for the harmonized examination of DUS of the candidate variety and, in particular, to identify appropriate characteristics for the examination of DUS.

Registration of plant varieties was started by the Authority with twelve crop species in 2007 which in due course has been extended to 54 crop species. The crop species notified for the purpose of registration and protection of plant varieties [The Gazette of India (2006a, 2007, 2009b, 2010a, 2010b and 2011b)] includes eight cereals (rice, wheat, maize, sorghum and pearl millet, durum wheat, dicoccum wheat and other *Triticum* species), seven grain legumes (chickpea, mungbean, urdbean, field pea, rajmash, lentil, pigeon pea), six fibre crop species [diploid cotton (two species), tetraploid cotton (two species) and jute (two species)], one sugar crop species (sugarcane), two tuber crop species (ginger and turmeric), eleven oilseed crop species (Indian mustard, karan rai, rapeseed, gobhi sarson, groundnut, soybean, sunflower, safflower, castor, sesame and linseed), two spices (black pepper and small cardamom), twelve horticultural crop species [including two flower species (rose and chrysanthemum), two fruit species (mango and coconut) and eight vegetable crop species (potato, brinjal / eggplant, tomato, okra / lady's finger, cauliflower, cabbage, onion and garlic)] and four medicinal & aromatic crop species (isabgol, brahmi, menthol mint, damask rose, periwinkle and brahmi). Further, DUS test guidelines for three species of orchid have been finalized and published in the PVJI.

The Authority is in process of developing and validating guidelines for DUS testing of more than 35 crop species at various institutions of Indian Council of Agricultural Research (ICAR), Indian Council of Forestry and Education Research (ICFRE), State Agricultural Universities (SAUs), etc. Some of the prioritized crops includes apple, pear, almond, walnut, cherry, apricot, citrus species, banana, litchi, guava, papaya, Indian gooseberry, pomegranate, Indian jujube, pineapple, bamboo, teak, shisham, tendu, sandal wood, deodar, chir, bottle gourd, bitter gourd, cucumber, pumpkin, pointed gourd, watermelon and muskmelon.

Once notified, applications may be filed for registration of varieties of the particular crop species under the categories of new plant varieties, Essentially Derived Varieties (EDV), extant varieties (notified under the Seeds Act, 1966), extant (Variety of Common Knowledge) and farmer's varieties. The overall process of registration of

Table 1. Year wise Applications received by the PPV & FR Authority

S. No.	Type of variety	Total number of applications received in different years						Total
		2007	2008	2009	2010	2011	2012 (31 st January 2012)	
1.	New Variety	74	154	179	438	164	04	1013
2.	Extant Variety [including variety notified under section 5 of Seeds Act, 1966 and Extant Variety about which there is common knowledge (VCK)]	355	387	382	97	257	03	1481
3.	Farmers' variety	2	5	44	4	939	01	995
4.	Essentially Derived Varieties	--	--	--	01	01	--	02
	Total	431	546	605	540	1361	08	3491

Source: www.plantauthority.gov.in

plant varieties followed by the Plant Varieties Registry of the Authority is illustrated in the box. So far the Authority has received 3,491 (as on 31st January, 2012) applications for registration of plant varieties including open pollinated varieties, hybrids, parental lines and transgenic varieties from different stakeholders such as farmers, public and private sector including multinational seed companies. Table 02 indicates the number of applications received in 2007, 2008, 2009, 2010, 2011 and 2012 for crop species notified by the Authority under different categories

Application for registration of plant varieties should be accompanied with the fee of registration notified by the Authority [new and essentially derived variety (Individual-Rs. 5,000/-; Institutional-Rs. 7,000/-; Commercial-Rs. 10,000/-), extant variety notified under the Seeds Act, 1966-Rs. 1,000/- and variety about which there is a common knowledge (Individual-Rs. 2,000/-; Institutional-Rs. 3,000/-; Commercial-Rs. 5,000/-)] (The Gazette of India, 2008 and 2009e). No fee is to be paid by a farmer for registration of a farmers' variety.

Criteria for Registration of Different Types of Plant Varieties

i. New Variety

A new variety should conform to the criteria of novelty [not been sold or otherwise disposed of in India, earlier than 1 year and outside India (in case of trees and vines earlier than six years, or, in any other case, earlier than four years)], distinctiveness (for at least one essential character from all varieties of common knowledge), uniformity (sufficiently uniform in its essential characteristics) and stability (if its essential characteristics remain unchanged after repeated propagation, or, in the case of a particular cycle of propagation, at the end of each cycle). After the

candidate variety is accepted for DUS testing and the applicant deposits the prescribed DUS test fee (PVJI, 2007, 2008b, 2009b, 2011a and 2011b) and specified seed material (as specified in the crop specific DUS test guidelines) in the Authority along with a certified data on germination test made not more than one month prior to the date of submission from an accredited laboratory. Seed material is sent to the respective DUS test Centres (see website of the Authority for notified DUS test centres) for conducting DUS test trial consisting of new varieties in tests referred to as "candidate varieties" the characteristics of which are compared with the characteristics of varieties of common knowledge, referred to as "reference varieties" selected from the database [Indian Information System as per DUS Guidelines (IINDUS 08.1) and Notified and Released Varieties of India (NORV)] developed by the Authority (Gautam *et al.*, 2011a). The varieties are grown over two similar growing seasons in two test locations. DUS test is said to be confirmed if distinctness is established for at least one essential character.

ii. Essentially Derived Varieties (EDV)

In respect of a variety (the initial variety), shall be said to be essentially derived from such initial variety when it is predominantly derived from such initial variety, or from a variety that itself is predominantly derived from such initial variety, while retaining the expression of the essential characteristics that results from the genotype

Type of variety	Type of test	No. of locations	No. of seasons
New	DUS test	2	2
Variety of common Knowledge	DUS test	2	1
Farmers'	Grow out test	2	1
Essentially Derived Variety	Manner of testing EDV shall be decided by Authority on case to case basis		

or combination of genotypes of such initial variety; is clearly distinguishable from such initial variety; and conforms (except for the differences which result from the act of derivation) to such initial variety in the expression of the essential characteristics that result from the genotype or combination of genotype of such initial variety. The application for registration of an EDV shall be accompanied by the relevant documents, along with other details specified in section 18 of the Act.

Under Section 5 (1) of the PPV & FR Act, 2001, the Competent Authority constituted a six member Expert Committee which will act as an advisory body to the PPVFR Authority for evaluation and recommendation of application filed for registration under EDV and other related issues. Preliminary examination is carried out in the Registry. Once the Registrar is satisfied that all the requirements are complete, he will submit the application with all relevant documents to the Expert Committee. The Committee shall evaluate and may suggest the tests and procedures for establishing whether it is a variety derived from the initial variety by conducting such tests and following such procedures as may be prescribed. Once the Committee is satisfied with the reports, necessary directions will be issued to the Registrar for the registration. The rights of breeder of a variety or an EDV are same provided that the authorization by the breeder of the initial variety to the breeder of EDV may be subject to such terms and conditions as both the parties may mutually agree upon.

iii. Extant Varieties

a. Extant Varieties notified under the Seeds Act, 1966

Extant varieties which have been notified under the Seed Act, 1966 are registrable under this category. The Authority constituted a seven member Extant Variety Recommendation Committee (EVRC) to examine the suitability for registration of such varieties (The Gazette of India, 2006b). On the basis of the recommendations of the EVRC, extant varieties shall be registered as per the provisions of the section 28 of the PPV & FR Act, 2001 (Nagarajan *et al.*, 2010b). No field tests are conducted for evaluating DUS. The passport data of recommended plant varieties are published in the Plant Variety Journal of India of the Authority for calling objections if any, within a specified time frame. The varieties for which no objections are received are accepted for registration. The applicant are required to submit 2/10 quantity of seed

material/ planting material specified for new varieties of same crop species before the issue of certificate of registration of plant varieties (PVJI, 2008a).

b. Farmers' Variety

A variety which has been traditionally cultivated and evolved by the farmers in their fields; or is a wild relative or land race or a variety about which the farmers possess the common knowledge are covered under this category. The criteria for distinctiveness, uniformity and stability for registration of a farmers' variety and variety about which there is a common knowledge has been notified by the Central Government (The Gazette of India, 2009c). Any person who applies for registration under clause (c) of Section 14 of the Act shall submit half of the quantity of seed material specified for a new variety in the respective crop species, divided into five equal numbers of packets for the purpose of field test and also for storing in the National Gene Bank and the seed supply procedures shall be such as may be specified in the Journal. Field test is conducted for confirming distinctiveness, uniformity and stability at the test Centres. The farmers' variety along with reference varieties and other similar variety are evaluated in the paired row test. The length of the row and plant population is kept such as specified in the Journal. A replicated trail is conducted for one season at two locations with limited purpose of confirming the distinctiveness, following the descriptors such as specified in the Journal. The uniformity levels for Farmers' variety for the respective species shall not exceed double the number of off-types such as specified in the Journal. If the variety meets the uniformity criteria, it is deemed to have met the stability criteria (Nagarajan *et al.*, 2008).

c. Variety of Common Knowledge (VCK)

A variety which is not released and notified under the Seeds Act, 1966 but is well documented through publications and is capable of satisfying the definition of 'variety', or have an entry in any official register of varieties or in the course of being made, or finds inclusion in a reference collection or is having a precise description in a publication, or has become a matter of common knowledge and the variety is under cultivation or marketing during the time of filing of application for registration (candidate variety should have been sold or otherwise disposed of in India one year prior to the date of filing of the application and it should not have been sold or otherwise disposed of 13 years prior to the date of filing of application and in case of trees and vines it should not have been sold or

otherwise disposed of 16 years prior to the date of filing of application) (PVJI, 2009a). The true representative seed of the variety should be available at the time of filing of application. The DUS shall be determined by conducting a field test for one season at two locations for the purpose of confirming the distinctiveness, uniformity and stability following the descriptors and plot size as may be specified in the Journal. Any person who applies for registration under clause (b) of Section 14 of the Act shall submit half the DUS test fee prescribed for new variety (PVJI, 2009b) and half the quantity of seed material specified for a new variety in the respective crop species, as divided into five equal numbers of packets for the purpose of field test and also for storing in the National Gene Bank and the seed supply procedures shall be such as may be specified in the journal.

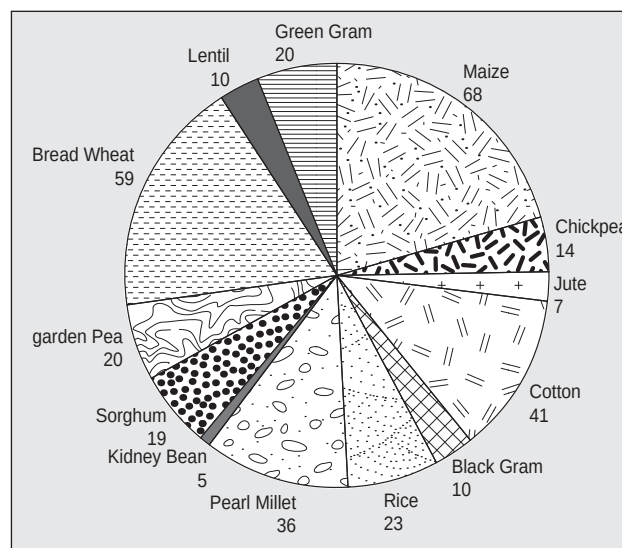
Since the criteria of distinctiveness, uniformity and stability for extant variety about which there is common knowledge and farmers' variety was notified on 29th June, 2009, the time limit for filing applications for registration of extant varieties (Common knowledge variety and farmers' variety) in case of twelve crop species notified on 1.11.2006 and six crop species notified on 31.12.2007 is extended for a period of three years from 30.6.2009 and the time limit for filing applications for registration of farmers' varieties in case of twelve crop species notified on 1.11.2006 and six crop species notified on 31.12.2007 is extended for a period of five years from 30.6.2009 (PVJI, 2011a).

iv. Trees and Vines

The DUS testing shall be field and multi-location based for at least two similar crop seasons and special tests will be laboratory based. Provided that in the case of trees and vines there shall be an option on the manner of the DUS testing that a panel of three experts shall visit the On-farm test sites for two similar crop seasons as may be specified [The Gazette of India, 2010c].

Special Tests

The Act provides for a mechanism of 'Special Tests' only when DUS testing fails to establish the requirement of distinctiveness. The DUS testing shall be field and multi-location based for at least two crop seasons and special tests be laboratory based. The Authority shall charge separate fees for conducting DUS test and special test on each variety. The tests are to be identified on certain set principles and will be notified crop species wise in due course and will be for characters for which breeding



work is going on and also these should have special significance in the trade of a particular variety. Broadly, these tests can be classified into five main groups: physical tests, biochemical tests, molecular tests, response tests and organo-leptic tests (Singh, 2011). To begin with the Authority has constituted a Task Force for identifying special tests for cotton, rice, oilseed, wheat, maize and medicinal & aromatic plants.

Certificate of Registration and Annual Fee

The Authority has so far issued 334 certificates of registration (241 of ICAR, 52 of SAUs, 38 of Private seed companies and 03 of farmers') in different crop species out of which 17 are for new varieties, 314 of extant varieties which are notified under Seeds Act, 1966 and 03 of farmers' varieties. The Authority has also opened a "National Register of Plant Varieties" having all details of the registered plant varieties and kept at the Head quarters of the Authority at New Delhi. This Register is an authentication of the plant breeders rights granted to the applicants. The certificate of registration shall be valid for nine years in case of trees and vines and six years in case of other crops. It may be reviewed and renewed for the remaining period as applicable for trees and vines and other crops on payment of renewal fees subject to the condition that total period of validity shall not exceed eighteen years in case of trees and vines from the date registration of the variety, fifteen years from the date of notification of variety under Seeds Act, 1966 and in other cases fifteen years from the date of registration of the variety. As a requirement under the Act, for the purpose of benefit sharing, the Authority shall also send a copy of

the certificate of registration to the National Biodiversity Authority and Indian Council of Agricultural Research (The Gazette of India, 2011a).

A breeder of the registered variety will have to pay annual fee which is determined on the basis of declaration given by him or his agent or licensee regarding the sales value of the seeds of the variety registered under the Act during the previous year and royalty, if any, received during the previous year from the sale proceed of seeds of the registered variety and verified by the Authority. The Authority with the prior approval of the Central Government has notified the Annual fee to be paid by the breeder, agent or licensee of the registered variety. Annual fee for a new variety shall be Rs. 2000/- plus 0.2 per cent of the sales value of the seeds of the registered variety during the previous year plus 1 percent of royalty, if any, received during the previous year from the sale proceed of seeds of a registered variety. For extant variety notified under Section 5 of the Seeds Act, 1966 (54 of 1966) the annual fee has been fixed for Rs. 2,000/- per year whereas for extant variety other than the extant variety notified under Section 5 of the Seeds Act, 1966 (54 of 1966) the annual fee shall be Rs. 2000/- plus 0.1 per cent of the sales value of the seeds of the registered variety during the previous year plus 0.5 percent of royalty, if any, received during the previous year from the sale proceed of seeds of a registered variety (The Gazette of India, 2009a).

National Gene Bank and Field Gene Bank

As per the Act it is mandatory to maintain the seed samples/ propagating material of registered plant varieties up to a period of protection provided to the candidate variety and also to address the issues for intellectual property of plant varieties including legal requirements such as infringement of plant breeder's rights, compulsory license, etc. Authority has established the National Gene Bank at Old Campus of National Bureau of Plant Genetic Resources (NBPGR), New Delhi for medium term storage of true samples of orthodox seed of all registered varieties for their entire period of protection. The seed samples kept in the National Gene Bank at low temperature (3-5°C) so as to maintain genetic purity, viability and health during the period of protection beyond which the denomination and variety may go under public domain. After the expiry of protection period, seed material may be submitted to NBPGR/any public repository (Choudhury, 2010).

For perennial plants (fruit trees and plantation crops) such as mango, citrus, eucalyptus, polar, rubber,

coffee, etc. which either produce 'recalcitrant (which are either short lived or do not withstand desiccation) seeds or no seeds at all, clonally propagated and have long regeneration cycles or sexually sterile, 'Field Gene Bank' is a practice worldwide as an effective 'ex-situ' conservation strategy. Such field gene banks are developed in places mostly near to the place of origin/diversity of the species concerned, where suitable agro-climatic conditions like soil, water, area being relatively free from disease/pest infestation are available. For collection and maintenance of varieties released (referral collection) of perennial crop species collected from different niches so as to preserve sub species/intra-varietal variability at one place, Authority has established three Field Gene Banks at Dapoli (for Tropical and sub-tropical crops), Ranchi (Eastern ecosystem) and Mashobra (for temperate crops). Further, two Field Gene Banks are being planned in Tamil Nadu (for Coastal ecosystem) and Rajasthan (for Arid ecosystem). These facilities shall also be used for capacity building, documentation and training on the issues related to registration of plant varieties (Singh *et al.*, 2011a).

Plant Varieties Protection Appellate Tribunal

The Act provides for establishment of Plant Varieties Protection Appellate Tribunal (PVPAT). All orders or decisions of the Registrar or Authority relating to registration of variety/ registration as an agent or licensee can be appealed in the Tribunal. Further all orders or decisions of Authority relating to benefit sharing, revocation of compulsory license and payment of compensation can be appealed in the Tribunal. The Tribunal consists of one Judicial Member and one Technical Member. The form of appeal and period within which it must be preferred has been prescribed in PVPAT (Application and Appeals) Rules, 2010. There is a transitory provision by which it is provided that till the PVPAT is established the IPAB will exercise the jurisdiction of PVPAT. The decisions of the PVPAT can be challenged in High Court. The Tribunal shall dispose of the appeal within one year.

Convention Countries

The Act provides that any country which has acceded to an international convention for the protection of plant varieties to which India is also a party or where India has entered into an mutual agreement with a country for granting plant breeders' right to the citizens of both the countries will be treated as convention country. Special provision is also there where a person has made an application for granting of breeder's right to a variety in a convention country

and that person makes an application for registration of such variety in India within twelve months after the date on which the application was made in that convention country then such variety shall be registered in India with effect from the date on which it was applied in that convention country.

Infringement and Penalty

If a person infringes the rights of the registered breeder in respect of the registered variety or registered denomination without his permission breeder then it constitutes infringement. The remedy for infringement would be discovery of documents, preserving of infringing variety or attachment of property of the infringer. In case of farmers, a right established under the Act shall not be deemed to be infringed if the farmer proves that at the time of infringement he was not aware of the existence of such right. The Act also provides punishment in terms of imprisonment and fine for applying false denomination, for selling varieties to with a false denomination and for falsely representing an unregistered variety as registered.

Opposition and Revocation

Any person within three months from the date of advertisement of an application for registration may file an opposition based on the grounds provided in the Act. Both opponent and applicant file their pleading and evidence and the opposition is finally heard by the Registrar. If the opposition is allowed then the applicants cannot proceed further with the registration. In case, the opposition is rejected then the variety proceeds for registration. Revocation for registration is decided by the Authority on application filed by any interested person on the grounds provided in the Act. No revocation is done without offering an opportunity of hearing to the registered breeder. If revocation is allowed by the Authority then the certificate of registration becomes invalid. Any person aggrieved with the decision of the Authority or Registrar in an opposition or revocation proceeding may file an appeal to the Tribunal and subsequently to the Higher Court.

Rights Provided under the Act

Breeders' Rights

An exclusive right on the breeder or his successor, his agent or licensee, to produce, sell, market, distribute, import or export the variety registered under the Act. A breeder may authorize any person to produce, sell, market or otherwise deal with the variety registered under this Act. Breeder shall enjoy provisional protection of his variety against

any abusive act committed by any third party during the period between filling of application for registration and decision taken by Authority. Enforcement of breeder right can be done by filing a suit for infringement in respect of registered variety and relief can be through discovery of documents, preserving infringement variety and document attachment of property of infringer. Breeders' rights would not apply in case when farmers save, exchange or use a part of the seed from the first crop of plants which they have grown for sowing on their own farms to produce a second and subsequent crops. Plant breeders would also not be able to exercise their rights in case where plants or propagating material of the protected varieties is used as initial sources of variation for the purposes of developing new plant varieties.

Researchers' Rights

A Researcher can use any of the variety registered under this Act for conducting experiment or research. The use of a variety by any person as an initial source variety for the purpose of creating other varieties comes under this provision. Authorization of the breeder of a registered variety is required where repeated use of such variety as parental line is done for commercial production of other new developed variety.

Farmers' Rights

The Act provides exhaustive and wide ranging rights to farmers in accordance with the FAO International Undertaking on Farmers' Rights and relevant CBD Articles on conservation and sharing biodiversity and benefit sharing (Gautam *et al.*, 2011b). It is one of the most important characteristics which distinguishes it from the UPOV which treats farmer's rights as a privilege and not a right in itself as compared to the rights granted to the breeders. The Act contains farmers' rights as positive rights, arising from the past, present and future contribution of farmers in conserving, improving and making available PGR, particularly those in centres of origin/diversity (Agarwal, 2011). The Act treats the farmer as plant breeder so far as the farmers' variety is concerned and they can register them under the Act without paying any fee. It protects farmers' interest by ensuring access to benefit sharing if their material is used for development of new varieties (Bala Ravi, 2004). In fact, a farmer is entitled to save, use, sow, re-sow, exchange, share or sell his farm produce including seed of a protected variety in the same manner as he was entitled before operation of the Act, provided that he shall not be entitled to sell branded seed

of a protected variety. Farmers have also been given a right to claim for compensation if the claimed characters under the given conditions are not realized. Farmers are entitled for recognition and reward from the Gene Fund provided that the material so selected and preserved (land races and wild relatives) has been used as donors of genes in varieties eligible for registration under the Act. In the event a farmer is unable to achieve the claimed performance of the variety which has been registered shall be entitled to compensation from registered breeder (Every breeder is required to provide full disclosure of the expected performance of the seeds or planting material of the registered variety). The compensation will be determined by the Authority. It has been kept mandatory for any breeder to secure consent of farmer(s) when a farmer's variety is used to develop an essentially derived variety (EDV). Also the innocent infringement clause insulates them against uncalled for long litigations. Farmers' have also been excluded from paying fee in any proceeding before the Authority or Registrar or Tribunal or the High Court. Farmers are also exempted from filing "affidavit sworn by the applicant that such variety does not contain any gene or gene sequence involving terminator technology". Moreover, feeling the lack of awareness among the farmers to protect their varieties, the Central Government has extended the time limit for registration of farmers' varieties from three to five years time period for applying and protecting their varieties (The Gazette of India, 2009d).

Rights of Communities

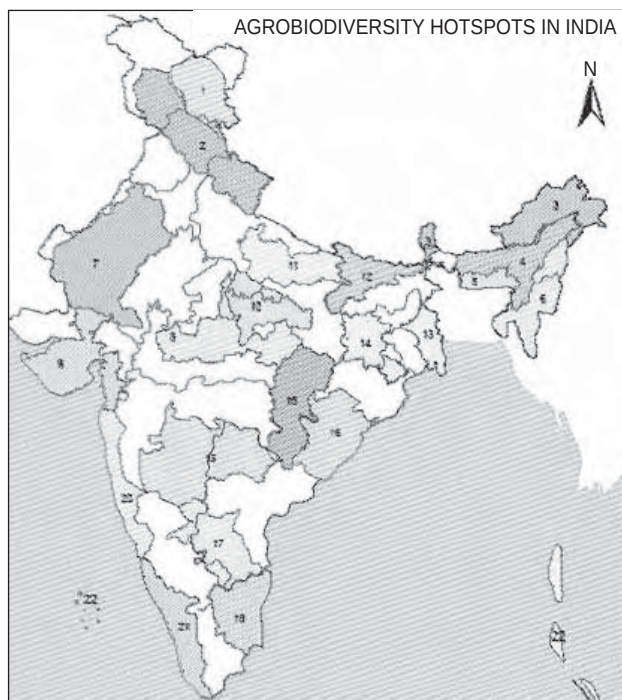
It is compensation to villagers or local communities for their significant contribution in the evolution of a variety which has been registered under the Act. Any person/group of persons/governmental or non-governmental organization, on behalf of any village/local community in India, can file in any notified centre, claim for contribution in the evolution of any variety. After verification, if the Authority is satisfied, and after giving an opportunity to the breeder to file an objection and of being heard, subjected to the limit notified by the Central Government, it may by order grant such compensation to be paid to the claimant. Authority can direct breeder of a variety to deposit compensation (arrear of land revenue) to the Gene Fund.

Benefit Sharing and Compulsory Licensing

The Act provides for benefit sharing involving registered varieties in two circumstances. The first applies specifically to EDVs [Section 26]. In the second, any village local

community can claim benefit for contributing to the development of a variety registered under the Act [Section 41]. For a variety registered as an EDV, any person or group of persons, being citizen(s) of India or firm or governmental or non-governmental organization formed or established in India, within a period of six months from the date of publication of the contents of the certificate of registration, can claim a share of benefits that may arise from its commercialization on behalf of any village or local community. The Authority shall establish the justification of the claims and determine the amount to be paid as benefit share on the basis of two criteria (a) the extent and nature of the use of genetic material of the claimant in the development of the variety for which benefit sharing has been claimed, and (b) the commercial utility and demand in the market for the variety. The amount of benefit sharing, if any, would have to be deposited in the National Gene Fund by the breeder of the variety. In the second circumstance, any person or group of persons, being citizen(s) of India or firm or governmental or non-governmental organization formed or established in India can make a claim on behalf of a village or local community for the contribution that they had made in the evolution of any variety registered under the Act (Applicant is required to provide the complete passport data of the parental lines from which a variety has been derived along with the geographical location in India from where the genetic material has been taken and all such information relating to the contribution, if any, of any farmer, village community, institution or organization in breeding, evolving or developing the variety). If, upon investigation, the claim was found justified, after the breeder was given an opportunity to file objection and to be heard, an amount of compensation as the Authority deems fit would be deposited by the breeder in the National Gene Fund (Singh, 2011e).

The Authority shall also ensure that the seeds of registered varieties are available to farmers and provide for compulsory license. Under Section 47 of the Act, after the expiry of 3 years from the date of issue of certificate of registration, any person can appeal on ground of inadequate seed supply, non availability of seed at reasonable price from the breeder and pray for the grant of compulsory license to undertake production, distribution and sale of seed or other propagating material of that variety. Authority will hear both parties and in public interest, may order breeder to grant a license to the third party on payment of a fee. Period of compulsory license may vary from case to



farming systems. The country is recognized as one of the eight Vavilovian Centres of Origin and Diversity of Crop Plants, having about 375 wild ancestors and close relatives of cultivated plants.

Agro-biodiversity is that part of biodiversity which nurtures people and which is being nurtured by people. It includes variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. Most of the country's agro biodiversity is in the custody of farming and tribal communities who followed age-old farming systems including shifting cultivation, made conscious and unconscious selections and inherited and perpetuated their seed over many generations (*in situ* on-farm conservation). Rich genetic resources useful to humans are the major indicators of the hotspots of agro-biodiversity. The areas rich in plant genetic resources, economic plant species, endemic species, progenitors of cultivated plants, their wild relatives, with vast array of variability in different ecosystems can be designated as 'Agro-biodiversity Hotspots' (Singh *et al.*, 2011b).

To define and demarcate the areas which are to be identified as Agro-biodiversity hot-spots, before the support and rewards can be framed for farmers/ community of farmers, Authority constituted a Task Force which after several rounds of discussions at different levels submitted its report which was published in two Volumes Book which have been widely distributed for creating awareness. The major recommendation of the Task Force was identification of 22 Agro-biodiversity hotspots (indicated in the map of India) distributed over 07 agro-geographical zones of India (Nayar *et al.*, 2009).

National Gene Fund

The Central Government has constitute a Fund called the National Gene Fund which would be enriched through the benefit sharing received in the prescribed manner from the breeder of a variety or an essentially derived variety registered under the Act, or propagating material of such variety or essentially derived variety; the annual fee payable to the Authority by way of royalty by the breeders of the registered variety; the compensation deposited in the Gene Fund under sub-section (4) of section 41; the contribution from any national and international organization and other sources. The Gene Fund shall, in the prescribed manner, be applied for meeting any amount to be paid by way of benefit sharing under sub-section (5) of section 26; the compensation payable under sub-section (3) of section

case maximum up to the period of protection. Authority can settle terms and conditions revoke or modify compulsory license.

Biodiversity and Agro-biodiversity Hot Spots

Biodiversity comprises the variety of all life on earth. It manifests at species, genetic and ecosystem levels. It is the outcome of over 3.5 billion years of evolutionary development, shaped by nature and human beings. Conserving biodiversity is basic to survival and well-being of human kind. Biodiversity is not distributed evenly across the globe. Certain countries, lying mostly in the tropics, are characterized by high species richness and more number of endemic species. Globally nearly 2.5 billion people rely heavily on wild and traditionally cultivated plant species for daily needs including employment and livelihood.

India is a mega-diverse country with only 2.5% of the land area, accounts for 7.8% of the recorded species of the world spread over 45,968 (11.18% of world) species of plants and 91,212 species of animals (7.43 % of the world) that have been documented in its ten bio-geographic regions (Gautam *et al.*, 2010). In India thousands of locally-adapted crop varieties are grown traditionally since ancient times and nearly 140 native breeds of farm livestock continue to thrive in its diversified

41; the expenditure for supporting the conservation and sustainable use of genetic resources including *in-situ* and *ex-situ* collections and for strengthening the capability of the Panchayat in carrying out such conservation and sustainable use and the expenditure of the scheme relating to benefit sharing framed under section 46 of the Act.

To fulfill the purposes of section 41 and section 45 of the Act, the Central Government shall frame one or more schemes to provide for all or any of the following: all matters connected with registration of the claims; processing of such claims for securing their enforcement and matters connected therewith; maintenance of records and registers in respect of such claims; utilization, by way of disbursal (including apportionment) or otherwise, of any amounts received in satisfaction of such claims; procedure for disbursal or apportionment by the Authority in the event of dispute regarding such claims; utilization of benefit sharing for the purposes relating to breeding, discovery or development of varieties and maintenance and audit of accounts with respect to the amounts received for claims in respect of registration of plant varieties.

To support and reward farmers, community of farmers particularly the tribal, rural communities engaged in conservation, improvement and preservation of genetic resources of economic plants and their wild relatives particularly in areas identified as agro-biodiversity hot spots. The Authority, as a mark of recognition for the selfless conservation of genetic resources by farmers/farming communities, has awarded "*Plant Genome Savior Community Recognition*" certificate to the five farmers/communities in 2007-08 and four farmers/communities in 2008-09 (Annual Reports, 2006 and 2008).

Following this, the Authority in consultation with Govt. of India has started "*Plant Genome Savior Community Award*". The award consists of Rs 10 lakhs in cash, a citation and a memento and will be given annually with a maximum of five awards per year. The award is open to all Indian farming/tribal/rural communities engaged in conservation, improvement and preservation of genetic resources of economic plants and their wild relatives. Gram Panchyats, State Agricultural University(s), Krishi Vigyan Kendra(s), Indian Council Agricultural Research centres, reputed Research institutes, Non-Governmental Organisation(s), community based organization and Farmer's Associations can sponsor applications. The applicant is required to submit information in support of their claims & a brief proposal for the utilization of award money towards community welfare measures/

development schemes including establishment of local seed/grain bank, water conservation facilities, facilities for grain/seed threshing/post harvest processing, farm schools or other such activities (Annual Report, 2009).

For 2009-10, awards were granted to Kopatgiri Nandiveerimath Seva Foundation, Karnataka for their work towards conservation and documentation of rare and endangered medicinal plant species in Kopatgiri hills, Gadag, Karnataka and Panchabati Gramya Unayana Samiti, Jeypore, Odisha towards their contribution in conservation of traditional land races of rice in Koraput region of Odisha (Extension Bulletin, 2011).

Other Related National Legislations

The international treaties/agreements/conventions led India to put in place the commensurate and compliant mechanisms and instruments. Some of the legal instruments passed by the Indian Government in response to international obligations includes the Seeds Act, 1966, the Patents Act, 1970 and its Amendment Acts: 1999, 2002 and 2005, the Geographical Indications of Goods (Registration & Protection) Act, 1999 and the Biological Diversity Act, 2002.

Seeds Act, 1966

Until 1966, there was no Central Legislation on Seeds. With the arrival of high-yielding varieties in food grain crops in 1960s, India realized the need for a seed law which could create a climate for making available of good quality seeds to the cultivators. This led to the enactment of the legislation of the Seed Act, 1966. The Act was passed by the Indian parliament in 1966 Seed Rules under the Act were framed and notified in September 1968 and the Act was implemented in its entirety in October 1969. The Seed Rules were notified in 1968. The Seed Act and Rules were amended in 1972, 1973, 1974 and 1981. Even though the concept of Seed certification was known in India, the enforcement of provisions of Seeds Act in the year 1969, gave beginning to the systematic arrangements for large scale seed certification. Seed Certification Agencies function in accordance with the Seeds Act 1966.

Seeds Act, 1966 and Seeds Rules, 1968 provide certification and minimum quality standards of notified kinds/varieties. It authorizes formation of advisory bodies like Central Seed Committee to oversee the setting of seed standards, release, and certification and implementation of other provisions of the Act assisted by the Central Seed Certification Board and the Central Variety Release Committee. At state level the provisions of the Act are

implemented by State Seed Certification Agency and the State Variety Release Committee. The Act also provides for constitution of Seed Certification Agencies, Seed Testing Laboratories, Appellate Authorities, etc. Seed quality control is achieved through pre- and post-marketing control, voluntary certification and compulsory labelling of notified kind/varieties. The Seeds (Control) Order 1983, issued under the Essential Commodities Act 1955, established a regulatory framework for controlling the distribution and supply of seeds in the market. In 1988, a New Policy on Seed Development was developed with the objective of making available to Indian farmers the best planting material from anywhere in the world and to encourage the export of seeds. Another National Seed Policy was announced in 2001.

The notification of the varieties is done under Section 5 of the Seeds Act in consultation with the Central Seed Committee. Minimum limits for germination, physical and genetic purity of varieties/hybrids have been prescribed and notified for labelling the seeds of notified kind/varieties under Section 6(a) of the Seeds Act. Size, colour and content of the label are also notified under Section 6(b) of Seeds Act. The validity period for the commercialization of NVs is 15 years with the option of revalidation. Second category is "truthfully labeled" variety (TLV) constituting seeds that are neither evaluated under the said multi-location trials nor notified but which truthfully conform to the standards labeled on the seed (<http://www.icar.org.in/files/Agril-Legislation.pdf>).

Patents Act, 1970

The British implemented the first patent statute in India in 1856, based on the British Patent Law of 1852, "On Protections of Inventions", and provided certain exclusive privileges to inventors of new manufactures for a 14-year term. The 1856 Act was modified in 1859 and renamed the "Act for granting exclusive privileges to inventors". Enactment of the Indian Patents and Designs Act, 1911 by the British created for the first time a system of patent administration in India under the direction of a Controller of Patents. The 1911 Act remained in effect, with various amendments, until an independent India enacted its first indigenous patent law the Patents Act, 1970 more than 50 years later which came into force on April 20, 1972 (Muller, 2007).

As India became the member of WTO, it was obligatory to amend its domestic intellectual property

laws in order to come into compliance with the WTO's TRIPS Agreement. The three amendments to the Indian Patents Act, 1970 have introduced a TRIPS consistent patent regime in the country which was brought about in the backdrop of intense debates that were focused on the need to establish a balance between the rights of the patent holders and the interests of the public at large. The first amendment of the Patents Act 1970 the Patents (Amendment) Act, 1999, formally implemented the mailbox procedure for patent applications claiming pharmaceutical and agro chemical products and made it retroactive to January 1, 1995.¹⁷³ The 1999 Act also formally implemented EMRs. Second, the Principal Act was amended by the Patents (Amendment) Act, 2002, so as to provide the TRIPS-required twenty-year patent term, reversal of the burden of proof for process patent infringement, and modifications to compulsory licensing requirements. A third amendment was introduced in January 1, 2005 (Patents (Amendments) Act 2005) to introduce product patent regime in areas, including pharmaceuticals that were hitherto covered by process patents.

India's new Patents Act excludes "plants and animals in whole or any part thereof other than micro-organisms but including seeds, varieties and species and essentially biological processes for production or propagation of plants and animals" from patentability. This provision was added to the Act via the 2002 amendments. The patent law also excludes from patentability all inventions arising out of the use of traditional knowledge (Yadav, 2011).

To encourage and to provide a legal framework for commercial exploitation of incremental innovation (minor improvements in technology using local resources in a sustainable manner), India is on the verge of enacting Utility Model Bill which will extend protection only to mechanical devices. The Bill has provisions for publication, public inspection, opposition and a national register of utility model. Only one form of protection either patent or utility model would be granted at a time. However, transmutability from patent to utility model is provided during the application stage.

Geographical Indication of Goods (Registration & Protection) Act, 1999

Under Articles 1 (2) and 10 of the Paris Convention for the Protection of Industrial Property, geographical indications are covered as an element of IPRs. They are also covered under Articles 22 to 24 of the Trade Related Aspects of

Intellectual Property Rights (TRIPS) Agreement, which was part of the Agreements concluding the Uruguay Round of GATT negotiations. India, as a member of the World Trade Organization (WTO), enacted the Geographical Indications of Goods (Registration & Protection) Act, 1999 has come into force with effect from 15th September 2003. The Act seeks to provide for the registration and better protection of geographical indications relating to goods in India. The Act is administered by the Controller General of Patents, Designs and Trade Marks- who is the Registrar of Geographical Indications. Geographical indication in relation to goods, means an indication which identifies such goods as agricultural goods, natural goods or manufactured goods as originating, or manufactured in the territory of a country, or a region or locality in that territory, where a given quality, reputation or other characteristics of such goods is essentially attributable to its geographical origin and in case where such goods are manufactured goods one of the activities of either the production or of processing or preparation of the goods concerned takes place in such territory, region or locality (The Gazette of India (E), 1999). To facilitate the registration of geographical indications a Geographical Indications Registry is being established. The head office of the Registry also maintains a Register of geographical indications having details of all registered GIs in India. Duration of protection of a GI is for ten years which can be renewed for next 10 years before the expiry of the initial protection period. The registered GIs related to agri-horticultural crops in India have been indicated in the Table 3.

The Biological Diversity Act, 2002

India being a Party to the CBD, to realize the objectives enshrined in the Convention, the Government of India enacted the 'Biological Diversity Act, 2002' (Kannaiyan, 2007). The Act primarily aims at giving effect to the provisions of the CBD, including regulating access to biological resources and associated traditional knowledge so as to ensure equitable sharing of benefits arising out of their use (Gautam *et al.*, 2010). The salient features of the Act are to regulate access to biological resources of the country with the purpose of securing equitable share in benefits arising out of the use of biological resources and associated knowledge relating to biological resources; to conserve and sustainably use biological diversity; to respect and protect knowledge of local communities related to biodiversity; to secure sharing of benefits with local people as conservers of biological resources and holders of knowledge and information relating to the use of biological resources; conservation and development of areas of importance from the standpoint of biological diversity by declaring them as biological diversity heritage sites; protection and rehabilitation of threatened species and involvement of institutions of state governments in the broad scheme of the implementation of the Biological Diversity Act through constitution of committees. To implement the provisions of the Act, National Biodiversity Authority was established on October, 2003 and its Rules were notified in 2004. Since stakeholders in biological diversity include the Central Government, State Governments, institutions of local self-governmental

Table 3. Registered Geographical Indications of India in Agriculture and Horticulture

S. No.	Geographical Indications	State	S. No.	Geographical Indications	State
1.	Darjeeling Tea (word & logo)	West Bengal	18.	Khirsapati (Himsagar) Mango	West Bengal
2.	Kangra Tea	Himachal Pradesh	19.	Fazli Mango grown in the district of Malda	West Bengal
3.	Coorg Orange	Karnataka	20.	Naga Mircha	Nagaland
4.	Mysore Betel leaf	Karnataka	21.	Virupakshi Hill Banana	Tamil Nadu
5.	Nanjanagud Banana	Karnataka	22.	Sirumalai Hill Banana	Tamil Nadu
6.	Mysore Jasmine	Karnataka	23.	Mango Malihabadi Dusseheri	Uttar Pradesh
7.	Udupi Jasmine	Karnataka	24.	Vazhakulam Pineapple	Kerala
8.	Hadagali Jasmine	Karnataka	25.	Devanahalli Pomello	Karnataka
9.	Navara Rice	Kerala	26.	Appemidi Mango	Karnataka
10.	Palakkadan Matta Rice	Kerala	27.	Kamalapur Red Banana	Karnataka
11.	Malabar Pepper	Kerala	28.	Guntur Sannam Chilli	Andhra Pradesh
12.	Monsooned Malabar Arabica Coffee	Karnataka	29.	Mahabaleshwar Strawberry	Maharashtra
13.	Monsooned Malabar Robusta Coffee	Karnataka	30.	Wayanad Jeerakasala Rice	Kerala
14.	Spices – Alleppey Green Cardamom	Kerala	31.	Wayanad Gandhakasala Rice	Kerala
15.	Coorg Green Cardamom	Karnataka	32.	Nashik Grapes	Maharashtra
16.	Eathomozhy Tall Coconut	Tamil Nadu	33.	Byadagi Chilli	Karnataka
17.	Pokkali Rice	Kerala	34.	Laxman Bhog Mango	West Bengal

Source: <http://ipindia.nic.in/girindia/images/RegGis.gif>

organizations, industry, etc., a three tiered structure at the national, state and local level is envisaged including National Biodiversity Authority to deal all matters relating to requests for access by foreign individuals, institutions or companies and all matters relating to transfer of results of research to any foreigner), State Biodiversity Boards to deal all matters relating to access by Indians for commercial purposes, and Biodiversity Management Committees to carry out conservation, sustainable use, documentation of biodiversity and chronicling of knowledge relating to biodiversity (The Gazette of India (E), 2003).

Documentation of Biological Diversity

Protection and preservation of traditional knowledge have been a matter of concern to the developing countries in general and India in particular. To promote sustainable use and equitable benefit sharing while conserving the biological diversity several agencies in India have independently initiated registration of biodiversity knowledge foster sustainable development and to protect the local interests against the global interests (Shastri, 2007). Traditional Knowledge Digital Library (TKDL) of Council of Scientific & Industrial Research (CSIR) is an international library on traditional knowledge has a rich database of information of the traditional knowledge available in public domain in a common language. People's Biodiversity Registers which record the status, uses and management of living resources and Community Biodiversity Register which provides spaces for the rights to communities about their biological and cultural heritage are some efforts for documenting biological resources and associated traditional knowledge in the country.

Conclusion

Intellectual Property Rights has been recognized as universal and its importance has been acknowledged by both developed and developing world. The drive towards stronger worldwide IP protection has intensified as a result of changes that have taken place in the global technology system. To provide an international frame work for the protection of IPRs, WTO introduced TRIPS Agreement which gave a strong impetus for the globalization of PVP regimes. Plant variety protection has become established as an instrument of protection of plant variety innovations in developed countries over the decades. Developing countries, with their diversity of farmers and seed systems, present special challenges for designing a supportive IPR system. The goal is to provide incentives for seed sector development while not creating unnecessary or

unrealistic limitations on the practices and livelihoods of smallholder farmers. This needs to have a balanced approach towards protecting the interests of the plant breeders in the formal sector and the traditional farming communities. After initial reluctance, many developing countries have accepted the TRIPS Agreement and have already revised or are in process of revisiting their IPR laws considering their specific conditions and needs. India has opted for a *sui generis* system of protection of plant varieties and has provided rights to farmers, breeders, researchers and equity concerns in the PPV & FR Act. All these provisions make it a unique Act, when compared to similar legislations in other countries. In a very short span of time the Authority has effectively progressed in implementing most of the provisions made under the Act for framing criteria of testing and registration of different types of plant varieties. It has also opened branch offices, national gene bank and field gene banks, identified agro-biodiversity hotspots and recognized and rewarded farming communities for their contributions in conserving genetic resources.

The Indian PVPFR Act is an effective *sui generis* system providing a balance between plant breeders' rights along with farmers' rights and researchers' rights. Its implementation will catalyze the availability of quality seeds of registered varieties and thereby contributing to the enhanced agricultural production and lead to the national food and nutritional security. At the same time, provisions for social recognition and economic reward made under the Act will support and promote the farm families to continue conservation, nurturing and enhancing agro-biodiversity of the country.

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References

- Agarwal R (November 19, 2011) <http://jurisonline.in/2011/11/protection-of-farmers-and-breeders-rights/>
- Annual Report (2006) Honoring innovative farmers'/farming communities. PPV & FR Authority, New Delhi, pp 22-24.
- Annual Report (2008) Second Plant Genome Savior Community Recognition Award. PPV & FR Authority, New Delhi, pp 25-27.
- Annual Report (2009) Constitution of Plant Genome Savior Community Award. PPV & FR Authority, New Delhi, pp 36.

- Bala Ravi S (2004) *Manual on Farmers' Rights*. MS Swaminathan Research Foundation. Chennai, 80p.
- Choudhury DR (2009) Guidelines for storage and maintenance of registered plant varieties in the National Gene Bank. *Technical Bulletin No. 02*, PPV & FR Authority, New Delhi, 42p.
- Extension Bulletin (2011) Plant Genome Savior Community Award. PPV & FR Authority, New Delhi.
- Gautam PL, M Srivastava, S Kumar and AK Singh (2011a) Registration of varieties in forestry. In: Forest Genetic Resource Management-Training Manual: Refresher course for IFS officers, September 19-23, Institute of Forest Genetic Resource Management and Tree Breeding, Coimbatore, Tamil Nadu, pp 1-17.
- Gautam PL, CA Reddy, JC Thompson and KP Raghuram (2010) Implementation of Biological Diversity Act in India. In: Proceedings of the Special session on Biodiversity and Sustainable Development, 97th Indian Science Congress, January 7, 2010, Thiruvananthapuram, Kerala, pp 69-81.
- Gautam PL, M Srivastava, DS Mishra, DS Rajganesha and AK Singh (2011b) Farmers rights under the Protection of Plant Varieties and Farmers' Rights Act of India. *Think India Journal* (submitted).
- Grunberg Anne Marie (2011) Overview of plant protection in the United States. In: Seminar on protection of plant variety and agricultural biotechnology inventions, 17-18 August, New Delhi.
- <http://ipindia.nic.in/girindia/images/RegGis.gif>
- <http://ipindia.nic.in/ipr/patent/patents.htm>
- <http://pvpbkkt.doa.gov.my/Authorized/PVPACT/index.htm>
- <http://www.cbd.int /convention>
- <http://www.cnvpvp.cn/en/index.html>
- <http://www.cpvo.europa.eu/main/en/home/community-plant-variety-rights/legislation-in-force>
- <http://www.fao.org/docrep/007/y5714e/y5714e03.htm>
- <http://www.fao.org/legal/treaties/033t-e.htm>
- <http://www.icar.org.in/files/Agril-Legislation.pdf>
- http://www.ipaustralia.gov.au/uploaded-files/2973/Plant_Breeders_Rights_kit_lowres.pdf
- <http://www.nbaindia.org>
- <http://www.plantauthority.gov.in>
- <http://www.planttreaty.org>
- http://www.upov.int/en/about/upov_convention.htm
- <http://www.wipo.int/exports/sites/www/about-ip/en/iprm/pdf/ch5.pdf>
- http://www.wto.org/english/thewto_e/whatis_e/whatis_e.htm
- http://www.wto.org/english/tratop_e/trips_e/intel2_e.htm
- Kannaiyan S (2007) Salient Features of Biological Diversity Act – 2002. NBA Bulletin - 11, National Biodiversity Authority, Chennai, Tamil Nadu, India, 20p.
- Kannaiyan S, VA Parthasarathy and D Prasath (2008) Intellectual Property Rights. In: Recent Initiatives in Horticulture (Eds.) KL Chadha, AK Singh and VB Patel. The Horticultural Society of India, New Delhi, pp 123-139.
- Kochupillai M (2011) The Indian PPV & FR Act, 2001: Historical and Implementation Perspectives. *J. Intellectual Property Rights*, **16**: 88-101.
- Muller MJ (2007) The Tiger Awakens: tumultuous transformation of India's patent system and the rise of Indian Pharmaceutical innovation. *University of Pittsburg Law Review* **68**: 492-641.
- Nagarajan S and PK Singh (2010a) Agro-biodiversity Conservation for Sustainable Agricultural Production: the PPV & FRA's Efforts. In: Proceedings of the Special Session on Biodiversity and Sustainable Development, 97th Indian Science Congress, January 7, 2010, Thiruvananthapuram, Kerala, pp 24-32
- Nagarajan S, RK Trivedi, DS Raj Ganesh, and AK Singh (2010b) India registers plant varieties under PPV & FR Act, 2001. *Curr. Sci.* **99**: 723-725.
- Nagarajan S, SP Yadav, and AK Singh (2008) Farmers' Variety in the Context of Protection of Plant Varieties & Farmers' Rights Act, 2001. *Curr. Sci.* **94**: 709-713.
- Nayar MP, AK Singh and KN Nair (2009) *Agrobiodiversity Hotspots in India: Conservation and Benefit Sharing*, I and II, PPV & FR Authority, New Delhi
- Patil FB and AK Singh (2011) Registration of Plant Varieties under PPV & FR Act, 2001 in India. In: National Seed Congress, February 11-12, 2012, College of Agriculture, Pune, pp. 18-24.
- PVJI (2007) *Notice of DUS test fee of crop species 01(01)*: February, 2007, 4p.
- PVJI (2008a) *Guidelines for submitting seed material of extant varieties in the PPV & FR Authority, 02(10)*: October, 2008, 10p.
- PVJI (2008b) *Notice of DUS test fee of crop species 02(04)*: April, 2008, 3p.
- PVJI (2009a) *Notice for registration of an extant variety about which there is common knowledge 03(9)*: September, 2009, 4p.
- PVJI (2009b) *Notice of DUS test fee for registration of variety about which there is a common knowledge, 03(11)*: November, 2009, 6p.
- PVJI (2009c) *Notice of DUS test fee of crop species, 03(11)*: November, 2009, 4p.
- PVJI (2011a) *Notice of DUS test fee of crop species, 05(02-03)*: March, 2011, 19p.
- PVJI (2011b) *Notice of DUS test fee of crop species, 05(04)*: April, 2011, 4p.
- PVJI (2011c) *Order for increasing time limit for filing applications for registration of extant varieties (Common knowledge variety and farmers' variety), 05(02-03)*: March, 2011, pp 10-15
- Shastri, R Kalpana (2007) *Mechanisms of Protection of Agricultural Innovations in India. Bulletin of Information Technology*, **27(6)**: November 2007, pp 3-11
- Singh AK, M Srivastava, PK Singh and PL Gautam (2011a) Implementation of PPV & FR Act, 2001 and Registration of Plant Varieties. In: National Symposium on Technological Interventions for Sustainable Agriculture, May 03-04, GBPUAT, Hill Campus, Ranichauri (Uttarakhand), pp 119-125.

- Singh AK, M Srivastava, SP Yadav, Susheel Kumar and PL Gautam (2011b) Climate change and livelihood of farmers and farming communities of India: Provisions under PPV & FR Act, 2001. *In: National Consultation for Production and Utilization of Orchids*. 19-21 February. pp 55-60.
- Singh AK, PK Singh, M Srivastava and DS Misra, (2011c) Implementation of PPV & FR Act, 2001 in India. *In: National Seed Congress*, January 29-31, 2011, College of Agriculture, Pune, pp 154-158.
- Singh AP, Padmavati Manchikanti and HS Chawla (2011d) Sui Generis IPR laws vis-à-vis Farmers' Rights in some Asian countries: Implications under the WTO. *J Intellectual Property Rights*, **16**: 107-116.
- Singh PK (2011) Implementation of Protection of Plant Varieties and Farmers' Rights Act, 200. *Indian J. Genet.*, **71(2)**: 190-198
- Soam SK, B Hanumanth Rao and Victoria Henson-Apollonio (Eds.) (2009) A Snapshot Guide to Intellectual Property Systems: A Compendium of Information from Developing Countries of Asia, Africa and Latin America. NAARM, Hyderabad and CGIAR CAS-IP, Rome, 290 p.
- Summary of the Fourth Session of the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture: 14-18 March 2011. *In: Earth Negotiations Bulletin*, International Institute for Sustainable Development (IISD), 09(550).
- The Gazette of India (1999) The Geographical Indications of Goods (Registration and Protection) Act, 1999. Extra pt II, December 30, 1999.
- The Gazette of India (2001) The Protection of Plant Varieties and Farmers' Rights Act, 2001. Extra pt II, October 30, 2001.
- The Gazette of India (2003) The Protection of Plant Varieties and Farmers' Rights Rules, 2003. GSR 738(E): September 12, 2003.
- The Gazette of India (2003). The Biological Diversity Act, 2002. Extra pt II, 5th February, 2003
- The Gazette of India (2005) Establishment of Protection of Plant Varieties and Farmers' Rights Authority. SO 1589 (E) November 11, 2005.
- The Gazette of India (2006a) Notification of crops with genera and species eligible for registration of varieties under the PPV & FR Act, 2001. SO 1884 (E) December 01, 2006.
- The Gazette of India (2006b) Protection of Plant Varieties and Farmers' Rights Regulations, 2006. GSR No. 619 December 07, 2006.
- The Gazette of India (2007) Notification of crops with genera and species eligible for registration of varieties under the PPV & FR Act, 2001. SO 2229 (E) December 31, 2007.
- The Gazette of India (2008) Protection of Plant Varieties and Farmers' Rights (Amendment) Rules, 2008. GSR 731, October 14, 2008.
- The Gazette of India (2009a) Notification of Annual Fees. SO 2182 (E) August 26, 2009.
- The Gazette of India (2009b) Notification of crops with genera and species eligible for registration of varieties under the PPV & FR Act, 2001. SO 1874 (E) July 27, 2009.
- The Gazette of India (2009c) Protection of Plant Varieties and Farmers' Rights (Criteria for Distinctiveness, Uniformity and Stability for Registration) Regulations, 2009. GSR No. 452 June 29, 2009.
- The Gazette of India (2009d) Protection of Plant Varieties and Farmers' Rights (Second Amendment) Rules, 2009. GSR No. 783 October 07, 2009.
- The Gazette of India (2009e) Protection of Plant Varieties and Farmers' Rights (Amendment) Rules, 2009. GSR 319, May 11, 2009
- The Gazette of India (2010a) Notification of crops with genera and species eligible for registration of varieties under the PPV & FR Act, 2001. SO 993 (E) April 30, 2010.
- The Gazette of India (2010b) Notification of crops with genera and species eligible for registration of varieties under the PPV & FR Act, 2001. SO 2883 (E) December 02, 2010.
- The Gazette of India (2010c) Protection of Plant Varieties and Farmers' Rights (Amendment) Rules, 2010. GSR No. 949 (E) December 03, 2010.
- The Gazette of India (2011a) Notification of bodies to which a copy of certificate of registration issued under the PPV & FR Act, 2001 shall be sent. SO 1912 (E) August 18, 2011.
- The Gazette of India (2011b) Notification of crops with genera and species eligible for registration of varieties under the PPV & FR Act, 2001. SO 1913 (E) August 18, 2011.
- Tripp R, N Lonwaars, and D Eaton (2007) Plant variety protection in developing countries. *A Report from the Field Science Direct Food Policy* **32**: 354-371
- www.bpi.da.gov.ph
- www.doa.go.th
- www.kephis.org
- www.ppvt.setjen.deptan.go.id
- Yadav M (2011) Scope of Patentable Subject Matter (Agricultural Biotechnology Inventions): Perspective from India. *In: Seminar on protection of plant variety and agricultural biotechnology inventions*, 17-18 August, New Delhi.

Accessing Plant Genetic Resources and Sharing the Benefits: Experiences in India

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Recent negotiations under the Convention on Biological Diversity and the adoption of Nagoya Protocol on Access and Benefit Sharing have placed biodiversity-rich developing countries in a better position to gain from their bioresources and to enhance their capacity to provide more incentives for conservation and sustainable use of biodiversity. India responded to its national obligations by enacting the Biological Diversity Act, 2002. This legislation, and the Biological Diversity Rules, 2004 framed under it, provide for a three-tier legal framework for regulating access to bioresources (and associated traditional knowledge) while promoting fair and equitable sharing of the resulting benefits. Indian citizens are free to access bioresources for research purpose but they are required to intimate the concerned State Biodiversity Boards (SBBs) prior to obtaining them for commercial purpose. On the other hand, persons other than Indian citizens, as defined under section 3 (2), are essentially required to obtain prior approval of National Biodiversity Authority (NBA) for accessing India's bioresources whether for research use or for commercial purpose. To promote benefit sharing, NBA's prior approval is also required whenever an Indian researcher/institution intends to transfer bioresources or results of research on them to the latter category of users. Furthermore, no person shall apply for seeking IPR protection over any innovative process/product, based on the use of bioresources, occurring in India or obtained from India, without prior approval of NBA and signing the agreement on benefit sharing. Applying for protection of plant variety under PPV&FRA is, however, exempted from this provision. Approvals are granted by NBA on a case by case basis, keeping in view the recommendations of an Expert Committee and imposing terms for benefit sharing in monetary or non-monetary mode. Implementing the Act's provisions presents a challenge since it requires active partnership and effective coordination involving the NBA at the national level, SBBs at the state level and Biodiversity Management Committees at the local level. Also considering that India's national legislation combines the role of the regulator (enforcing authorized access to bioresources) with that of the promoter (promoting conservation and sustainable use of bioresources, benefit sharing provisions, and also creating public awareness), and the advisor (advising the central and state governments on some key issues and national concerns). India's experiences in implementing its national legislation may be of immense regional and international interest.

Key Words: Access and benefit sharing, Access to genetic resources, Access to PGR and benefit sharing, Agro-biodiversity, Farmers' rights in India, Institutional mechanism for ABS in India, Nagoya Protocol and Indian legislation, Regulating traditional knowledge

Biological resources form an essential and continuous input into all crop improvement and animal breeding efforts, including the programmes of public and private sectors, and also sustain livelihood activities of farming communities (FAO, 2010). Developing more insect-resistant and herbicide-tolerant crop varieties, employing new tools and techniques of modern biotechnology, also requires bio-prospecting to locate target genes, cloning their DNA and injecting them into locally adapted high yielding varieties hoping that the projected expression and stability of the added genetic information from exotic sources will dramatically increase the yield and, hence, marketability of their proprietary crop varieties/ livestock breeds (Rana, 2004; Gepts, 2006; Suneetha and Pisupati, 2009; Engels *et al.*, 2010; Nair, 2011).

Stimulated by unprecedented technological advances, appreciation of the monetary and non-monetary value of biological resources has grown enormously in recent years leading to increasing conflict over rights and responsibilities for these resources, including both the naturally growing as well as the cultivated forms (Dutfield, 2000; Kamau and Winter, 2009; Gokhale, 2011). The Convention on Biological Diversity (CBD), 1992 recognized sovereign rights of nation-states over their bioresources and also over determining terms of access to them subject to their national legislation. In accordance with this requirement, national governments are framing policies, rules and procedures, through appropriate legislation that regulate access to biological resources and related traditional knowledge within their territorial jurisdiction (Tvedt and Young, 2007; Morgera and Tsoumani, 2011).

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I. Background

India is a party to several biodiversity-related conventions including CBD and the International Treaty on Plant Genetic Resources for Food & Agriculture (ITPGRFA). India is also signatory to international trade agreements including WTO-TRIPS. It has also signed recently the Nagoya Protocol on Access & Benefit Sharing (MoEF, 2011).

To meet its national obligations under CBD, India enacted the Biological Diversity Act, 2002 with clear specification of access regulations for domestic and foreign users of bioresources growing in India or obtained from India (Rana, 2010). This legislation, and the Biological Diversity Rules, 2004 framed under it, provide a three-tier legal framework for regulating access to bioresources (and associated TK) while ensuring fair and equitable sharing of resulting benefits. For a national legislation on access and benefit sharing (ABS) to be effective, however, its recognition at the international level is essential so as to provide enabling legislation in user countries and also to support an effective monitoring mechanism for proper realization of the equity benefits. The Nagoya Protocol on ABS, adopted recently under CBD, is expected to fulfill this task.

The National Biodiversity Authority (NBA), established in 2004 in Chennai, is charged with the overall responsibility of implementing this Act, in partnership with the State Biodiversity Boards (SBBs) and the local Biodiversity Management Committees (BMCs). It is intended that these access regulations will be facilitative, subject to some essential restrictions and appropriate benefit sharing agreements, and the use of bioresources will help in their conservation, sustainable use and sharing of the resulting benefits. There is, however, a growing apprehension that technologies which develop and make use of these resources seem to outpace the ability of social organizations to understand their impact and also the capability of national laws to cope with them (Kamau and Winter, 2009; Oliva, 2010; WFC, 2010).

Under CBD, Article 15 provides for regulating access to genetic resources and ensuring fair and equitable sharing of the resulting benefits with primary stakeholders and other identified beneficiaries. Accordingly, access to bioresources, and associated traditional knowledge, is regulated in India under its national legislation wherein the sharing of benefits is linked to promoting conservation and sustainable use. Obtaining authorised access to bioresources, where applicable, is essential and the

offences under this Act are cognizable and non-bailable. IPR issues like the Breeder's Rights, on the other hand, are addressed by provisions under the Protection of Plant Varieties & Farmers' Rights Act (PPV&FRA), 2001 and the Patents Act, 1970 (as amended in 2002 and 2005) to meet the obligations under WTO-TRIPS. There is harmony in implementing these three legislations and it has been ensured that plant genetic resources are made available for research, as well as for commercial use, through well defined procedures under a 3-tier system and subject to certain specified restrictions.

II. The Changing Scenario

India is one of the mega biodiversity-rich countries of the world. With only 2.4% of the land area, it accounts for 7.8% of all the recorded species on this planet. India also ranks 10th in the world and 4th in Asia in plant diversity. It is one of the eight Vavilovian Centres of Origin and Diversity of Crop Plants and an acknowledged centre of rich crop diversity, being home to 167 important cultivated species and 320 species of their wild relatives (Rana and Arora, 1990). Available data show that 45,968 species of plants and 91,364 species of animals have already been documented in India.

India spearheaded the International Undertaking on Plant Genetic Resources in 1980s, supporting the concept that PGR were common heritage of humankind and should be made available for research in an unrestricted manner for developing improved crop varieties to boost agricultural production. During the 1930-1980 period, seed samples of landraces and farmers' varieties were taken away freely by scientists of the developed countries through systematic explorations, without signing any agreements and benefit sharing/technology transfer arrangements. India has also contributed significantly to global gene banks of International Agricultural Research Centres under the CGIAR system (Rana, 2004).

Agricultural biodiversity is an important subset of biological diversity and it has been largely developed, used and conserved through human effort. Access to crop genetic resources, in particular, has now come to occupy centre stage in recent years following the emergence of IPR protection in various forms, particularly the breeder's rights, and enormous growth in seed sector and herbal healthcare business (Laird *et al.*, 2005; Kamau and Winter, 2009; Robinson, 2010; Winter, 2011). Disagreeing provisions under some major international agreements, including CBD and ITPGRFA on one hand and WTO-

TRIPS on the other, have further complicated the situation (Dutfield 2000, Carrizosa *et al.*, 2004, Feit *et al.*, 2005, Pant 2009, Rana 2010, Nair 2011).

It is widely recognized, however, that unrestricted access to biological resources of crop plants, developed initially and conserved mostly by the farming communities, determines largely the pace and success of all plant breeding efforts by both public and private sectors. In this context, provisions of the national legislation, on regulating the access to plant genetic resources (PGR) and realizing the fair and equitable sharing of benefits arising from their sustainable use, is discussed in this paper while keeping in view our national obligations under some relevant international treaties/agreements. The way ahead lies in generating increasingly more benefits through greater use of bioresources, through employment of recent advances in molecular biology and biotechnology, and sharing them with the rightful beneficiaries in a fair and equitable way (Rana, 2004; Tvedt and Young, 2007; Ved and Goraya, 2008; Oli and Dhakal, 2009; World Future Council, 2010, Dewar, 2010; Johnson, 2011).

International Developments

Access to genetic resources and the sharing of benefits are admittedly complex issues and need to be viewed from at least three distinct dimensions, namely, perspective of the developers and the users, management and governance at the national level, and also the national obligations under international treaties/ agreements. The first category represents the main stakeholders and key beneficiaries like the local farming communities, public sector research institutions, private sector seed companies and multinational corporations. The second group involves policy makers, legislators, managers and administrators concerned with management, governance and regulation. The third dimension reflects the national obligations under multilateral environment and also trade agreements, mainly the legally binding treaties CBD, ITPGRFA and WTO-TRIPS.

The Key Role of CBD

The need to regulate access to genetic resources and ensure a fair and equitable sharing of the resulting benefits was at the core of the adoption of CBD. Access, where granted, shall be on mutually agreed terms (MAT) and subject to prior informed consent (PIC) of the Contracting Party providing such resources. A series of principles and requirements around access and benefit sharing (ABS) were established under its process with a view to

increasing transparency and equity in the international flow of genetic resources. Somehow not many countries have been able to effectively implement them and the on-going ABS negotiations are often paralysed by complex challenges.

CBD also points to the importance of cultural diversity and traditional knowledge (TK). Article 8(j) of CBD on Traditional Knowledge, Innovations and Practices, calls on Parties to “respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practices and encourage the equitable sharing of the benefits arising from the utilization of such knowledge innovations and practices”.

It needs to be appreciated that the three main objectives of the CBD (stated under Article 1), namely, conservation of biodiversity: both in-situ (Article 8) and ex-situ (Article 9), sustainable use of its components (Article 10), and fairly and equitably sharing the benefits arising from such use (Article 15), are inseparable in implementing the CBD. They together provide the foundation of biodiversity-rich developing countries’ expectations to gain substantially from their genetic resources (and associated TK) by providing them to users, based on PIC and MAT, while also gaining from access to modern biotechnology tools/ techniques and products (Articles 16 and 19). Resorting to unauthorised access to bioresources, including plants with medicinal properties along with traditional knowledge associated with them, or getting patented any innovation/ process/ product based on the use of such resources is sometimes referred to as “biopiracy” (Chaudhury, 2003; Swiderska, 2006; Robinson, 2010).

Nagoya Protocol on Access and Benefit Sharing

The Nagoya Protocol, on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits arising from their Utilization, is an international agreement under CBD. Its objective is to promote sharing of the benefits arising from utilization of genetic resources in a fair and equitable way, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding, thereby contributing to the conservation of biological diversity and the sustainable use of its components. Adopted by the Conference of the Parties to CBD at its tenth meeting on 29 October 2010

in Nagoya (Japan), it will remain open for signature by Parties to the Convention from 2 February 2011 until 1 February 2012 at the United Nations Headquarters in New York. The protocol now has 61 signatories, but will enter into force 90 days after 50 countries, who are Parties to CBD, have consented to be bound by it, which means they must ratify the text. The protocol envisages the setting up of an international regime on access and benefit sharing of genetic resources, which will lay down the basic ground rules on how nations shall cooperate in obtaining genetic resources and sharing the benefits arising from their utilization.

ITPGR: Multilateral System for Global Food Security

The International Treaty on Plant Genetic Resources for Food and Agriculture, facilitated by FAO of the United Nations, entered into force in 2003 bringing conformity in provisions of the International Understanding on PGR and those of CBD, under the UNEP. Its primary objective is to promote global food security and its mandate includes conservation of agricultural biodiversity and sustainable use of plant genetic resources for food and agriculture. To begin with, it has established a multilateral system to facilitate access to genetic resources of 64 crops, listed in Annexes I and II of the Treaty, and seeks to promote fair and equitable sharing of benefits arising from their use. These crops together account for 80 percent of all human food consumption and comprise a pool of genetic resources that are accessible to everyone. Articles 12 and 13 include provisions on access and benefit sharing respectively.

Contracting Parties agree to share designated accessions stored in their national gene banks along with relevant information on them. This gives scientific institutions and private sector plant breeders the opportunity to work with, and potentially to improve, the materials stored in gene banks or even the germplasm collections growing in fields. By facilitating research, innovation and exchange of information without restrictions, this approach cuts down on the costly and time consuming need for breeders to negotiate contracts with individual gene banks. The Multilateral System sets up opportunities for developed countries with technical know-how to use their research laboratories to build on what the farmers in developing countries have accomplished in their fields.

WTO-TRIPS and Breeder's Rights

Plant genetic resources, that serve as the essential building

blocks for developing improved varieties of crop plants, were recognized as the common heritage of humankind under the International Understanding on PGR adopted in 1983, facilitated by the FAO Commission on PGR. This scenario changed with the WTO-TRIPS agreement coming in to force in 1995 since its Article 27.3b required its member parties to provide some form of protection as intellectual property rights (breeder's rights), either through patents or an effective sui generis national legislation. Union Ministry of Commerce is the nodal agency for its implementation in India.

Since disclosure of the lineage of improved varieties is not required by the Patent Offices, origin of parental lines (used by the breeders) remains hidden with the result that the CBD principles of PIC and MAT cannot be applied and the obligation for fair and equitable sharing of benefits cannot be met. This inconsistency can be removed through a suitable revision of the provisions of this international trade agreement to bring them in harmony with those of CBD and this is being attempted by the biodiversity-rich developing countries during the on-going negotiations under the Doha Round.

India has taken the lead in this context since its national legislation, the Protection of Plant Varieties & Farmers' Rights Act, 2001 requires the applicants to disclose the information on lineage and origin of the improved variety to be protected and assurance of CBD-compliance. It is also noteworthy that the Indian legislation provides exemption for the farmers' rights and researcher's rights while granting the breeder's rights. This national legislation, however, needs to be recognized under bilateral/ multilateral/ international agreements in order to be effective and the recently adopted Nagoya Protocol on International Regime on Access & Benefit Sharing is a positive development in this direction.

III. Indian Response to International Treaties

National Legislation for Implementing the International Treaties

The Biological Diversity Act, 2002, was enacted in India in response to CBD's provision that the authority to determine access to genetic resources rests with the national governments and it is subject to their national legislation. It also provides further support to other complementary national laws already in force, namely, the Wildlife (Protection) Act, 1972 as amended in 1991, and the Protection of Plant Varieties & Farmers' Rights (PPVFR) Act, 2001. It also provides suitable linkage to

the provision for patenting of products and processes/ technologies, based on the use of bio-resources and associated indigenous traditional knowledge (ITK), under Section 10(4) of the Patents (Amendment) Act, 2002. The stage was thus set for developing a national movement for implementing these combined provisions for access and benefit sharing to ensure food and livelihood security, based on conservation, development and sustainable use of bio-resources.

Salient Provisions of the Biological Diversity Act, 2002

Primarily aimed at promoting conservation and sustainable use of all categories of biological resources, this umbrella legislation regulates access to them while determining mode/ quantum of fair and equitable benefit sharing, and signing agreements with the users based on mutually agreed terms. Its key provisions are summarized below:

- to regulate access to biological resources of the country with the purpose of securing equitable share in benefits arising out of the use of biological resources; and associated traditional knowledge (TK) relating to biological resources;
- to conserve and sustainable use of all biological diversity components;
- to respect and protect traditional knowledge of local communities related to biodiversity;
- to secure sharing of benefits with local people as developers and conservers of biological resources and holders of knowledge and information associated with their use;
- to promote conservation and development of areas of importance from the standpoint of biological diversity by declaring them as biological diversity heritage sites;
- to provide support to on-going programmes on protection and rehabilitation of rare, endangered and threatened species;
- to ensure increasing involvement of institutions and state governments in the broad scheme of implementing the Biological Diversity Act, through constitution of appropriate committees.

In brief, this Act seeks to regulate access to India's biological resources, and associated TK, with a view to securing equitable sharing of benefits arising from their use. Its primary objectives include promoting *in-situ* conservation of bio-resources and their sustainable use

and linking them to the goals of food security, healthcare, livelihoods and eco-friendly development concerns through suitable applications of the National Biodiversity Fund. It also addresses supportive mechanisms like documenting and protecting biodiversity-related TK, conservation and development of designated areas as biological diversity heritage sites and also the protection of threatened species and their habitats.

- A notable feature of this legislation lays in differentiating the applicants in two categories, namely, persons who are citizens of India and the others including non-resident Indians, persons who are not citizens of India and body corporates, associations or organizations – not incorporated or registered in India; or incorporated or registered in India but having any non-Indian participation in its share capital or management.

Recognising that the Indian citizens owe allegiance to the Indian Constitution and can be called upon in person to the courts to ensure compliance to this Act's provisions, a practical differentiating way has been adopted under which the applicants of the second category are required to obtain prior approval of NBA for seeking access to India's bio-resources (and associated TK) for research and commercial use or engaging in bio-survey and bio-utilization activities [Section 3 read with Section 19). They are also required to seek prior approval of the NBA for transferring research results abroad (Section 4), for applying for IPR (Section 6) and also for third party transfer of the granted approval (Section 20), by submitting applications in specified formats and after payment of prescribed fee for each of the above mentioned purposes. This provision is thus differentiating for the specified purpose but it is not discriminatory since non-resident Indians are also included in this category.

Access of Indian citizens to bio-resources for research is unrestricted and free. However, the Section 7 states that no person, who is a citizen of India or a body corporate, association or organization which is registered in India, shall obtain any biological resource for commercial utilization, or bio-survey and bio-utilization for commercial use except after giving prior intimation to the concerned State Biodiversity Board and adhering to its directives.

Restrictions Imposed on Granting Access

Certain restrictions have been imposed under Rule 16 on NBA's approvals for activities related to access to bio-

resources, requiring the Authority to take steps to restrict or prohibit requests for such access on considering the following reasons:

1. The request for access is for any endangered taxa;
2. The request for access is for any endemic and rare species;
3. The request for access may result in adverse effect on the livelihoods of the local people;
4. The request for access may result in adverse environmental impact which may be difficult to control and mitigate;
5. The request for access may cause genetic erosion or adversely affect ecosystem functioning;
6. When the use of resources is for purposes contrary to national interest and other related international agreements entered into by India.

Protection of Traditional Knowledge Associated with Bioresources

The subject of protection of knowledge, practices and innovations of local people and communities is quite complex. The informal knowledge available with people presents following difficulties in being recognised for purposes of IPR:

- “Community” as such is not a legal entity.
- Knowledge is quite often in parallel held by individual organisations, groups of people, communities.
- The conditions of novelty and innovative step, necessary for granting of patent, are not satisfied in case of traditional knowledge.

Considering these complex nuances, an enabling provision for protection of traditional knowledge has been made under this legislation. The modalities for protecting indigenous knowledge are still emerging and evolving and therefore the measures for doing so have been left open and flexible under this provision. It provides for inter alia registration of knowledge, and for developing sui generis system for protecting traditional knowledge.

Exemptions provided under the BD Act:

The following exemptions have been provided under this Act to promote bona fide use of bioresources for research and non-commercial use:

- Provisions of Section 3 (access to bio-resource) and Section 4 (transfer of research results) shall not apply to the approved collaborative research projects, conforming to the policy guidelines issued by the

Ministry of Environment and Forests (MoEF) vide its notification dated 8 November, 2006.

- Provision of Section 6 shall not apply to any person making an application for any right under the Protection of Plant Varieties and Farmers’ Rights Act, 2001. Where any right is granted under this law, the concerned authority granting such right shall endorse a copy of such document (granting the right) to the NBA.
- Provisions of Section 7 (prior intimation to SBB for commercial use) shall not apply to the local people and communities including village healers/vaids, farmers and other traditional growers and also to Indian users of these bio-resources for research.
- Normally traded commodities, 190 bio-resources as notified by the MoEF vide its notification dated 26 October, 2009, subject to the clarification issued on 16 February, 2010, would be exempt from purview of this Act provided they are traded as commodities.

Links to the Protection of Plant Varieties & Farmers’ Rights Act and the Patents Act

Any person seeking any kind of IPR in or outside of India for any invention/ technology/ product or process, based on any biological resource (or associated knowledge) obtained from India, is required to obtain prior permission of the NBA [Section 6].

There is no overlap between BDA and the Plant Varieties Protection (PVP) & Farmers’ Rights Act and the scope and objectives of these two legislations are different. The PVP legislation accords intellectual property rights to a person for developing a new plant variety. On the other hand, the biodiversity legislation is primarily aimed at regulating access to biological resources and associated knowledge so as to ensure equitable sharing of benefits arising from their use. In order to harmonise both the legislations, an exemption has been provided under Section 6(3) of the Biodiversity Act for applicants seeking protection of varieties under the PVP Act. The intention of Section 6(3) is to ensure that before granting of the IPRs under PVP or the Patents Acts, NBA gets an opportunity to realize equitable sharing of benefits arising out of the use of biological resources and knowledge. As the PVP legislation also has a provision for benefit sharing, an exemption has been provided in the Biodiversity Act for applicants seeking protection under the PVP Act. The Authority under the PVP legislation would be required to endorse a copy of the right granted under this Act to the NBA.

Likewise, Section 6 (1) of the BD Act links to the requirement under Section 10 (4) of the Patents (Amendment) Act, 2002 that requires disclosure of the source and geographical origin of the biological material, used in developing an invention /innovation. A sample of the bioresource is also required to be deposited in the designated national repository institution.

Realizing Fair and Equitable Benefit Sharing under the Biological Diversity Act

A schematic diagram is presented in Annex 1 showing how applications submitted to the NBA for grant of access are processed. While showing the mechanism, it also indicates the role played by the Expert Committee on ABS. The NBA is required to develop and notify guidelines for imposing terms for fair and equitable benefit sharing and efforts in this context are going on. A National Consultation was also organized on 23 April 2010 at Chennai to obtain further inputs from different experts and stakeholders for this purpose. Until these guidelines are finalized and notified, some working guidelines have been developed by the Expert Committee on ABS and followed while making recommendations regarding benefit sharing on a case-by-case basis (Annex 2).

Options for sharing non-monetary benefits, adopted from the non-binding Bonn Guidelines, are provided under Section 21 as listed below:

- Transfer of technology
- Location of production, R&D units in areas inhabited by ‘benefit claimers’
- Associating Indian scientists and benefit claimers with the R&D activities
- Setting up of venture capital
- Payment of monetary [and royalty] benefits
- Product development
- Institutional capacity building
- Education and awareness raising activities

For sharing benefits in monetary form, consideration

is given to potential commercial value of the innovation/ product/process/ technology, expected volume of potential business and the capacity to pay of the applicant. Terms and conditions for benefit sharing are finally entered in to the agreement when mutually agreed between the NBA and the Applicant.

Procedure for Applying to NBA for Access to Bioresources

Four kinds of applications forms have been prescribed and fee for each of these categories have been specified. These may be downloaded from NBA’s website. Relevant information on these Application Forms and fees is presented in Table 1.

Applying terms for benefit sharing on a case by case basis notwithstanding, a generalized and indicative scheme for sharing monetary benefits, arising from commercialization of innovations/processes/Products based on the use of bioresources, and associated TK, is given below for guidance purpose only (Table 2).

Approval for accessing bioresource, bio-survey & bio-utilization, transfer of research results, seeking IPR and third party transfer of already accessed bioresource is given by NBA by signing a written agreement with the applicant as required under Rule 14(5).

The amount realized by the NBA through fees, royalties and other sources goes to the National Biodiversity Fund that is used for the following purposes:

- Channeling benefits to the ‘benefit claimers’.
- Helping the conservers and developers of biological resources/ local communities in support of their on-location efforts towards conservation and sustainable use.
- Promoting conservation of bio-resources and development of areas from where these are accessed.
- Supporting conservation efforts for the designated ‘Biodiversity Heritage Sites’.
- Capacity building.

Table 1. Prescribed Application Forms and Fees for Seeking Approval of NBA

Application Format	Purpose	Application Fee
Form I [Sections 3 and 19, Rule 14].	Access to Bioresources/TK by foreigners/ Commercial Use, Bio-survey/ Bio-utilization.	Rs. 10,000/-
Form II [Section 4, Rule 17].	Transfer of Research Results/ Data.	Rs. 5,000/-
Form III [Section 6, Rule 18].	Seeking IPR	Rs. 500/-
Form IV [Section 20, Rule 19].	Third Party Transfer of Bioresources	Rs. 10,000/-

Table 2. Benefit Sharing Terms for IPR and Commercialisation of the Product

Commercial Use Category	Benefits from direct commercial use	Benefits from commercial use after licensing to a licensee (third party)
The Applicant commercialises the process/product	The applicant shall pay royalty @ up to 3% of the highest ex-factory sale price of the product sold or used for captive consumption (in such cases, the price would be determined on the basis of the price which the product would get if sold in the market).	The applicant pays a mutually agreed upfront amount until the product/ innovation enters into commercial production.
The Applicant licenses the process/product to a Licensee	The Applicant shall pay up to 5% of the license fee received from the Licensee as one-time benefit sharing at this stage. The Applicant shall also provide a copy of the contract, entered into, to the Authority.	Upon commercialization, the applicant shall further pay, in addition to the payment made earlier, up to 5% royalty on the amount received by him as his royalty-charges from the licensee on an annual basis.
The Applicant collects the bioresource from its natural populations, with prior approval of the concerned SBB/ BMC/ State Wildlife Board, and exports it as a commodity under DGFT permit.	The Applicant shall pay 5% of the total FOB value of the bioresource under export to the Authority.	-----

National Biodiversity Authority

In exercise of the powers conferred by Sub-Section (1) (4) of Section 8 of the Biological Diversity Act, 2002, NBA was established by Government of India in October, 2003 at Chennai, Tamil Nadu under the Section 8 of the Act for pursuing the implementation of the Biological Diversity Act, 2002 at the national level. It consists of a Chairperson, 10 Ex-officio and 5 Non-official members. The main functions of this Authority are:

1. To lay down procedures and guidelines to govern the activities provided under Section 3, 4 and 6 (Permission to foreigners/non-resident Indians and foreign companies).
2. To regulate activities and advise the government of India on research/ commercial use of bio-resources, bio-survey and bio-utilization.
3. To grant approval under Section 3, 4 and 6 based on the following considerations:
 - Certain persons not to undertake Biodiversity related activities without approval of National Biodiversity Authority (Section 3) (Access to biological resources or Associated knowledge).
 - Results of research not to be transferred to certain persons without approval of National Biodiversity Authority (Section 4) (Transfer of Research Results).
 - Applications for seeking IPR rights not to be made without prior approval of the NBA (Section 6).
4. To grant approval to certain persons seeking transfer of already accessed biological resource/associated

traditional knowledge (Third Party Transfer) (Section 20).

5. To determine and impose terms of equitable benefit sharing, arising out of the use of accessed biological resources and associated traditional knowledge (Section 21).
6. To advise the State Governments in the selection of areas of biodiversity importance to be notified under Section 37 (1) as heritage sites and measures for their management.
7. To take any measure, on behalf of the Central Government, necessary to oppose the grant of IPR in any country outside India on any bioresource obtained from India or knowledge associated with it which is derived from India.

NBA has been charged with the overall responsibility of implementing this legislation in partnership with the State Biodiversity Boards and the Biodiversity Management Committees at the grass root level. The provision of mandatory consultation of BMCs by the NBA and SBBs would ensure formalisation of PIC by the communities and the involvement of BMCs in the decision making process.

It is noteworthy that NBA has been assigned three major functions merged together. It is expected to act as the regulator for enforcing the law's provisions under sections 3, 4, 6 and 20. It also has the responsibility to develop and issue guidelines for facilitating access to biological resources and for fair and equitable benefit sharing under Section 21. Its advisory role includes advising the Central Government on matters relating to conservation of biodiversity, sustainable use of its components and

equitable sharing of the benefits arising out of the utilization of biological resources, and associated TK. It is also expected to advise the State Governments towards the selection of areas of biodiversity importance to be notified as heritage sites and the measures for their management. Viewed from this perspective, some situations may arise requiring adjustments in balancing these roles within the provisions of the Biological Diversity Act and the Rules framed under it.

NBA's role is truly challenging as it acts as the regulator and also the promoter of conservation and sustainable use of bioresources in addition to acting as the advisor to the Central and State governments on matters related to biodiversity.

IV. Implementing Access and Benefit Sharing under the Biological Diversity Act

Biodiversity is a multi-disciplinary subject, involving diverse activities. Its major stakeholders include the Central Government, State Governments, institutions of local self-government, local communities, farming communities, research institutions, industry and civil society organizations. Notwithstanding the fact that the Contracting Party to the CBD is the national government and the Union Ministry of Environment & Forests is the nodal ministry, biodiversity is essentially a state subject. Even at the Central Government level, several union ministries have overlapping authority in managing different components and concerns of biodiversity. Thus, implementing the Biological Diversity Act requires effective coordination among all the concerned authorities and also other major stakeholders.

The Act provides for its implementation through a 3-tier system comprising the National Biodiversity Authority (NBA), the State Biodiversity Boards (SBBs) and the Biodiversity Management Committees (BMCs) at the local communities level. Functions of this system at all the three levels have been well defined. There is a provision for setting up of a Committee on Agriculture and also some expert committees as needed. The NBA has been established and it is operating from Chennai. SBBs have also been constituted in 26 States though they often lack the guidance of technical experts at the top. The task of setting up of BMCs remains a challenge although some states have gone ahead notably in this direction and 31,542 BMCs have already been constituted. Over 400 People's Biodiversity Registers are under preparation. However, infrastructure still remains poor and there is lack

of adequate capacity at the lower two levels, particularly at the level of local communities. There is an urgent need for generating awareness at all levels about the Act's main provisions and objectives and also about the benefits that are likely to accrue following its effective implementation.

The NBA has also constituted the following expert committees to assist in its functioning:

- Expert Committee on Access and Benefit Sharing for processing all the applications and making recommendations for their approval or otherwise.
- Expert Committee for framing the guidelines for determining contributions to and utilization of National Biodiversity Fund.
- Expert Committee on preparing guidelines on ameliorative measures for biodiversity rich areas that are threatened by overuse, abuse or neglect.
- Expert Committee on Agro-biodiversity
- Expert Committee for implementing the Project for establishing "Indian Biodiversity Information System (IBIS)".
- Expert Committee for the preparation of Training Module for Officers staff and various stakeholders on legal, social, technical aspects of implementation of various provisions of Biological Diversity Act, 2002.
- Expert Committee for preparation of guidelines on creating structures, running administration and maintaining of accounts and other related matters pertaining to Biodiversity Management Committees
- Expert Committee on reviewing the agreements' formats.

There is an urgent need at present to develop a strong National Biodiversity Information System, suited to the needs of our country and to serve as a referral facility for networking. Although several options are available for securing equitable sharing of benefits, arising from the use of bio-resources (and associated ITK) but there are not many case studies available as yet to provide learning experiences. Furthermore, some progress in this direction notwithstanding, there is still no adequate monitoring mechanism in place to ensure proper compliance of the contracting agreements, signed between the NBA and the users on mutually agreed terms. Another major limitation is that provisions of our national legislation on ABS do

not yet have international recognition and compliance abroad.

Several National Bureaus, mandated with the conservation and sustainable use of bio-resources under the ICAR, are currently engaged in systematic registration of elite genetic resources of crop plants, livestock and fish. Over 800 elite plant genetic resources and nearly 130 elite livestock breeds have already been registered. There is need to provide legal protection to such registered elite genetic stocks by invoking relevant provisions under the Protection of Plant Varieties Act, the Biological Diversity Act and other relevant legislation and administrative measures. Some ground work has already been done but some hazy areas still remain awaiting clarity. Issues relating to benefit claimers and farmers' rights require more attention. These discussions need to be continued and supported to reach some meaningful conclusions and well laid out procedures. As it appears, beginning may have to be made with documenting them in relevant communities' Biodiversity Registers, duly endorsed by the

concerned SBBs, and finally by the NBA, in partnership with the ICAR.

Our crop and livestock genetic resources are still evolving under in-situ on-farm conditions, moving gradually towards better adaptation to situations in which they are grown in the face of emerging outbreaks of pests and diseases and also non-biotic stresses. These evolutionary processes, abruptly cut off by the ex-situ conservation strategy, need to be continued and strengthened under the in-situ on-farm conditions, managed by the farming communities who are living with their bioresources under different agro-ecosystems. In-situ conservation and sustainable use of bioresources is strongly supported under the Biological Diversity Act. Considering that effective implementation of this Act requires joint effort and active collaboration of several union ministries of the central government and also the state governments, it is proposed that this challenging task be undertaken as a standalone national mission on 'Implementing the Biological Diversity Act for Adaptation to Climate Change'.

BOX 1

Legal Framework for Regulating ABS in India

It comprises a three tiered structure at the national, state and local levels with distinct roles, supportive of each other.

National Biodiversity Authority (NBA): All matters relating to requests for access by foreign individuals, institutions or companies, and all matters relating to transfer of results of research to any foreigner are dealt with by the National Biodiversity Authority.

State Biodiversity Boards (SBB): All matters relating to access by Indians for commercial purposes are under the purview of the State Biodiversity Boards (SBB). The Indian industry is required to provide prior intimation to the concerned SBB about the use of biological resource. The State Board has the power to restrict any such activity, which violates the objectives of conservation, sustainable use and equitable sharing of benefits.

Biodiversity Management Committees (BMCs): Institutions of local self government are required to set up Biodiversity Management Committees in their respective areas for conservation, sustainable use, documentation of biodiversity and chronicling of traditional knowledge relating to biodiversity. SBBs are expected to take decisions in consultation with BMCs where appropriate. NBA and SBBs are required to consult the concerned BMCs on matters related to use of biological resources and associated knowledge within their jurisdiction.

- There is no overlap in the functions of NBA and SBBs. Their domains and functions are very distinct from each other. All matters relating to requests by foreign individuals, companies or institutions and all matters relating to transfer of results of research to any foreigner, are dealt with by NBA. All matters relating to access by Indians for commercial purposes are under the purview of the concerned State Biodiversity Boards. Approvals prior to applying for IPR over innovations, based on the use of bioresources and associated TK, are also accorded by NBA.

V. Some Notable Accomplishments

1. Regular Meetings of the NBA held

The NBA has held 21 meetings so far and their proceedings are available on its website to ensure transparency and also to provide an opportunity to all the stakeholders for their inputs. Several consultations have also been organized at the national level to promote implementation of the BDA and developing guidelines for dealing with traditional knowledge associated with bioresources,

2. Progress in constituting and operationalising the SBBs and BMCs

To establish and effectively operate a 3-tier system presents a great challenge in managing skills. With the constitution of SBBs in 26 states and over 4,000 BMCs in these states until October 2011 (Table 3), the NBA is challenged with supporting these entities with adequate policy and regulatory guidance, provision of much needed tools, methods and guidelines to translate the provisions under the Act, especially those related to ABS provisions, into practice so that such activities can promote better realization of provisions of the Act with respect to ABS issues. Inadequate information on biodiversity and their potential for use, its economic value and potential, tools and guidelines on different provisions under the Act, limited capacities with the implementation structures and awareness about ABS provisions under the Act, are key challenges before the NBA, and also the MoEF. Moreover, the ABS provisions are yet to have an on-ground impact largely due to lack of national guidelines available for ABS, capacities to implement the provisions under the Act and awareness on how to use the Act for the benefit of supporting conservation, sustainable use and sharing the benefits equitably. Efforts are underway to get the SBBs constituted in the remaining states of Bihar and Jammu & Kashmir.

3. NBA-SBBs Interface Workshops

Interactive meetings between the Authority members and SBBs are being regularly organized providing an opportunity to review the progress made in implementing provisions of the Act and also to discuss ways and means of overcoming difficulties faced in this process. Sixth National Meet in this series was held at Chandigarh in September, 2010.

4. Capacity Building at the State Level

NBA is trying to strengthen capacity of SBBs at various levels by utilizing the opportunity provided by fund

Table 3. Setting up Biodiversity Management Committees

S. No.	State	No. of BMCs
1.	Andhra Pradesh	35
2.	Goa	5
3.	Gujarat	11
4.	Himachal Pradesh	2
5.	Karnataka	3,592
6.	Kerala	200
7.	Madhya Pradesh	50 district Panchayats, 313 Janpad Panchayats, 23043 Gram Panchayats, 237 Nagar Panchayats, 14 Nagar Nigams, 86 Nagar Palikas, 3969 Gram Sabhas (in progress) ⁺
8.	Manipur	15
9.	Mizoram	234
10.	Nagaland	10
11.	Punjab	51
12.	Tamil Nadu	1
13.	Tripura	13
14.	Uttar Pradesh	1
15.	Uttarakhand	37
16.	West Bengal	33
Total		4,240 +

support under the India-UNDP/GEF/UNEP (Biodiversity) Programme. Two projects are under implementation at present and these are briefly described below:

A 3-year project (2009–2012), under Small Grants Programme, is being implemented on strengthening institutional structures for implementing the Biological Diversity Act in Jharkhand and Madhya Pradesh states with the broad objective of capacity building at various levels and bringing in behavioral changes to manage natural resources in an integrated, participatory and sustainable manner. Owing to the close link between the Biological Diversity Act 2002, National Environmental Policy 2006, Schedule Tribes and other Traditional Dwellers (Recognition of Forest Rights) Act 2006, National Biodiversity Action Plan 2008 and India's Fourth National Report to the CBD, inclusion of natural resource dependent tribal and marginalized population, particularly women, in the planning and decision making process is one of the critical and vital elements of the strategy. This intervention has a focus mainly in Jharkhand and Madhya Pradesh states known for their rich biodiversity. The project will help to address the challenges in implementation of the Biological Diversity Act by strengthening the SBBs and BMCs through capacity building, public awareness activities, developing databases and their networking. The initiative in the two states is on the pattern of a pilot project that will function as a template in strengthening the other SBBs in India.

This has been followed by a 4-year Full Scale Project

(2011-2014), with fund provision of USD 6,278,000, on capacity building in 5 more states for strengthening the implementation of the Biological Diversity Act & Biological Diversity Rules, with a focus on Access & Benefit Sharing Provisions, in Andhra Pradesh, Gujarat, Himachal Pradesh, Sikkim and West Bengal.

One 3-year project (2010-2013, funded by the World Bank, is also being implemented by the MoEF and ICAR on National Agriculture Innovations, with a strong component on biodiversity and livelihoods, in three economically backward districts in Himachal Pradesh, Rajasthan and Andhra Pradesh.

5. Expanded Role of the Expert Committee on Access and Benefit Sharing

NBA was established in October, 2003 but the decision for constituting the Expert Committee, on scrutinizing applications received by the NBA for granting approval and making its recommendations, was taken by the 4th meeting of the Authority held on 6 October, 2005. To begin with, two expert committees were set up; one dealing with applications received for access on a case by case basis and the other on recommending the terms for benefit sharing in each case recommended for approval. On gaining some experience, these two committees were merged into one committee in 2009 and named as the Expert Committee on Access and Benefit Sharing. This expert committee has 22 members at present, representing different areas of specializations. Two member secretaries of SBBs have also been made members to gain experience and participate in decision making. Five more member secretaries of different SBBS are also invited to attend meetings of the EC on a rotational basis. This Committee, treated by the NBA as a Standing Committee, has evolved over the years by gaining from its experience and has now become a strong institutional mechanism for implementing the benefit sharing provisions of the Biological Diversity Act and the Rules framed under it. On recommendations of this Committee, 359 applications have been granted approval by the Authority and 93 agreements on benefit sharing on mutually agreed terms have been signed so far (Table 4).

6. Documenting Biodiversity in People's Biodiversity Registers (PBR)

Documenting bioresources, and associated traditional knowledge, is among the responsibilities assigned to the BMCs. Model format and guidelines for preparation of such registers have been developed and uploaded on the

Table 4. Status of Applications as on 13.10.2011

Category of Forms	Received	Cleared	Under Process	Closed	Agreements Signed
Form I	101	27	52	22	16
Form II	35	14	21	0	11
Form III	458	298	143	17	50
Form IV	50	20	25	5	16
Incomplete	13	0	0	13	0
Total	657	359	241	57	93

Authority's website. Workshops are being organized to assist BMCs in this effort and 932 PBRs have been documented so far under different SBBs (Table 5).

7. Designation of Repositories under the BDA

In exercise of the powers conferred by Section 39(1) of the Biological Diversity Act, 2002, the Ministry of Environment & Forests designated 13 institutions to act as repositories for different categories of biological resources (Table 6). These designated repositories shall also keep in safe custody the representative samples, as voucher specimens of the biological material accessed in accordance with the provisions of Section 19 (Persons other than Indian citizens accessing any bioresource or any person seeking IPR on innovation based on the use of bioresources and associated TK).

8. Normally Traded Commodities Notified

Under Section 40, bioresources normally traded as commodities are exempted from provisions of this Act. As per the notification issued by the Union Ministry of Environment & Forests on 26 October, 2009 and subject to the subsequent clarification issued on 16 February, 2010, 190 bioresources (species) have been designated as normally traded commodities and so exempted. This list, however, remains contested and it is likely to be revised considering that some known threatened species happen to be included in it.

9. Commercial Use of Medicinal Plants by Herbal Industry

Global demand for herbal products in recent years

Table 5. Preparation of People's Biodiversity Registers

S. No.	State	No. of PBRs Documented
1.	Andhra Pradesh	5
2.	Karnataka	212
3.	Kerala	74
4.	Madhya Pradesh	480
5.	Uttarakhand	139
6.	West Bengal	17
7.	Manipur	2
8.	Jharkhand	3
	Total	932

Table 6. Repositories designated under the BDA

S. No.	Name of the Institution	Category of Bioresources
1	Botanical Survey of India, Kolkata	Flora (Angiosperms, Gymnosperms, Pteridophytes, Bryophytes, Lichens, Macrofungi, Macroalgae)
2	National Bureau of Plant Genetic Resources, New Delhi	Plant genetic resources
3	National Botanical Research Institute, Lucknow	Flora (Angiosperms, Gymnosperms, Pteridophytes, Bryophytes, Lichens, Macrofungi, Macroalgae)
4	Indian Council of Forestry Research and Education, Dehradun (Forest Research Institute, Dehradun; Institute of Forest Genetics and Tree Breeding, Coimbatore; and Tropical Forest Research Institute, Jabalpur)	Flora (Angiosperms, Gymnosperms, Pteridophytes, Bryophytes, Lichens, Macrofungi, Macroalgae). For TFRI only: Fauna (Termites, butterflies, moths)
5	Zoological Survey of India, Kolkata	Fauna
6	National Bureau of Animal Genetic Resources, Karnal	Genetic resources of domestic animals
7	National Bureau of Fish Genetic Resources, Lucknow	Fish genetic resources
8	National Institute of Oceanography, Goa	Marine flora and fauna
9	Wildlife Institute of India, Dehradun	Faunal resources in Protected Areas
10	National Bureau of Agriculturally Important Microorganisms, Mau Nath Bhanjan	Agriculturally important microorganisms
11	Institute of Microbial Technology, Chandigarh	Microorganisms
12	National Institute of Virology, Pune	Viruses
13	Indian Agricultural Research Institute, New Delhi	Microbes/ Fungi

has experienced a quantum jump in volume of plant material traded within and outside the countries of origin. International market of medicinal plants has been estimated at US\$ 60 billion per year, growing at a rate of 7% annually. India is one of the richest countries in the world as regards genetic resources of medicinal and aromatic plants. Medicinal plants, as a group, comprise about 8,000 species and account for nearly half of all the higher flowering plant species documented in India. Even though over 105 plants provide the basic raw materials used in modern medicine the world over, the number of plants used on a sizeable scale is just around 40 in India. Furthermore, marketing of raw herbal drugs is highly unorganized and unregulated, often without any premium on quality (Robinson, 2010).

About 90% of the medicinal plants, used by herbal industry in India, are collected from the wild source and more than half of these collections involve destructive harvesting. As a result of such exploitative practices combined with excessive collections, many important medicinal plants are becoming endangered or threatened. NBA is currently engaged in consultation with the Ayurvedic Drug Manufacturers Association and several other major players to address this problem with a view to promoting sustainable use practices and registration of bulk users of herbal materials for healthcare, cosmetics and food supplements.

Draft guidelines for commercial use of India's natural and biological resources and traditional knowledge, developed by NBA, is facing opposition from some industries that deal in products such as herbal drugs, cosmetics and nutritional supplements (Unnikrishnan, 2010). NBA's EC-ABS has constituted a sub-committee to critically review the draft guidelines and suggest improvements for developing recommendations for further consideration of the NBA.

VI. An Overview of the Implementation and also Some Concerns

1. Ownership Rights/Sovereign Rights and the Primary Beneficiaries

Habitats/ Ecosystems	Ownership Rights and Beneficiaries
Natural bioresources in protected areas (PA) network	Sovereign rights acknowledged to the State (Government of India). Monetary benefits expected to be flowing to the claimants and beneficiaries through the channel of Biodiversity Fund at the national, state and BMC levels.
Natural bioresources outside the PAs (Forest Areas)	Tribal communities and Forest Dwellers' Rights granted over their lands and also for collection of NTFP.
Agricultural/ Cultivated bioresources	Farmers and Farming Families
Communities' common lands	Local Communities

2. Three Major Functions of the NBA

A. NBA Functioning as the Regulator

S. No.	Concerns	Remarks
i.	Enforcement of the provisions under sections 3, 4 and 6.	Procedures and guidelines for this purpose need to be laid down to ensure clarity and transparency.
ii.	Enforcement of the Act's provisions with an effective system for reporting for violations and follow up actions.	There is need for a separate wing having trained cadres for enforcement of legal provisions and reporting of violations. Example of enforcement under Wildlife Act, 1972: Case of Petr Svacha and Emil Kucera, Czech entomologists, caught collecting butterflies in Darjeeling area in 2008 and sentenced by the court (Mitra, 2008). Svacha paid his fine but Kucera jumped bail and sneaked out of India.
iii.	Capacity at the national level with adequate support base at the state and local levels.	The NBA is expected to be centre of excellence on all matters dealing with biodiversity, including scientific, policy matters and legal affairs. Biodiversity databases need to be developed at both the national and state levels with an efficient networking system.
iv.	Constitution, strengthening and functioning SBBs	Many SBBs have part-time non-technical chairmen. Member-secretaries are on mostly on deputation and get transferred frequently. There is need for adequate infra-structure and technical staff at this level.
v.	NBA as an autonomous national organization.	There is need to strengthen the organization with sufficient funding allocations made under the 12 th Plan. More project-based funding needs to be encouraged.
vi.	Inspecting capacity at the exit points [Custom Department]	There is an urgent need for preparation of working manuals and organizing proper training for the custom officials manning the exit points.
vii.	Effective regulation and monitoring of bulk use by the herbal and other user industries.	It is important to bring the major pharmaceuticals and herbal drug manufacturers in the fold through proper monitoring mechanism. The bulk users need to declare quantity/location and timing of collections to promote sustainable use.
viii.	Conservation of threatened species.	Section 38 provides for notifying threatened species and prohibits or regulates their collection while also taking appropriate steps to rehabilitate and preserve those species. National database on threatened species needs to be developed on priority, enabling the NBA to develop suitable management plans. Some states have already notified their lists of threatened species and the rest should be encouraged to do so at the earliest.
ix.	Designated Repositories under the Act.	Thirteen institutions have been designated as repositories for different categories of biological resources but no guidelines for their roles have been notified as yet. There is also no follow up and monitoring. There is also a glaring gap since no internationally recognized repository has been designated for microorganisms, which is a requirement for the patent system.
x.	Notification of normally traded commodities	A list of 190 species (bioresources) has been notified but inclusion of several threatened species has been protested. The list needs an early revision.
xi.	Restrictions on granting access by SBBs under Section 24 read with Rule 6.	There is need for the NBA to take a lead by developing and notifying suitable guidelines to assist the SBBs and also organize training workshops for capacity building.
xii.	Monitoring of implementing the benefit sharing terms.	The agreement signed by the applicant with the NBA contains mutually agreed terms for benefit sharing. Applicant is required to submit reports on an yearly basis along with supportive documents but proper mechanism of monitoring need to be developed for follow up action.
xiii.	Protection of traditional knowledge associated with bioresources.	National consultations notwithstanding, this remains the weak link. It is a complex and highly debated topic and deserves high priority to move forward.

B. NBA Functioning as the Promoter

Concerns	Remarks
i. Conservation of bioresources	National Biodiversity Action Plan has indicated broadly some activities that should be undertaken by the NBA. This needs to be followed up by developing a suitable work-plan that may be linked up to the projects that are being implemented by the NBA in several states, focusing on <i>in-situ</i> on-farm conservation and related activities with the involvement of self-help groups and local NGOs.
ii. Sustainable use of bioresources	NBA has not yet been able to notify the much awaited guidelines for this purpose with the result that exploitative practices, combined with excessive collections, are continuing putting a large number of species at risk, particularly the medicinal and aromatic plants. NBA is currently engaged in consultation with the bulk users, like the Ayurvedic Drug Manufacturers Association, and several other major players to address this problem with a view to promoting sustainable use practices. To begin with, bulk users, particularly in herbal healthcare and food supplements sector, are being encouraged to provide information on the quantities, location, source and timing of collections, and also to register themselves with the concerned SBBs. Even when such information is declared, there is no effective monitoring of such extractions from the wild populations. Voluntary checks do not seem to be working and there is need to develop and enforce and effective system with proper checks and balances.
iii. Fair & equitable sharing of profits arising from the use of bioresources	This is the most critical element in implementing the provisions on ABS but the expected guidelines to deal with this topic, at the national as well as state levels, have not been notified as yet. This needs to be done without further delay. It is, however, commendable that the Expert Committee has developed a working module for this purpose (Annex-2) and this may be used after suitable refinements where required.
iv. National Biodiversity Fund (Section 27)	All charges and royalties received by the NBA, and also the grants, are to be credited to this Fund which shall be applied for: – Channeling benefits to the benefit claimers; – Conservation and promotion of biological resources and development of areas from where such bio-resources or knowledge associated thereto have been accessed; – Socio-economic development of areas referred to above in consultation with the local bodies concerned. About Rs.50 lakhs have been received in this Fund so far and there is an urgent need to notify the guidelines for channeling this amount. An Expert Committee has been constituted for this purpose and this process needs to be completed at the earliest.
v. Responding to Stakeholders' grievances	On receiving inputs from some stakeholders about the difficulties that they were facing because of their reservations regarding some items contained in the formats of different categories of agreements, the NBA promptly constituted an Expert Committee for this purpose and formats of all the four kinds of agreements were suitably revised.
vi. Partnerships with major sectors	The NBA continues to hold consultations with major stakeholders including the seed industry and the herbal healthcare sector to promote sustainable utilization of bioresources and greater generation of benefits for sharing with the beneficiaries. More active partnerships with major sectors need to be developed.
vii. Institutional support	Need to identify and involve leading institutions, particularly at the local level, and also the local NGOs to assist the BMCs.
viii. Promoting research on key issues and engage consultants.	NBA is required to commission studies and engage consultants to assist the Authority in the effective discharge of its functions.
ix. Creating awareness and promoting people's participation.	Much more effort is required in this direction with proper planning, funding support and media coverage.

C. NBA functioning as the Advisor to the Central and State Governments

S. No.	Concerns	Remarks
i.	Meeting the national obligations under CBD.	NBA is required to advise the Central Government on any matter concerning conservation of biodiversity, sustainable use of its components and promoting fair and equitable sharing of benefits arising out of the use of biological resources and associated traditional knowledge. There is need to further develop the National Biodiversity Action Plan and ensure its implementation by the concerned departments/ institutions and organizations.
ii.	Extending support to SBBs.	NBA is expected to provide technical assistance and guidance to SBBs, coordinate their activities and sanction grants-in-aid to SBBs and BMCs.
iii.	Respect and protect the knowledge of local people relating to biological resources.	NBA to develop suitable recommendations for this purpose, including measures which may include registration of such knowledge at the local, state or national levels and legal protection through <i>sui generis</i> system.
iv.	Planning and organizing suitable training/ capacity building programmes.	NBA is expected to plan and organize training of personnel engaged or likely to be engaged in programmes for the conservation of biodiversity and sustainable use of its components.
v.	IPR protection of India's bioresources and associated TK in other countries.	NBA to take necessary measures, including appointment of legal experts to oppose grant of IPR in any country outside India on any biological resource and associated knowledge obtained from India in an illegal manner.

To sum up, the 3-tier structure for implementing the Biological Diversity Act, and the Rules framed under it, poses formidable challenges but also offer great opportunities to work in partnership for promoting conservation and sustainable use of biological resources linked to fair and equitable sharing of benefits arising from their utilization. There are more than six major union ministries who exercise authority on different components of biodiversity and decisions have to be taken on evolving consensus on a case by case basis. The central and state governments are also required to work in unison even when their priorities often differ. The required infrastructure and capacity are still inadequate, particularly at the states' and grass root levels where conservation and sustainable use practices need to be strengthened and where primary beneficiaries of the benefit sharing mechanism are striving to earn their livelihoods, often based primarily on bioresources around them. This situation led to a slow tempo of implementation but the pace has picked up in recent years. Notification of guidelines on ABS and several other basic components of the implementation plan need to be issued on priority to assist the SBBs, BMCs and users of bioresources. It is equally important to keep simplifying the procedures for granting access to bioresources and to address the common grievances of the users. It may be desirable to make some policy adjustments to permit sector-wise approach to suit requirements of bulk users in sectors like herbal pharmaceuticals, cosmetics, food supplements and seeds among many others. Even when the delegation of regulatory function to some other central government departments (like the

ICAR/DARE for agricultural biodiversity) may not be considered feasible until some minimum conditions are met, developing selective partnerships may be helpful in promoting implementation of the provisions on access and benefit sharing.

VII. The Way Ahead

The National Biodiversity Authority, constituted under India's national legislation on regulating access to bioresources, and the associated traditional knowledge, has been charged with the responsibility of implementing this legislation in partnership with the State Biodiversity Boards and the Biodiversity Management Committees at the grass-root level. It has been assigned three major functions merged together. It is expected to act as the regulator for enforcing the law's provisions under sections 3, 4, 6 and 20. It also has the responsibility to act as the promoter for creating public awareness and also developing and issuing guidelines for facilitating access to biological and for fair and equitable benefit sharing under section 21. It also has an advisory role that includes advising the Central Government on matters relating to conservation of biodiversity, sustainable use of its components and equitable sharing of the benefits arising out of the utilization of biological resources, and associated TK. It is also expected to advise the State Governments towards the selection of areas of biodiversity importance to be notified as heritage sites and the measures for their management. Thus, NBA's role is truly challenging as it acts as the regulator and also the promoter as well as the advisor. Viewed from this perspective, some situations may arise requiring adjustments in balancing these roles

within the provisions of the Biological Diversity Act and the Rules framed under it. For example, preference may be accorded to creating awareness rather than going for enforcing punitive measures.

It needs to be appreciated that India's CBD-compliant sui generis national legislation has a judicious mix of commendable provisions that link up conservation and sustainable use of bioresources with fair and equitable sharing of benefits arising from their authorized use. Notwithstanding some infirmities, it was expected to strengthen, realign and converge its on-going programmes to meet national obligations under CBD based on an all-inclusive and vibrant system (Rana, 2004; Bala Ravi, 2006; Rana, 2010). The pace of its implementation has picked up in recent years but its effectiveness is still considered very low. The major factor responsible for this below expectation performance appears to be the lack of adequate awareness about its provisions, not only among the general public but also among the policy makers and managers alike, more particularly those concerned with access and benefit sharing. This limitation is further compounded by poor infrastructure and little capacity building at the grass-root level. Institutional support is mostly missing at the local level, affecting adversely the scientific content of crucial conservation activities. On the positive side, SBBs have been constituted in 26 of the 28 states and they are being increasingly involved in decision making by the NBA, even though the much needed guidelines on ABS have not yet been notified. It is now the turn of the BMCs to be empowered to play an active role in this process. The Expert Committee on ABS has also evolved over time into a capable institution, streamlining its procedures and operations.

There is also an urgent need for developing partnerships with the lead institutions, and also the private sector, in conserving, sustainable use and managing bioresources based on suitable terms of scientific cooperation and principle of reciprocity (Rana, 2010).

Promoting sustainable use practices deserve more attention and high priority, particularly by the herbal healthcare, cosmetics and food supplements sector (Ved and Goraya, 2008). It is widely known that around 90% of the medicinal plants, used by herbal industry in India, are collected from the wild source and more than half of these collections involve destructive harvesting. As a result of such exploitative practices combined with excessive collections, many important medicinal plants are becoming endangered or threatened. NBA is currently engaged in

consultation with the Ayurvedic Drug Manufacturers Association and several other major players to address this problem with a view to promoting sustainable use practices and registration of bulk users of herbal materials (Brindavanam and Agarwal, 2010).

The ICAR/DARE also needs to develop and finalise its own policy and guidelines on access to and exchange of plant genetic resources, in consultation with the NBA, to meet national obligations under the ITPGRFA and bilateral agreements.

Adoption of Nagoya Protocol to CBD on Access and Benefit Sharing during the COP-10 meeting last year is a positive development since it is likely to provide a fillip to developing a much awaited international regime with a framework that balances access to genetic resources on the basis of PIC and MAT with fair and equitable sharing of benefits, while also taking into account the important role of TK. The agreed definition of 'genetic resources', adopted under the Nagoya Protocol on ABS, now includes 'derivatives' and this augers well with the position taken by the biodiversity-rich developing countries on this issue. With the adoption of this Protocol, the fair and equitable sharing of benefits has been reaffirmed as a fundamental component of biodiversity-dealing strategies and a set of rules has been agreed upon to facilitate, promote and ensure its effective implementation. This Protocol has also brought in TK, associated with biosources, under the ambit of benefit sharing even though the realization of benefit sharing is linked basically to provisions of national legislation and regulatory mechanisms adopted by countries providing the bioresources. However, this lead needs to be developed further through pro-active negotiations under CBD (Schei and Tvedt, 2010).

The United Nations has declared 2010-2020 as the Decade of Biodiversity and COP-11 meeting of the Parties to CBD will be held in Hyderabad in October, 2012. With India ascending to the presidency of the CBD for the period 2012-2014, there will be vast opportunities ahead for playing significant lead role towards promoting equitable and fair sharing of benefits arising from the use of biological resources, even in the face of growing trend toward protecting/ patenting of improved crop varieties and elite genetic stocks. The 2010 Nagoya Protocol on ABS, expected to enter in to force by the next year, is likely to pave the way for rapid progress in this direction (WFC, 2010; Glowka, 2011; Morgera and Tsoumani, 2011; Nair, 2011). With these positive developments, it may well be that disagreeing provisions under the WTO-

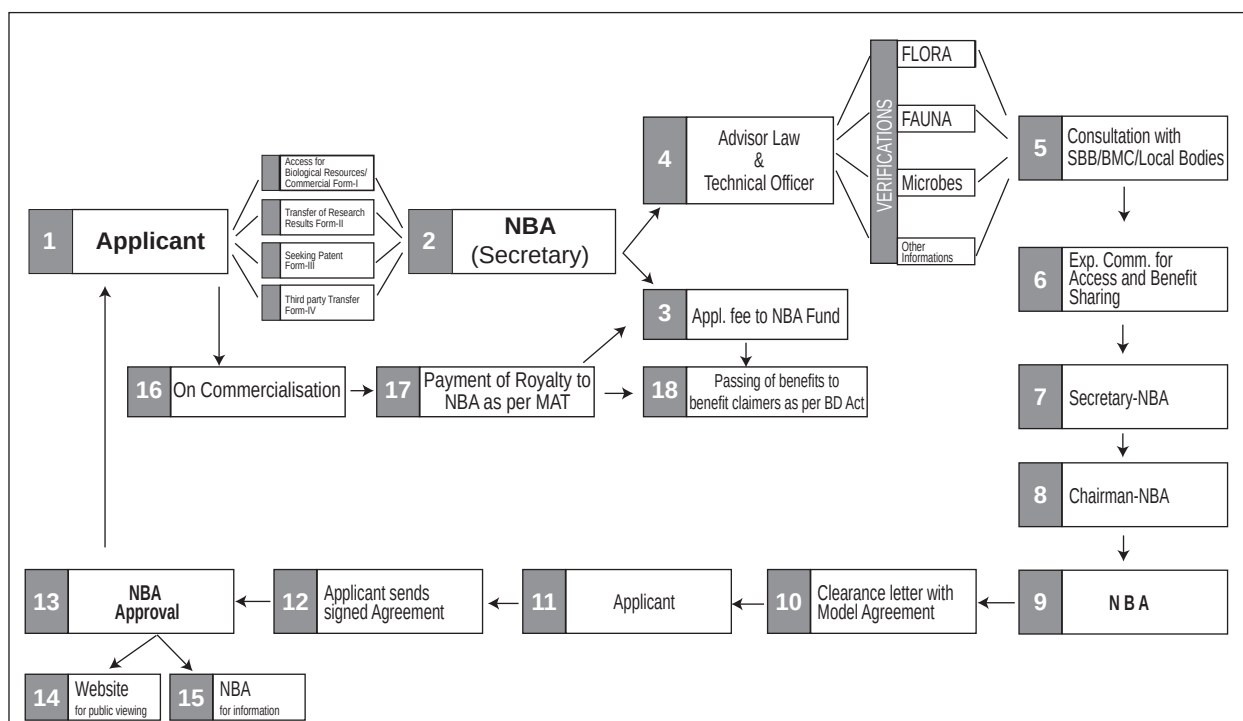
TRIPS and CBD may also get reconciled and provide synergy in implementation of these important international agreements on trade and environment (Nair, 2011; Johnson, 2011; Winter 2011, Glowka 2011).

References

- Bala Ravi S (2006) Infirmities and inconsistencies of Indian legislation on access and benefit sharing. *Curr. Sci.* **90**: 15-19.
- Berglund M (2005) The protection of traditional knowledge related to genetic resources: The case for a modified patent application procedure. <http://www.law.ed.ac.uk/ahrc/script-ed/vol2-2/TK.asp>.
- Brindavanam NB and RK Agarwal (2010) Partnership in implementing the Biological Diversity Act. Presentation to the 13th meeting of the NBA-Expert Committee, held in Chennai on 17-18 May, 2010, Ayurvedic Drugs Manufacturers Association, Mumbai.
- Carrizosa S, SB Brush, D Brian, BD Wright and McGuire PE, Eds. (2004) Accessing Biodiversity and Sharing the Benefits: Lessons from Implementing the Convention on Biological Diversity. IUCN Environmental Policy and Law Paper No. 54. IUCN, Gland, Switzerland.
- Chaudhury SK (2003) Microbial piracy in India: How to fight back? *J. Intellectual Property Rights* **8**: 389-399.
- CBD Secretariat (2002) Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization. SCBD, Montreal.
- Dewar D (2010) Seed Industry Applauds Adoption of International Treaties. *Crop Life International*. Seed World, Nov. 2010. Grand Forks, ND 58201, USA.
- Dutfield G (2000) Intellectual Property Rights, Trade and Biodiversity, Seeds and Plant Varieties. Earthscan Publications, London.
- Engels, JMM, H Dempewolf and V Henson-Apollonio (2010) Ethical Considerations in Agrobiodiversity Research, Collecting and Use. Springer Netherlands and Bioversity Library, Rome.
- FAO (2010) Access to Plant Genetic Resources, the Sharing of Benefits, arising out of their Utilization and the Realization of Farmers' Rights. Chapter 7: State of the World's Plant Genetic Resources for Food and Agriculture: The Second Report. FAO, Rome. 2010.
- Feit U M von den Driesch and Lobin W (Eds.) (2005) Access and Benefit Sharing of Genetic Resources. Report of an International Workshop held in Bonn (Germany) on 8-10 November, 2005.
- Gepts, P (2006) Plant Genetic Resources and Utilization: The Accomplishments and Future of a Societal Insurance policy. *Crop Sci.* **46**: 2278-2292.
- Glowka L (2011) The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits arising from their Utilization. CBD Secretariat, Montreal.
- Gokhale Y (2011) Access and Benefit Sharing in Indian Context: A Developing Country Perspective. TERI Special Paper Series, 2011.
- Johnson R (2011) Bridging the Gap Between the Biodiversity Convention and TRIPS: A New Way to Approach Technological Innovation and Economic Development. *Gonzaga J. Internatl. Law* **14**: 1-29.
- Kamau EC and Winter G (2009) Genetic resources, traditional knowledge and the law: Solutions for access and benefit sharing. Earthscan, London. 494p.
- Ministry of Environment & Forests (2011) Approval for signing of the Nagoya Protocol on Access and Benefit Sharing. PIB, GOI, MoEF, New Delhi, 20 April 2011.
- Mitra P (2008) Czech butterfly smuggler helped by embassy to flee India. *The Times of India*, Oct 30, 2008.
- Morgera E and E Tsioumani (2011) Yesterday, today and tomorrow: looking afresh at the Convention on Biological Diversity. In: 21 Yearbook of International Law, Edinburgh School of Law, University of Edinburgh, UK.
- Nair MD (2011) GATT, TRIPS and CBD – Relevance to agriculture. *J. Intellectual Property Rights* **16**: 176-182.
- Nature-on-line (2008) Court fines entomologists for illegal collecting in India. *Nature* **455**: 276. 17 September, 2008.
- Oli KP and TD Dhakal (2009) Access and Benefit Sharing from Genetic Resources and Associated Traditional Knowledge. ICIMOD, Kathmandu.
- Oliva MJ (2010) Nagoya Protocol on Access and Benefit Sharing -Technical Brief. Union for Ethical Bio Trade, Geneva, Switzerland. 2010.
- Rana RS (2004) Emerging trends in managing and using rice genetic resources. *Asian Biotech. Dev. Review* **7**: 49-66.
- Rana RS (2010) Regulating access to genetic resources and promoting benefits sharing in India. *Indian J. Plant Genet. Resour.* **23**: 253-264.
- Rana RS and RK Arora (1990) Indian National Plant Genetic Resources System – An overview. Bioversity International Publications, Rome. Web-version/174/ch18.
- Robinson DF (2010) Confronting Biopiracy: Challenges, Cases and International Debates, Earthscan, London.
- Schei PJ and MW Tvedt (2010) 'Genetic resources' in the CBD: The wording, the Past. The Present and the Future. FNI Report 4/2010. Lysaker, FNI, 2010.
- Suneetha MS and Pisupati B (2009) Benefit Sharing in ABS: Options and Elaborations. UNU-IAS, Yokohama, Japan.
- Swiderska K (2006) Banishing the Pirates: A New Approach to protecting the Traditional Knowledge. IIED, London, UK.
- Tvedt MW and T Young (2007) Beyond Access: Exploring Implementation of the Fair and Equitable Sharing Commitment in the CBD. IUCN, Gland, Switzerland.
- Unnikrishnan CH (2010) Industry opposes draft guidelines for use of bio resources: Concern at ambiguity over centralized licensing system and valuation of revenue potential. Mint, e-Paper, Corporate News. Posted: Wed, Mar 3, 2010.
- Ved DK and GS Goraya (2008) Demand and Supply of Medicinal Plants in India. Bishen Singh and Mahendra Pal Singh, Dehradun & FRLHT, Bangalore.
- Winter G (2011) Access and benefit sharing for genetic resources: history, rationale, objectives and instruments. Multi-stakeholder Expert Dialogue on ABS for Genetic Resources for Food and Agriculture, Workshop, 25-26 January, 2011, Brussels.
- World Future Council, CISDL (2010) Crafting future just biodiversity laws and policies. Paper Presented in the First Meeting of Intergovernmental Committee on the Nagoya Protocol, 9 June, 2011, Montreal, Canada.

ANNEX 2

Schematic Presentation of Processing of Applications under Biological Diversity Act, 2002 and Rules 2004



* For details please go through Biological Diversity Act, 2002 & Rules, 2004

Source: NBA

National Biodiversity Authority: Expert Committee on Access & Benefit Sharing

Access to Bioresources/TK in India for Research/ Bio-survey & Bio-utilization, Commercial Use, Transfer of Results of Research relating to Indian Bioresources, Seeking IPR on innovation based on Bioresource/TK, Third Party Transfer of the Accessed Bioresource or for Obtaining Bioresources for Export

An Indicative Template for Benefit Sharing under the Biological Diversity Act, 2002 (Actual terms are determined on a case-to-case basis)

Purpose of Access	Procedure for Applying and Terms for Benefit Sharing
Access for research: For Indian citizens:	Free access, guided by rules and regulations notified by NBA and SBBs. Applying for IPR, on any process/ product based on the accessed bioresource and associated traditional knowledge, shall require prior approval of NBA and entering into benefit sharing agreement.
For others:	Application in Form I is to be submitted to NBA along with payment of prescribed fee of Rs.10,000/- [Section 19, Rule 14]. Quantity of bioresource and its location, and also the objective, are to be specified. An agreement on benefit sharing, as provided under Section 21, is to be entered into with NBA. In case of bioresource of high economic value, upfront payment may be imposed by the NBA. Yearly reports on the progress of research /bio-survey & bio-utilization are also to be submitted to NBA. Applying for IPR, on any process/ product based on the accessed bioresource and associated traditional knowledge, shall require prior approval of NBA and entering into benefit sharing agreement.

B. Access for Commercial utilization/Bio-survey and Bio-utilization For Indian citizens For others	Free access, guided by rules and regulations notified by NBA and subject to prior intimation to the concerned SBB who may impose some conditions for such access. Quantity of bioresource and location are to be specified. Yearly reports on the progress of research are to be submitted. Applying for IPR, on any process/ product based on the accessed bioresource and associated traditional knowledge, shall require prior approval of the NBA. Application in Form I to be submitted to NBA along with payment of prescribed fee of Rs.10,000/- [Section,19, Rule 14]. Quantity of bioresource and location are to be specified. The Applicant shall pay an upfront amount as benefit sharing, to be decided on a case-to-case basis. An agreement is also to be signed by the applicant. Yearly reports on the progress of research are to be submitted. Applying for IPR, on any process/ product based on the accessed bioresource and associated traditional knowledge, shall require prior approval of NBA and entering into benefit sharing agreement.
C. Transfer of Results of Research relating to bioresources occurring in, or obtained from India, for monetary consideration to foreign nationals/companies and NRIs.	Application in Form II to be submitted along with payment of prescribed fee of Rs.5,000/-.[Section 19, Rule 17]. Transfer of data/ information only and not the bioresource. For persons/ companies, other than Indian citizens/ companies, evidence of authorized access to the bioresource shall be provided. Complete information on commercial value of the research results is also to be provided. Yearly reports on the progress of research are to be submitted to the NBA. Commercialisation of the transferred results of research to be done with the prior approval of NBA. Seeking of IPR shall also be on prior approval of NBA and on entering into benefit sharing agreement.
D. Seeking IPR over Innovation/ProductBased on the Use of Indian Bioresources/TK Options: The Applicant commercialises the innovation/ product. The Applicant assigns/ licenses the process/ product to a third party for commercialization.	Application is to be made in Form III with fee payment of Rs.500/- Benefit sharing terms shall be decided on a case-to-case basis. Equitable benefit sharing may be done in monetary or non-monetary mode; options provided under Section 21 and Rule 20. Benefit sharing shall be in any of the options of non-monetary benefits, as provided under Section 21 read with Rule 20, on mutually agreed terms. OR Benefit sharing shall be in monetary form as stated below: The Applicant shall pay royalty @ 3% of the highest ex- factory sale price of the product sold or used for captive consumption. Regular reports on the progress of commercialization and sale of the product, along with verifiable documents, shall be submitted to the NBA with supportive documents by 30th April every year. In case the applicant assigns/ licenses the process/ product to a third party, the licensee, for commercialization, the applicant shall pay to NBA 5% of the license fee received by him from the licensee. The licensee shall also enter into a fresh agreement with NBA and agree to pay royalty @ 5% of the ex-factory sale price of the product sold, and also kept for captive consumption, annually throughout the term of the agreement.. Additional terms will be as follows: The applicant shall undertake to inform NBA within 90 days from the date the patent is granted. The applicant, if he is an Indian citizen, shall give prior information to the concerned SBB regarding the location and quantity of the bioresource to be accessed by him, and shall follow the benefit sharing terms and also the restrictions, if any. Imposed by the SBB (and BMC, where applicable) in the interest of promoting conservation and sustainable use. In case the applicant is covered under Section 3(2) of BDA, he shall apply to NBA for access to the required bioresource in Form I, with the prescribed fee. No further transfer of the license shall be permitted without prior approval of NBA.

E. Transfer of the already accessed bioresource to third party abroad for research purpose	Application to be made in Form IV with fee payment of Rs.10,000/-. [Section 20]. Specific purpose for third party transfer shall be stated in the application and adhered to [Rule 19]. Terms for benefit sharing shall be as follows: No product/ process, coming out of the proposed research project, shall be commercialized without entering into benefit sharing agreement with NBA. No IPR shall be applied on any product/ process coming out from the proposed research project without prior approval of NBA and without signing of agreement with NBA for sharing benefits. No further transfer of the bioresource shall be permitted without prior approval of the NBA (and entering into fresh agreement with NBA on benefit sharing terms). Reports on the progress and final outcome of the proposed research shall be submitted to NBA.
F. Indian citizens/ organizations/ companies seeking export of bioresource, obtained from India, for commercial purpose.	Application to be made to NBA in Form IV with payment of Rs.10,000/-. Prior approval of the concerned SBB/ BMC/ State Wildlife Board for export shall be required. Objective of exporting the bioresource shall be stated and adhered to. The Applicant shall pay royalty @ 5% of the total FOB value of the bio-resource under export as benefit sharing. This amount shall go to the concerned SBB for promoting conservation and development activities at the source location. The bioresource to be used for the specified purpose only. Applying for IPR, on any process/ product based on the accessed bioresource, shall require prior approval of NBA and entering into benefit sharing agreement.

Enhanced Utilization of Plant Genetic Resources in Crop Improvement Programmes

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On domestication, the crop species typically inherited a small fraction of the natural genetic variation present in their wild progenitors. On-farm crop diversity diminished further with the advent of modern plant breeding, resulting in the creation of plant varieties that optimized adaptation at the cost of adaptability. Every quantum jump in productivity was also accompanied by a narrowing down of the breeders' crossing block. Once a new threshold is reached, plant breeders tend to make crosses within the small and related set of this newly improved germplasm only. This has led us to a predicament of stagnation in genetic gains. Changes in biotic and abiotic stress regimes on account of climate change and natural resource depletion are expected to pose serious challenges in view of the narrow genetic base of breeding programmes. The problem is likely to be accentuated by restricted germplasm flow in deference to propriety concerns. Enhanced utilization of plant genetic resources (PGR) is clearly warranted. Impediments to use of PGR including lack of local adaptation and linkage drag are discussed along with measures to overcome them. 'Genetic incorporation' as a PGR utilization strategy in contrast to the generally followed 'gene introgression' is highlighted. It is a base broadening exercise which gradually improves current adaptation of breeding material and has the potential to cater to unforeseen breeding needs. Crop wild relatives (CWR) are a subset of PGR which show great scope for enhanced utilization as they represent distinct, genetically diverse but underutilized gene pools for crop improvement. Instances of commercial deployment of genes from the wild are listed. Salient pre-breeding work for wheat improvement at PAU is discussed as an illustration for enhancing use of PGR.

Key Words: Crop Improvement, Crop Wild Relatives, Gene Introgression, Germplasm Utilization, Plant Genetic Resources

About 4,00,000 species of flowering plants are estimated to exist today (Govaerts, 2001; Bramwell, 2002). Thousands of these species are or have been used by human beings in one form or the other. Most of these partially domesticated or wild-collected species are found in tropics. Nearly 7,000 species mentioned in the records of Plant Resources Project of South Asia (PROSEA) are used in that region (Jensen *et al.*, 1991) and a similar number of species have been listed as Plant Resources of Tropical Africa (PROTA). Apart from this, several thousand plant species are in use in Mediterranean and temperate regions of the world. The uses of these plant species include food, food additives, feed and fodder, fuel and various uses as household and industrial materials. Two major further uses of plants are as medicinal plants (between 65,000-118,000 species) and ornamentals (about 30,000 species). It was this human-plant contact, happening on an evolutionary time-scale, which led to plant domestication and emergence of agriculture. About 7,000 plant species are, or have been cultivated to some degree, world-wide (Wilson, 1992). A large proportion of these domesticated species catered to the primary human need-food. The number of such species however dwindled sharply with loss of traditional

cultures and the shift to high production agriculture for supporting the human population explosion. In the present era only 103 species of plants contribute 90% of the food needs of the world (Prescott-Allen and Prescott-Allen, 1990). Further, just 30 plant species, mainly comprising of staples, supply most of human nutrition and three of these (wheat, maize and rice) provide more than half of the planet's food (Heywood, 2008). Thus, the agricultural revolution that began 10,000 years ago has gradually, but consistently seen a narrowing down of the number of plant species on which humankind depends. At the same time, the loss of natural plant diversity has continued apace and as per 'Gran Canaria Declaration on Climate Change and Plant Conservation' as many as two-thirds of the world plant species are in danger of extinction during the course of 21st century. Shrinking diversity at the species level in both natural and cultivated domains provides the larger context in which the utilization of plant genetic resources may be placed.

Loss of Genetic Diversity in Crop Plants

Plant genetic resources can be broadly considered as all materials that are available for improvement of a cultivated

plant species. The entire gamut of plant material, of current as well as potential use in breeding of a crop, thus qualifies as plant genetic resources. In the typical plant breeding sense, however, genetic resources are generally those materials that without selection for adaptation to the target environment do not have an immediate use for the breeders (Hallauer and Miranda, 1981). The relationship of a crop with its plant genetic resources has often been viewed through the concept of primary, secondary and tertiary gene pools (Harlan and de Wet, 1971). Beyond these gene pools, based on ease of sexual genetic transfers, are the rapidly expanding possibilities of transfer of isolated or cloned genes. The gene pools may gradually coalesce into a virtual gene ocean. The entire biodiversity of living species may, thus, come to be viewed as a potential genetic resource (Dhillon and Agrawal, 2004). While the possibilities of horizontal gene transfer offer the prospect of molecular unification of the biosphere, the crop plant species have derived their identity from a process of division and isolation. Domestication created the fundamental demarcation of plant genetic resources into cultivated and wild types. By its very nature of being a rare event, crop domestication represents an acute bottleneck and sampled a small proportion of total diversity of the wild population (the 'founder effect': Ladizinsky, 1985). The narrow genetic base because of bottlenecks at domestication has been highlighted for various crop species including rice, durum and bread wheat, *Phaseolus* beans, tomato, pigeonpea, chickpea, *Citrus*, and possibly *Musa* and yam (Spillane and Gepts, 2001). The bottleneck is perpetuated further by various reproductive isolation factors preventing gene flow. The domesticated plants may be carried by the cultivators to sites far removed from its original habitat. During transfer between latitudes, there may be a further narrowing of the genetic base because the population would not be well adapted to the new day-length conditions, and so only a small number of the genotypes would survive (e.g., potato in temperate areas). Examples of crops with narrow genetic bases arising during migration include soybean in the US, maize in Africa and the US (Tallury and Goodman, 2001), sorghum, millet and lentil in South Asia (Erskine *et al.*, 2001). There may be other chance occurrences that narrow the genetic base such as disease epidemics, which may decimate populations. Often domestication is accompanied by an amphiploidization event, as in case of hexaploid wheat, thus erecting barriers to gene flow from diploid progenitors.

Post-domestication, the crops evolved under human selection but continued to possess a breadth of genetic variation in order to overcome challenges from changes in biotic and abiotic milieu. The advent of modern plant breeding resulted in creation of plant varieties that optimized adaptation at the cost of adaptability. On farm diversity was seriously undermined. Every quantum jump in productivity was also accompanied by a narrowing down of the breeders' crossing block. Once a new threshold is reached, plant breeders tend to make crosses within the small and related set of this newly improved germplasm only. This places a ceiling on the further progress or gain from a breeding programme on account of insufficient genetic diversity. For instance, once the small initial set of semi-dwarf wheat or rice lines were produced, it became counter productive to involve the much larger set of tall lines in crosses. Tall segregants virtually competed out the dwarf ones and produced a large proportion of undesirable individuals, at least in early segregating generations. Ironically in case of wheat, the two major yield jumps, first on account of semi-dwarf plant type and second resulting from winter wheat x spring wheat hybridization meant that breeders would restrict their subsequent efforts to within the improved sets, though both improvements resulted from use of a divergent gene pool.

The narrowed genetic base of germplasm is often evident from plateau in yield gains as have been observed in several crop plants. Historically, instances of more disastrous consequences have also been observed. Often quoted instances include the blight epidemic caused by *Phytophthora infestans* in potato (*Solanum tuberosum*) in Western Europe in 1845/1846, the havoc caused by *Bipolaris* on T-cytoplasm maize in the USA in 1970 (Campbell and Madden, 1990) and the *Fusarium graminearum* epidemic in wheat and barley in western USA during 1994 to 1996 (FAO, 1996a).

Plant breeders sometimes adopt a deliberate diversity restricting approach to conserve market or industrial processing oriented quality traits. The examples of malt barley have been well studied and breeding with a defined, small set of parents has been argued to be advantageous (Wych and Rasmusson, 1983). Further, narrowing of the genetic base may result from specialization within crops: for example, breeding of winter wheat has been mainly done by using only winter germplasm and breeding of spring wheat by using only spring germplasm (Spillane and Gepts, 2001). The genetic base of hot peppers (*Capsicum annum*) is partitioned by the specialized requirements for

distinct uses (e.g. thin pericarp required for drying, whilst fresh use requires small fruit). The genetic base of *Brassica* is similarly partitioned into different morphological types.

The Need for Enhancing PGR Utilization

Multiple cycles of narrowing of genetic diversity in crop plants in recent years have been topped with extensive churning and utilization of the available variation. It is now imperative in most of the situations to explore beyond the elite germplasm or even beyond the species boundary. There is a need to integrate wide hybridization and alien introgression with mainstream plant breeding. The need for enhanced utilization of plant genetic resources is reflected in the Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources for Food and Agriculture (PGRFA) adopted at the International Technical Conference on Plant Genetic Resources held in 1996 (FAO, 1996b). The plan has genetic enhancement and base broadening, besides on-farm diversification as its priority areas.

Presently, the need for enhancing PGR utilization has acquired greater urgency. The need for greater genetic diversity in sources of resistance to biotic stresses had often been emphasized and several successful uses of PGR are known. Recently, the prospects of using genetic approaches for combating abiotic stresses also have improved on account of increased insight into tolerance mechanisms and availability of molecular tags. Relevant variation for pursuing this approach in the cultivated germplasm is however inadequate (Hajjar and Hodgkin, 2007) and use of land races/crop wild relatives has acquired importance. The abiotic stress tolerance agenda has expanded further in response to emerging climate change scenario. Climate change is now a certainty and looms as a threat of unprecedented scale to agricultural systems and food security of the country. It demands an urgent reorientation of breeding programmes in terms of genetic and genomics input as well as screening strategy. Utilization of newer sources of genetic variation is warranted. Another major change in the present situation is the apprehended shrinkage of germplasm exchange. In the emerging IPR regime it has become crucial to impart self-sufficiency to the breeding programmes. Breeding programmes with greater depth of genetic resources are expected to flourish. Continuously developing a wider spectrum of genetic variability thus becomes an essential upstream activity. Regular infusion of diverse genetic variation can help offset negative consequences of shrinking germplasm exchange to some

extent. Another aspect of the present situation arises from decades of intensive and exploitative agricultural practices which have taken a toll of valuable natural resources. Resources like water will have to be rationalized in face of scarcity while self imposed restrictions, as on use of nitrogenous fertilizers and pesticides, have become essential for environmental health. This poses an extremely tough challenge to crop improvement as further gains in productivity need to come in spite of reduced inputs. Such variation is again likely to be available in land races and wild relatives rather than improved materials. All these considerations point to an urgent intensification of PGR utilization and reorientation of crop breeding goals and practices.

Impediments to the Use of PGR in Crop Improvement

Lack of environmental adaptation of the PGR to be used as donor is a major impediment to its use in classical plant breeding. Linkage drag is the other major reason restricting the use of PGR in crop improvement. Assuming a target locus in the centre of a 100 cM chromosome, about 53 cM remain around the target gene in the third backcrossing generation (BC_3), and in BC_{10} the average linkage drag is still about 20 cM (Stam and Zeven, 1981; Welz and Geiger, 2000). If this linkage drag contains undesirable alleles from the PGR, the performance of the backcrossing products can be unsatisfactory. Linkage drag accompanying translocated rather than recombining chromosomes can be several times more tenacious and sometimes pose almost insurmountable difficulties in commercial utilization of alien genes. Epistasis or co-adaptation of genes within both breeding population and PGR means that natural or artificial selection has favoured specific combinations of alleles at different gene loci within each type of material. The specific allele combinations are lost after crossing and recombining the two types, leading to so-called 'recombination losses' (Hausmann *et al.*, 2004). It takes several generations to establish new favourable allele combinations through selection.

Efficient utilization of germplasm requires awareness of target traits for which variation in elite germplasm is lacking, followed by identification of suitable donor germplasm. An efficient transfer methodology should be in place and implemented in a timely manner. Further, choice of recipient genotype should ensure commercial viability of the end product. Coordination at all these steps is an essential components for successful PGR utilization as exemplified by incorporation of grassy stunt virus (GSV)

resistance from *Oryza nivara* to cultivated rice (Brar and Khush, 1997) and indicated by the following chronology of developments. Dr. SD Sharma had collected wild rice *O. nivara* from Eastern India in 1966 and 6723 accessions were conserved at IRRI, Philippines. At that time GSV was an unimportant disease and no screening work was in progress. Wide adoption of semi-dwarf rice varieties led to emergence of GSV as a major disease. In early 1970s, GSV destroyed 2,87,000 acres of rice in Indonesia, India, Sri Lanka, Vietnam and Philippines. Outbreak of GSV led to screening of this material by Drs. GS Khush and KC Ling at IRRI. Only one accession was found to be highly resistant. Resistance was transferred to IR24 and subsequently several other cultivars including IR36. This resistance from *O. nivara* became widely deployed, covering 74 million acres in Indian subcontinent, China and South East Asia.

PGR utilization involving a pre-breeding step will translate into commercial use in a time frame different from the one applicable to conventional breeding. The long duration of gene transfer process discourages crop breeders to exploit exotic and un-adapted donors. This is well illustrated by another example from rice, the saga of bacterial leaf blight resistance gene *Xa-21*. The broad spectrum resistance conferred by this gene was observed in *Oryza longistaminata* lines from Mali, Africa in 1977. It took almost 20 years of intensive research using molecular as well as conventional tools for commercial deployment of this gene. For donor species with distinct/non-homologous genomes (unlike *O. longistaminata* which has same genome designation as cultivated rice) the gene transfer and commercial utilization is likely to take even longer. Several rust resistance genes (*Yr 40*, *Lr 57*, *Lr58* etc.) have been mobilized from non-progenitor wild wheats at Punjab Agricultural University, Ludhiana. Almost two decades of continuous efforts starting with evaluation of donor accessions in the 1980s was required before the genes could be transferred to elite wheat lines (Dhaliwal *et al.*, 2003). PGR utilization, particularly when distant sources are involved, requires continuity and sustained efforts over time frames which sometimes may not be harmonious with regular project tenures.

Systematic documentation of information on PGR collections can greatly enhance their utilization for crop improvement. Of particular importance are information on economically important traits, e.g. resistances, quality and specific adaptation traits. Beyond preliminary evaluation, information on genotype x environment interactions and

affiliation to heterotic pools (if hybrid breeding is relevant) can facilitate targeted exploitation of PGR. In the Indian context several publications are now available for use by breeders of foodgrain crops (Dhillon *et al.*, 2006b), oilseeds and cash crops (Dhillon *et al.*, 2004b) and horticultural crops (Dhillon *et al.*, 2004c). The breeders also need to look beyond crop specific information and be aware about policy matters and regulations for PGR exchange and utilization (Dhillon *et al.*, 2004a; FAO, 2010).

Approaches to PGR Utilization

It is unlikely that all of the potentially useful combinations have been assembled in any single group of locally adapted stocks (Simmonds, 1962). At the same time it may not be possible for a mainstream breeding programme to exploit new un-adapted germplasm to create new gene combinations that might excel over the best pre-existing commercially deployed materials. While adapted germplasm may be at one type of adaptive peak, the exotic prospective donor will be at a different peak, with a major maladaptive valley preventing gene flow between them (Whitlock *et al.*, 1995). Base broadening may be likened to building bridges between different fitness peaks. The conventional breeding methodology will need to be modified to achieve this. While this is a matter of disassembly of co-adapted gene complexes, more serious problems to utilization of PGR are posed when the donor is distant and one or more types of reproductive barriers may be present. In such cases a pre-breeding phase becomes mandatory. Pre-breeding refers to activities designed to identify desirable characteristics/genes from un-adapted plant genetic resource and to transfer them to an intermediate product that breeders can manipulate.

Simmonds (1993), Spoor and Simmonds (2001) have listed two major approaches to utilization of PGR: introgression and incorporation. They have strongly argued in favour of incorporation in contrast to the generally followed single gene transfers or introgression. Salient features of the incorporation approach are as follows:

- Making use of the broadest possible starting materials, consistent with the specific objectives of the programme. Evaluation of such material is, in this context, often irrelevant, since most of the starting material is expected to be un-adapted to the target environments anyway.
- A need for extensive recombination (If natural outcrossing rates are sufficiently high, recombination is easy; otherwise controlled crossing or the use of male sterility genes may be necessary).

- Weak and progressively decentralized selection. Whenever possible, selection should be based on multiple large populations and carried out over several generations in target environments.
- The maintenance of the above process as a programme distinct from conventional breeding programmes, until usable material is produced.

Examples of application of the incorporation approach include the development of barley (*Hordeum vulgare*) composite-cross at Davis, California (Cooper *et al.*, 2001), dynamic gene pool management in wheat (Goldringer *et al.*, 2001); pearl millet (*Pennisetum glaucum*) composite populations developed in Africa (Niangado, 2001). Another, long-term base-broadening project in maize is the Hierarchical Open-ended Population Enrichment (HOPE) project in Canada (Kannenberg and Falk, 1995; Kannenberg, 2001). Other projects in maize include the Genetic Enhancement of Maize (GEM) programme in which material was selected on the basis of the evaluation data of the previous Latin American Maize Programme (LAMP) (Pollock and Salhuana 2001). In the PAU maize breeding programme, it was seen that intra-population improvement became more rewarding when accompanied by introgression of new germplasm (Dhillon *et al.*, 2006a). Similarly for inter-population three broad based heterotic pools were developed to serve as source of populations for derivation of inbred lines (Dhillon *et al.*, 1997).

In addition to introgression and incorporation, Cooper *et al.* (2001) listed pre-breeding as the third PGR utilization approach. The first two approaches are based on freely recombining donors presumably from the primary gene pool and leaves out the major category of crop wild relatives (CWR) which is covered under the third approach. The utilization approach to be followed for CWR would actually depend on its genomic constitution. A full-fledged pre-breeding phase would be typically necessary where the donor species genome is distinct/non-homologous to the recipient crop species. Often a chromosome engineering step would be involved for translocating the relevant donor chromosome segment to the recipient genome. This would entail use of specific genetic stocks (as in case of *Ph1* locus mediated homoeologous recombination in wheat) or ionizing radiation facilitated translocations. A large number of chromosomal translocations from alien species for rust resistance have been obtained in wheat using these two methods. On the other hand, an incorporation based approach can be followed for wild progenitors whose genomes show good homology with the cultivated species.

In case of homology with the donor, the AB-QTL method provides an excellent opportunity for transfer of 'hidden genes' (e.g., for productivity) following a simultaneous molecular marker analysis and gene transfer approach (Tanksley and Nelson, 1996). This method has helped crop breeders to view un-adapted germplasm and crop wild relatives as potential donor of traits which are not evident in the donor phenotype. In contrast to the AB-QTL method, Eshed and Zamir (1994) suggested the approach of establishing a population of NILs such that the donor chromosome segments are evenly introgressed over the whole recipient genome. Ideally, the total genome of the exotic donor is represented in the established set of NILs. This NIL population, named introgression library (IL), consists of a set of lines, each carrying a single marker-defined donor chromosome segment introgressed from an agriculturally un-adapted source into the background of an elite variety (Zamir, 2001). A major drawback of the AB-QTL and IL approach is that exploration of even a single donor line involves huge amount of breeding as well as molecular marker work. It is hard to extend this approach to large number of donor lines. Moreover, there are no specific guidelines for narrowing down to a smaller set of donors as we are looking mainly for hidden and interactive variation in context of a particular recipient line.

Narrowing down to a smaller set of prospective donors is not just an issue for AB-QTL and IL based approach but also essential for taking up detailed evaluation and subsequent utilization. This can be achieved by assembling core collections. Core collection may be defined as a limited set of accessions representing, with a minimum of repetition, the genetic diversity of a crop species and its wild relatives (Frankel, 1984). In context of specific gene bank collection, the core collection represents the genetic spectrum in the whole collection and should include as much of its genetic diversity as possible (Brown, 1995). The practical norm is to limit the entries in a core collection to ~10%, using the sampling theory of selectively neutral alleles, with a ceiling of 3000 per species. This level of sampling is effective in retaining 70% of alleles of entire collection. However, core collections based on basic passport and characterization data for major morphological characters, and developed primarily to make genetic diversity available to researchers have limited value unless this is evaluated extensively for traits of economic importance. This will make the core collection and eventually entire collection more useful

to plant breeders and other crop improvement scientists (Upadhyaya *et al.*, 2008). In some major crops, size of the entire germplasm collection is very large, even a core collection size becomes difficult for extensive evaluation by breeders or researchers. To overcome this, the concept of 'Mini-core collections', was given. A mini-core collection consists of 10% accessions in the core collection and only 1% of the entire collection (Upadhyaya and Ortiz, 2001) and represents the diversity of the entire core collection. These can be thoroughly evaluated and the information so derived can be utilized for improving the efficiency of breeding programmes. Molecular biology and bioinformatics can facilitate assessment and utilization of genetic diversity e.g., Generation Challenge Program (GCP) on 'Unlocking Genetic Diversity in Crops for the Resource-Poor' (www.generationcp.org) is designed to utilize molecular tools and comparative biology to explore and exploit the valuable genetic diversity existing in germplasm collections held at the CGIAR and national gene banks, with particular focus on drought tolerance.

Utilization of Crop Wild Relatives

Crop wild relatives (CWR) are species closely related to crops, including crop progenitors. CWR have been identified as critical resources that are vital for wealth creation, food security and environmental stability in the future (Meilleur and Hodgkin, 2004; Stolton *et al.*, 2006; Maxted *et al.*, 2008). Historically, the commercial use of wild relatives started in the late 19th century when wild *Vitis* species were used as rootstocks to protect grapes cultivars from *Phylloxera* aphids and *Meloidogyne* nematodes (Prescott-Allen and Prescott-Allen, 1988). In sugarcane, virus resistance was incorporated from *Saccharum spontaneum* in the first half of the 20th century and later all sugarcane varieties were developed using three to five species (Stalker, 1980). In 1941, first tomato variety having *Fusarium* resistance gene from *Lycopersicon pimpinellifolium* was released and subsequently a large number of wild species have been used to introgress genes into cultivated tomato (Rick and Chetelat, 1995). In the middle of 20th century, the value of CWR was widely recognized and breeding efforts to explore the potential of wild relatives were initiated in many crops which paid rich dividends e.g. late blight resistance from *Solanum demissum* and *S. stoloniferum*, resistance to viruses from these species and from *S. chacoense* and *S. acaule* in potato (Ross, 1986). Starting with the work of Sears (1956), large set of stocks carrying the wheat-alien translocations conferring resistance to diseases and

insect pests were developed and characterized in wheat (Friebe *et al.*, 1996). The use of wild relatives increased in 1970s and 1980s (Hodgkin and Hajjar, 2008) and in the mid 1980s, Prescott-Allen and Prescott-Allen (1988) asserted that the achievements were substantial enough to recognize the potential of wild relatives. By this time there are about 31 crops where CWR have been used to the extent that cultivars with wild genes were available (Prescott-Allen and Prescott-Allen, 1988). International Board for Plant Genetic Resources (IBPGR) working with national programmes, initiated a number of collecting missions that primarily focused on CWR (IBPGR, 1991). With the improvement in interspecific hybridization techniques and advent of molecular markers for tagging and mobilization of useful genes, breeders evinced greater interest in use CWR for crop improvement.

The availability of total holdings of wild and weedy relatives of different crops as revealed by SINGER (<http://singer.grinfo.net/>) range from about 400 accessions (sorghum) to more than 5000 (wheat). The proportion of wild or weedy relatives in gene bank holdings has significantly increased in a span of 20 years starting from 1983 (Plucknett *et al.*, 1987) to 2004 (<http://singer.grinfo.net/>). During this period, CWR representation increased from 0.0 to 4.95% in wheat, 0.5 to 7.08% in common bean, 0.001 to 5.27% in barley, and 0.4 to 4.97% in pigeonpea (Hodgkin and Hajjar, 2008). The increase in proportion of wild relatives in gene banks reflects the expectations of collectors and gene bank managers regarding the usefulness of wild relatives.

Summarizing the use of wild relatives for improvement of major crop species in the last 20 years, Hajjar and Hodgkin (2007) have listed the number of traits for whose improvement CWR was used in a particular crop. They showed that extent of utilization varies from crop to crop. Tomato takes lead with 55 traits followed by rice and potato with 12 traits each. Using CWR, wheat was improved for 9 traits and sunflower for 7 traits. Millet featured on the list with 3 traits and maize and chickpea with 2 traits each.

Impressive instances of commercial deployment genes from the wild species are now available in several crops. Gene introgression from synthetic wheats developed at CIMMYT using *Ae. tauschii* and *T. turgidum*, have resulted in cultivars having improved water-logging tolerance (Villareal *et al.*, 2001) and disease resistance (Mujeeb-Kazi *et al.*, 2001). Several wheat-alien translocations conferring rust resistance have been commercialized.

The classical example of successful commercial deployment of grassy stunt virus resistance from *Oryza nivara* in rice varieties grown on a global scale has already been discussed (Brar and Khush, 1997). In potato, resistance to late blight from *Solanum demissum* and *S. stoloniferum*, resistance to viruses from these species and from *S. chacoense* and *S. acaule*, and resistance to potato cyst nematode from *S. vernei* and *S. spengazinii* has been introgressed in several lines, whereas blight resistance in cultivar 'Biogold' was transferred from *S. bulbocastanum* (Bradshaw and Ramsey, 2005). Resistance to herbicides (imodazolinone and sulfonylurea) has been transferred from *Helianthus annuus* in sunflower hybrid cultivar 'Clearfield' (Seiler and Gulya, 2004). A chickpea variety 'BG 1103' having drought and high temperature tolerance derived from *C. reticulatum*. In barley, six cultivars having drought tolerance derived from *H. spontaneum* have been released by ICARDA (Hodgkin and Hajjar, 2008).

As far as heterosis breeding is concerned, CWR played a significant role by contributing sterile cytoplasm in different crops. In rice, CMS source derived from wild rice *O. sativa* f. *spontanea*, were used to produce hybrid cultivars in 1976 and presently about 45% area of rice acreage is under hybrid varieties in China. Similarly in other crops CMS sources have been derived from various wild relatives e.g. in sunflower from *H. annuus* and *H. petiolaris*, in wheat from *T. timopheevi* and in pigeonpea from *Cajanus cajanifolius* and *C. scarabaeoides*.

CWR are now well acknowledged as donors of enhanced yield potential and promising materials have been generated in several crops, particularly rice (Cheema *et al.*, 2008). Earlier, yield enhancing QTLs affecting tillers and other traits were introgressed from *O. rufipogon* in rice (Xiao *et al.*, 1998). Similarly in other crops yield QTLs derived from wild relatives have been reported, e.g. in tomato (Tanksley *et al.*, 1996) and chickpea (Singh and Ocampo, 1997; Singh *et al.*, 2005).

With respect to quality traits, a few instances of CWR utilization are reported. Improved protein quality (HMW) in durum wheat from related species, *T. dicoccum* and *T. dicoccoides*; double protein contents in cassava from *Manihot oligantha*; increased fruit size and soluble solids in tomato from wild species; increased amount of anti-cancer compounds in broccoli from *Brassica villosa*. The *T. dicoccoides* gene *GpcB1* conferring high grain protein content has found its way into several wheat cultivars (Brevis and Dubcovsky, 2010).

Some estimates of economic impact of genetic transfers

from CWR are available (Frison and Attah-Krah, 2008). For example, traits incorporated from wild relatives into sunflower are worth USD 267-384 million annually to the sunflower industry in USA. A wild tomato accession has contributed 2.4% increase in TSS worth USD 250 million. Wild groundnut has contributed resistance to root knot nematodes that cost groundnut growers around the world approximately USD 1 billion annually. The utilization of CWR so far is indicative of the great potential that this category of PGR holds. The resource remains grossly underutilized and the above achievements represent no more than the proverbial tip of the iceberg. Systematic pre-breeding efforts would however be needed to harness the variation for crop improvement.

Illustrating Utilization of Plant Genetic Resources: PAU Wheat Improvement Programme as an Example

A broad genetic base, handled through a precise and fast breeding technology would be the hallmark of the new era breeding programmes. Wheat and rice improvement research at PAU has already made significant progress in this direction. New germplasm streams are being created accompanied by molecular marker interventions allowing their rapid channelization for commercial use. The diversifying input has come from well characterized sets of wild/related species of wheat (1500 acc.) and rice (2000 acc.). Using these donors several thousand introgression lines have been generated which are at various stages of utilization in the breeding programme. Salient research activities aimed at utilization of plant genetic resources, particularly the wild relatives in case of wheat are listed:

- A new major gene (*Yr40/Lr57*) for resistance to stripe as well as leaf rust was introgressed from *Ae. ovata* into bread wheat and stably translocated using *Ph* locus manipulation (Kuraparthi *et al.*, 2007a). It is highly effective against prevalent races of both rusts and has been mobilized into high yielding backgrounds using molecular markers.
- A novel major gene for leaf rust resistance (*Lr58*) was introgressed from *Ae. triuncialis* (Kuraparthi *et al.*, 2007b) and is being transferred to elite wheat lines using cytogenetic and molecular techniques.
- Potentially new gene (s) for resistance to both stripe and leaf rust has been incorporated from *Aegilops umbellulata* into elite wheat lines including PBW 343. It is in the process of being mapped and designated.

- QTLs for stripe rust resistance from diploid A genome species (*Q yrtm.pau.2A* from *Triticum monococcum*, and *Q yrtb.pau.5A* from *T. boeoticum*) have been tagged with molecular markers and transferred to relevant wheat cultivars. These adult plant resistance genes offer the prospect of durable resistance (Singh *et al.*, 2007).
- *Aegilops kotschyi* and *Ae. tauschii* lines possessing high iron and zinc content in the grain were identified and are being used as donors (Chhuneja *et al.*, 2006; Rawat *et al.*, 2009).
- QTLs for higher iron and zinc content in the grain (*Q GFe.pau-2A*, *Q GFe.pau-7A* and *Q GZn.pau-7A*) have also been identified and transferred from *T. boeoticum*.
- QTLs for cereal cyst nematode resistance (*Q cre.pau-1A*, *Q cre.pau-2A*) have been transferred from *T. monococcum* (Singh *et al.*, 2010).
- To improve processing quality in wheat, novel HMW glutenin subunits have been transferred from *T. urartu* and *T. diccoides* to wheat variety PBW 343, resulting in improved sedimentation value.
- A major gene (*GpcB1*) for high protein content and enhanced micronutrient content, originally derived from *T. diccoides* has been transferred to a wide range of wheat genotypes using marker assisted selection (Pal, 2010).
- About 100 accessions of *Aegilops tauschii* have been characterized for cellular thermotolerance traits such as membrane thermostability and TTC cell viability and heat tolerant accessions identified (Gupta *et al.*, 2010).
- *Aegilops speltoides* is being used for transfer of stay green habit to both tetraploid and hexaploid wheat.
- CMS lines based on different alien cytoplasm including *T. timopheevi* have been developed in wheat (Adugna *et al.*, 2003). Restorer gene pool has been developed by using diversifying genetic input from synthetic hexaploid wheats.
- PAU collection of *Aegilops tauschii*, the D genome donor of wheat, was subjected to diversity analysis based on SSR markers and agromorphological traits (Chhuneja *et al.*, 2010).
- An efficient hybridization and trait transfer protocol has been designed for introgression from *Aegilops tauschii* to bread wheat (Sehgal *et al.*, 2010). The

method is based on direct hybridization (bridging species not involved) and is being used for transfer of components of heat tolerance.

The precision and speed imparted by marker assisted gene tagging and transfer is being used to offset some of the difficulties associated with use of wild/weedy and un-adapted donor germplasm. Complementary research efforts in the Department of Plant Breeding and Genetics and School of Agricultural Biotechnology and the excellent context for wheat improvement provided by the dynamic and responsive farming community of Punjab state has helped orient this programme to real needs.

In the face of challenges ahead, it is thus imperative to strengthen PGR utilization efforts. Future needs of crop improvement in terms of biotic and abiotic stresses, and sometimes even for consumer preference, cannot be pre-judged completely. A broad genetic base is our safeguard against all such exigencies. The diversity also ensures continued genetic gains. It is the key to sustainable crop improvement.

References

- Adugna A, GS Nanda, Kuldeep Singh and NS Bains (2004) A comparison of cytoplasmic and chemically induced male sterility for hybrid seed production in wheat. *Euphytica* **135**: 297-304.
- Bradshaw JE and G Ramsey (2005) Utilization of the commonwealth potato collection in potato breeding. *Euphytica* **146**: 9-19.
- Bramwell D (2002) How many plant species are there? *Plant Talk* **28**: 32-34.
- Brar D and G Khush (1997) Alien introgression in rice. *Plant Mol. Biol.* **35**: 35-47.
- Brevis JC and J Dubcovsky (2010) Effects of chromosome region including the grain protein content locus *Gpc-B1* on wheat grain and protein yield. *Crop Sci.* **50**: 93-104.
- Brown AHD (1995) The core collection at the crossroads. In: T Hodgkin T, AHD Brown TJL van Hintum and EAV Morales (eds) *Core Collections of Plant Genetic Resources*. Rome: IPGRI/John Wiley and Sons, Sayce Publishing, pp 3-19.
- Campbell CL and LV Madden (1990) *Introduction to Plant Disease Epidemiology*. New York: John Wiley & Sons.
- Cheema KK, NS Bains, GS Mangat, A Das, Y Vikal, DS Brar, GS Khush and K Singh (2008) Development of high yielding IR64 x *Oryza rufipogon* (Griff.) introgression lines and identification of introgressed alien chromosome segments using SSR markers. *Euphytica* **160**: 401-409.
- Chhuneja P, HS Dhaliwal, NS Bains and Kuldeep Singh (2006) *Aegilops kotschyi* and *Aegilops tauschii* as sources for higher levels of grain Iron and Zinc. *Plant Breed.* **125**: 529-531.
- Chhuneja P, T Garg, R Kumar, S Kaur, A Sharma, NS Bains, M Ahuja, HS Dhaliwal and K Singh (2010) Evaluation of *Aegilops tauschii* Coss. germplasm for agromorphological

- traits and genetic diversity using SSR loci. *Indian J. Genet.* **70**: 328-338.
- Cooper HD, C Spillane and T Hodgkin (eds) (2001) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, 452p.
- Dhaliwal HS, P Chhuneja, RK Gill, RK Goel and H Singh (2003). Introgression of disease resistance genes from related species into cultivated wheats through interspecific hybridization. *Crop Improv.* **29**: 1-18.
- Dhillon BS and Anuradha Agrawal (2004) Plant Genetic Resources: Ownership, access and intellectual property rights. In: *Plant Genetic Resources Oilseed and Cash Crops*. BS Dhillon, RK Tyagi, S Saxena and A Agrawal (eds). Narosa Publishing House, New Delhi, India, pp 1-19.
- Dhillon BS, RK Tyagi, Arjun Lal and S Saxena (eds) (2004a) *Plant Genetic Resource Management*. Narosa Publishing House, New Delhi, India, 434p.
- Dhillon BS, RK Tyagi, S Saxena and A Agrawal (eds) (2004b) *Plant Genetic Resources Oilseed and Cash Crops*. Narosa Publishing House, New Delhi, India, 215p.
- Dhillon BS, RK Tyagi, S Saxena and GJ Randhawa (eds) (2004c) *Plant genetic Resources Horticultural Crops*. Narosa Publishing House, New Delhi, India, 332p.
- Dhillon BS, AK Sharma, D Kumar, NS Malhi and NN Singh (2006a) Maize. In: *Plant Genetic Resources: Foodgrain Crops*. BS Dhillon, S Saxena, A Agrawal and RK Tyagi (eds). Narosa Publishing House, New Delhi, India, pp 90-136.
- Dhillon BS, S Saxena, A Agrawal and RK Tyagi (eds) (2006b). *Plant Genetic Resources Foodgrain Crops*. Narosa Publishing House, New Delhi, India, 345p.
- Dhillon BS, NS Malhi and VK Saxena (1997) Development and improvement of heterosis pools in maize. In: *The Genetics and Exploitation of Heterosis in Crops-An International Symposium*, CIMMYT, Mexico, pp 74-75.
- Erskine W, S Chandra, M Chaudhary, A Sarker, B Sharma, M Tufail and MC Tyagi (2001) Broadening the Genetic Base of Lentil in South Asia In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, pp 341-350.
- Eshed Y and D Zamir D (1994) A genomic library of *Lycopersicon pennellii* in *L. esculentum*: a tool for fine mapping of genes. *Euphytica* **79**: 175-179.
- FAO (1996a) Report on the State of the World's Plant Genetic Resources for Food and Agriculture, prepared for the International Technical Conference on Plant Genetic Resources, Leipzig, Germany, 17-23 June 1996. Rome: Food and Agricultural Organization of the United Nations.
- FAO (1996b) Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources and the Leipzig Declaration, adopted by the International Technical Conference on Plant Genetic Resources, Leipzig, Germany, 17-23 June 1996. Rome: Food and Agricultural Organization of the United Nations.
- FAO (2010) The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture. Rome.
- Frankel OH (1984) Genetic perspectives of germplasm conservation. In: W Arber, K Llimensee, WJ Peacock and P Starlinger (eds) *Genetic Manipulation: Impact on Man and Society*. Cambridge: Cambridge University Press, Part III, Paper No. 15.
- Friebe B, J Jiang, WJ Raupp, RA McIntosh BS Gill (1996) Characterization of wheat-alien translocations conferring resistance to diseases and pests: current status. *Euphytica* **91**: 59-87.
- Frison E and K Atta-Krah (2008) Foreword. In: N Maxted, BV Ford-Lloyd, SP Kell, JM Iriondo, E Dullloo, and J Turok (eds) *Crop Wild Relatives, Conservation and Use*. CAB International. pp xxiii-xxv.
- Goldringer I, J Enjalbert, J David, S Paillard, JL Pham and P Braban (2001) Dynamic Management of Genetic Resources: a 13-year Experiment on Wheat. In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, pp 245-260.
- Govaerts R (2001) How many species of seed plant are there? *Taxon* **50**: 1085-1090.
- Gupta, S, S Kaur, S Sehgal, A Sharma, P Chhuneja and NS Bains (2010) Genotypic variation for cellular thermotolerance in *Aegilops tauschii* Coss., the D genome progenitor of wheat. *Euphytica* **175**: 373-381.
- Hajjar R and T Hodgkin (2007) The use of wild relatives in crop improvement: A survey of developments over the last 20 years. *Euphytica* **156**: 1-13.
- Hallauer AR and JB Miranda (1981) Quantitative Genetics in Maize Breeding. Ames: Iowa State University Press.
- Harlan JR and JMJ de Wet (1971) Toward a rational classification of cultivated plants. *Taxon* **20**: 509-517.
- <http://www.public.iastate.edu/usda-gem/methods.html>.
- Hausmann BIG, HK Parzies, T Presterl, Z Sus'ic' and T Miedaner (2004) Plant genetic resources in crop improvement. *Plant Genet. Res.* **2**: 3-21.
- Heywood VH (2008) The use of economic potential of wild species: an Overview. In: N Maxted, BV Ford-Lloyd, SP Kell, JM Iriondo, E Dullloo, and J Turok (eds) *Crop Wild Relatives, conservation and use*. CAB International, pp 585-604.
- Hodgkin T and R Hajjar (2008) Using crop wild relatives for crop improvement: Trends and Perspectives. In: N Maxted, BV Ford-Lloyd, SP Kell, JM Iriondo, E Dullloo, and J Turok (eds) *Crop Wild Relatives, Conservation and Use*. CAB International, pp 535-548.
- <http://singer.grinfo.net/>
- IBPGR (1991) International Board for Plant Genetic Resources, Annual Report for 1990. IBPGR, Rome.
- Jensen PCM, RHMJ Lemmens, LPA Oyen, JS Siemonsma, FM Stavast and JLCH van Valkenburg (eds) (1991) Basic list of species and commodity Grouping. Final version. PROSEA Foundation, Bogor.
- Kannenberg LW (2001) HOPE, a hierarchical, open-ended system for broadening the breeding base of maize. In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford,

- UK, pp 311-318.
- Kannenbergh LW and DE Falk (1995) Models for activation of plant genetic resources for crop breeding programs. *Can. J. Plant Sci.* **75**: 45–53.
- Kuraparthi V, P Chhuneja, HS Dhaliwal, S Kaur, RL Bowden and BS Gill (2007a) Characterization and mapping of cryptic alien introgression from *Aegilops geniculata* with novel leaf rust and stripe rust resistance genes *Lr57* and *Yr40* in wheat. *Theor. Appl. Genet.* **114**: 1379-1389.
- Kuraparthi V, S Sood, P Chhuneja, HS Dhaliwal, S Kaur, RL Bowden, BS Gill (2007b) A cryptic wheat-*Aegilops triuncialis* translocation with leaf rust resistance gene *Lr58*. *Crop Science* **47**: 1995-2003.
- Ladizinsky G (1985) Founder effect in crop-plant evolution. *Eco. Bot.* **39**: 191-199.
- Maxted N, SP Kell and BV Ford-Lloyd (2008) Crop wild relatives conservation and use: establishing the context. In: N Maxted, BV Ford-Lloyd, SP Kell, JM Iriondo, E Dulloo, and J Turok (eds) *Crop Wild Relatives, conservation and use*. CAB International, pp 3-30.
- Meilleur BA and T Hodgkin (2004) In situ conservation of crop wild relatives. *Biodiversity and Conservation* **13**: 663-684.
- Mujeeb-Kazi A, G Fuentes-Davila, RL Villareal, A Cortes, V Roasas and R Delgado (2001) Registration of 10 synthetic hexaploid wheat and six bread wheat germplasm resistant to kernal bunt. *Crop Sci.* **41**: 1652-1653.
- Niangado O (2001) The State of Millet Diversity and its Use in West Africa In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, pp 147-158.
- Pal Sukram, Parveen Chhuneja, Achla Sharma, RP Singh and NS Bains (2010) Introgression of quality traits from *Triticum dicoccoides* to bread wheat variety PBW343. *Crop Improvement* **37**: 183-188.
- Plucknett DL, N Smith, JT Williams, NM Anisshetty (1987) Gene banks and the world's food. Princeton University Press, Princeton, New Jersey.
- Pollock LM and W Salhuana (2001) The Germplasm Enhancement of Maize (GEM) Project: Private and Public Sector Collaboration. In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK. pp 319-330.
- Prescott-Allen R and C Prescott-Allen (1988) Genes from the Wild: Using Wild Genetic Resources for Food and Raw Materials. International Institute for Environment and Development, Earthscan Publications, London.
- Prescott-Allen R and C Prescott-Allen (1990) How many plants feed the world? *Conservation Biol.* **4**: 365-374.
- Rawat N, VK Tiwari, K Neelam, GS Randhawa, P Chhuneja, Kuldeep Singh and HS Dhaliwal (2009) Development and characterization of *Triticum aestivum*-*Aegilops kotschy* amphiploids with high grain iron and zinc contents. *Plant Genet. Resour.: Characterization and Utilization* **7**: 271–280.
- Rick CM and RT Chetelat (1995) Utilization of related wild species for tomato improvement. *Acta Hort.* **412**: 21-38.
- Ross H (1986) Potato breeding problems and perspectives. *Fortschritte der Pflanzenzuchtung* **13**. Paul Parey. Berlin and Hamburg, Germany.
- Sears ER (1956) The transfer of leaf rust resistance from *Aegilops umbellulata* to wheat. *Brookhaven Symp. Biol.* **9**: 1-22.
- Sehgal SK, S Kaur, S Gupta, A Sharma, R Kaur and NS Bains (2010) A direct hybridization approach to gene transfer from *Aegilops tauschii* Coss. to *Triticum aestivum* L. *Plant Breeding* **130**: 98-100.
- Seiler GJ and Jr TJ Gulya (2004) Exploration for wild *Helianthus* species in North America: Challenges and opportunities in the search for global treasures. *International 16th Sunflower Conference Proceedings* **1**: 43-68.
- Simmonds NW (1962) Variability in crop plants: its use and conservation. *Biol. Rev.* **37**: 422-465.
- Simmonds NW (1993) Introgression and incorporation. Strategies for the use of crop genetic resources. *Biological Reviews* **68**: 539-562.
- Singh Kuldeep, P Chhuneja, Inderjit Singh, SK Sharma, T Garg, M Garg, Beat Keller and HS Dhaliwal (2010) Molecular mapping of cereal cyst nematode resistance in *Triticum monococcum* L. and its transfer to the genetic background of cultivated wheat. *Euphytica* **176**: 213–222.
- Singh Kuldeep, Meenu Ghai, Monica Garg, Parveen Chhuneja, Parminder Kaur, Thorsten Schnurbusch, Beat Keller and HS Dhaliwal (2007) An integrated molecular linkage map of diploid wheat using a *Triticum boeoticum* x *T. monococcum* RIL population. *Theor. Appl. Genet.* **115**: 301–312.
- Singh K B and B Ocampo (1997) Exploitation of wild *Cicer* species for yield improvement in chickpea. *Theor. Appl. Genet.* **95**: 418-423.
- Singh Sarvjeet, RK Gumber, N Joshi and K Singh (2005) Introgression from wild *Cicer reticulatum* to cultivated chickpea for productivity and disease resistance. *Plant Breeding* **124**: 477-480.
- Spillane C and P Gepts (2001) Evolutionary and Genetic Perspectives on the Dynamics of Crop Genepools. In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, pp 25-70.
- Spoor W and NW Simmonds (2001) Base-broadening: Introgression and Incorporation. In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, pp 71-80.
- Stam P and AC Zeven (1981) The theoretical proportion of the donor genome in near- isogenic lines of self-fertilizers bred by backcrossing. *Euphytica* **30**: 227–238.
- Stalker HT (1980) Utilization of wild species for crop improvement. *Adv. Agron.* **33**: 111-145.
- Stolton S, N Maxted, BV Ford-Lloyd, SP Kell and N Dudley (2006) Food Stores: Using protected areas to secure crop genetic diversity. WWF arguments for protection series. Gland, Switzerland.
- Tanksley SD and SR McCouch (1997) Seed banks and molecular maps: unlocking genetic potential from the wild. *Science* **277**: 1063-1066.

- Tanksley SD and JC Nelson (1996) Advanced backcross QTL analysis: a method for the simultaneous discovery and transfer of valuable QTLs from unadapted germplasm into elite breeding lines. *Theor. Appl. Genet.* **92**: 191-203.
- Tanksley SD, S Grandillo, TM Fulton, D Zamir, Y Eshed, V Petiard, J Lopez and T Beck-Bunn (1996) Advanced back cross QTL analysis in a cross between an elite processing line of tomato and its wild relative *L. pimpinellifolium*. *Theor. Appl. Genet.* **92**: 213-224.
- Tallury SP and MM Goodman (2001) The State of the Use of Maize Genetic Diversity in the USA and Sub-Saharan Africa. In: HD Cooper, C Spillane and T Hodgkin (eds) *Broadening the Genetic Base of Crop Production*. CAB International, Wallingford, UK, pp 159-180.
- Upadhyaya HD and R Ortiz (2001) A mini core subset for capturing diversity and promoting utilization of chickpea genetic resources. *Theor. Appl. Genet.* **102**: 1292-1298.
- Upadhyaya HD, CLL Gowda and DVSSR Sastry (2008) Plant genetic resources management: collection, characterization, conservation and utilization. *Journal of SAT Agric. Res.* **6**: 1-16.
- Villareal RL, K Sayre, O Banuelos and A Mujeeb-Kazi (2001) Registration of four synthetic hexaploid wheat (*Triticum turgidum/Aegilops tauschii*) germplasm lines tolerant to waterlogging. *Crop Sci.* **41**: 274.
- Welz HG and Geiger HH (2000) Marker-assisted selection. I Qualitative traits. In: BIG Haussmann, HH Geiger, DE Hess DE, CT Hash and P Bramel-Cox (eds) *Application of Molecular Markers in Plant Breeding (training manual)*, <http://www.icrisat.org/text/research/grep/homepage/mol/molecular.htm>. Patancheru: ICRISAT.
- Whitlock MC, PC Phillips, FBG Moore and SJ Tonsor (1995) Multiple fitness peaks and epistasis. *Annual Review of Ecol. Systematics* **26**: 601-629.
- Wilson EC (1992) *The Diversity of Life*. The Penguin Press, Allen Lane, UK, 421 p.
- www.generationcp.org
- Wych RD and DC Rasmusson (1983) Genetic improvement of malting barley cultivars since 1920. *Crop Sci.* **23**: 1037-1040.
- Xiao J, J Li, S Grandillo, SN Ahn, L Yuan, SD Tanksley and SR McCouch (1998) Identification of trait improving quantitative trait loci alleles from a wild rice relative. *Oryza rufipogon. Genetics* **150**: 899-909.
- Zamir D (2001) Improving plant breeding with exotic genetic libraries. *Nature Reviews Genetics* **2**: 983-989.

Valuation of Plant Genetic Resources

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Plant genetic resources refers to the biological diversity of crops and their wild relatives, encompassing both phenotypic and genotypic variation, including cultivars or varieties recognised as agro-morphologically distinct by farmers and genetically distinct by crop improvement scientists. The value of plant genetic resources is as per the people who depend on it. However, as the costs of conservation mount, it seems to be true that every conservation action needs to be supported with argument that shows tangible and measureable benefits from such action to get the funding needed. In this paper the value of plant genetic resources is briefly discussed, along with the cost of plant genetic resources conserved in genebanks and on farms. This is followed by brief review of literature on economic valuation of plant genetic resources/biodiversity and some issues in such valuation efforts. Some studies on valuation plant genetic resources from different perspectives are discussed. The paper is concluded with a question as to the need for economic valuation of plant genetic resources on which it is difficult to place a value.

Key Words: Biodiversity, Direct use value, Economic valuation, Farmers' perspective, Genebanks, Indirect use value, Plant genetic resources, Uncertainty value

Introduction

Agricultural biodiversity refers to all diversity within and among domesticated crop, tree, aquatic, and livestock systems. Plant genetic resources (PGR) that is the focus of this paper refers to the biological diversity of crops and their wild relatives, encompassing both phenotypic and genotypic variation, including cultivars or varieties recognised as agro-morphologically distinct by farmers and/or genetically distinct by crop improvement scientists.

“Beauty is in the eye of the beholder”—and the value of PGR is as per the people who depend on it. However, as the costs of conservation mount, every conservation action needs to be supported with argument that shows tangible and measureable benefits from such an action to get the funding needed. The genetic variation present in plants has always been considered very valuable and it has been presumed that this natural resource will be available for all time to come to be used by humans. However, it is now realised that the genetic variation present in the centres of diversity could be lost if it is not properly cared for. The problem became pressing with the increased agricultural development required by the rapidly increasing population. This had a profound impact on traditional agriculture, including traditional cultivars. Many factors, natural and human, resulted in the loss of traditional landraces and biodiversity in general which triggered efforts by various

national and international organizations to collect and conserve plant genetic resources. The great wealth of genetic diversity still existing in plant gene pools holds vast potential for current and future uses of humankind (Harlan, 1992). One end of the conservation spectrum is that the plant genetic resources are irreplaceable and it is essential that we should be concerned with their conservation, at species level, gene pool level or at the ecosystem level. Genetic diversity is a natural buffer mechanism against the genetic vulnerability, which has been built into the genetic structure of traditional cultivars (Council, 1972; Anon, 1973; Brown, 1983; Chang, 1994). Countries which still have a significant amount of genetic diversity and species diversity have a responsibility unto themselves as well as to the world at large to conserve it and make it available to for use (Ramanatha Rao *et al.*, 1994). At the other end of the spectrum is the argument that the costs of conservation need to be in consummate with its value and hence for providing appropriate support to conservation actions economic evaluation of biodiversity in general and PGR in particular are mooted. In this paper an attempt is made to look at various ways of valuation of PGR and the importance of such a valuation.

Why is Agro-biodiversity Important?

Plant genetic resources is an integral part of agro-ecosystems and agro-biodiversity, whose value has always been assumed, will continue to serve as a direct

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and indirect reservoir of genetic materials and knowledge, required for providing needed requirements of current and future generations of human society. Agro-ecosystems will, therefore, become a battleground where the natural aspects of biodiversity and the societal culture, including the knowledge systems associated with it, will survive or perish in the course of environmental changes and development (Sajise, 2003). In several countries, policy makers have responded to concerns over declining levels of biodiversity in general, PGR in particular and this has led to the introduction of a range of policy measures. Estimating the costs for such measures that promote conservation is relatively easy; however, it is much more difficult to estimate the benefits. Economics can help guide the design of biodiversity policy by eliciting public preferences on different attributes of biodiversity. However, this is complicated by the generally low level of awareness and understanding of what biodiversity means on the part of the general public (Christie *et al.*, 2006). Since many of the estimates will be/are based on highly theoretical concepts, assumptions and perceptions, it is important to treat them as guidelines and not standards.

It is also well recognized that the great wealth of plant genetic diversity existing in genepools of economically useful plants, including their wild relatives, has great potential for current and future uses for humankind. It is seen as a defence against genetic vulnerability that results from narrow genetic base, a defence against biotic and abiotic stresses, and also against changing climatic conditions and productions systems. These defence mechanisms result from either through farmers building this defence into the genetic structure of landraces or through modern crop improvement. Both these elements are important in the long run towards sustainable agriculture in spite of numerous obstacles in achieving this. At the same time, there are many examples that have demonstrated the significant benefits arising out of the efforts undertaken in the conservation of PGR and their effective use. For example, rice production in Asia increased by 42% from 1968 to 1981 following the use of high yielding and short duration cultivars derived from genebank collections. The increase was about 110 million tons in one year. At the price of USD 250 per ton, profit of USD 27,500 million per year was generated while the money used for the conservation of rice genetic resources worldwide was estimated to be less than USD 2 million per year. A conservative estimate is that 50% of the profit is due to rice improvement based on the use of rice genetic resources

derived from rice genebanks (see Evenson *et al.*, 1998). Another example is the hybrid pigeon pea called ICPH 8 developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). This pigeon pea, which requires only 100 days to mature, increases yield by 30 to 40% and can be cultivated under a wide range of conditions. The shorter maturation period required by ICPH 8 meant savings of up to USD 100 million a year to growers as ICPH 8 is resistant to serious damage by fungal and viral diseases (Ramanatha Rao *et al.*, 1997). In the seed industry, 6.5% of all genetic research which resulted in a marketed innovation was concerned with germplasm from wild species and landraces compared with only 2.2% emanating from technological approaches of induced mutation (Sajise, 2003). A one-time, permanent yield increase from genetic improvements for five major U.S. crops has generated an estimated \$8.1-billion gain in economic welfare worldwide (Rubenstein, 2005). Thus, what plants used on the agro-ecosystems impact on the value of goods produced in these systems and impact on livelihoods of all those that are dependent on them (Ramanatha Rao, 2009).

Cost of Plant Genetic Resources Conserved in Genebanks and on Farms

Before going into the question of value of PGR, it may be necessary to look into the cost of conservation. In contrast to the fairly extensive research into the values and benefits of biodiversity and its conservation in general (*e.g.* Pearce *et al.*, 1991; Munasinghe and Lutz, 1993; Pearce and Moran, 1994; von Braun, 1994), the costs of PGR conservation have received much less attention (Virchow, 1999). Although, it was estimated that approximately US \$ 740 million were spent 1995 in national and multi-lateral activities for the conservation and utilisation of PGRFA (ITCPGR, 1996) (current figures are not known), there is no price for the acquisition of accessions. Although, some genebanks have started charging for the supply of accessions that they conserve, in general, accessions in *ex situ* storage are more or less freely available, with some sort of agreements, to *bona fide* users upon request; only the quarantine and transportation costs are charged occasionally. Access restrictions are being introduced by charging a fee for each requested accession or limiting the access to the whole collection, under the facilitated accesses agreement of the Convention on Biological Diversity. Although, there is not yet a price fixed for PGR, the above mentioned existing expenditures for conservation urge a closer theoretical analysis of the

costs and distribution among the players. To identify all involved conservation costs, it is necessary to differentiate the costs from *in situ* and *ex situ* conservation on the farmer level, the national and international levels as well as on the level of the private sector. Very few genebanks have attempted to estimate costs of *ex situ* conservation (Gupta *et al.*, 2002) and still fewer efforts have been made on *in situ* conservation (Wale, 2011).

For the purposes of estimating cost of *ex situ* conservation activities may be differentiated into: acquisition costs, including the tasks of surveying, inventorying, collecting, and shipping to the genebank as well as multiplication, characterization and the first evaluation of the collected material at the genebank; maintenance costs, including conservation preparations, running-costs and the germination control and regeneration; processing costs, including information record and multiplication costs; and costs for supporting activities, *e.g.* institution and capacity building and the creation of institutional legal frameworks (Virchow, 1999). The cost of conservation is highly crop- and location-specific; therefore, it is imperative to calculate it for estimating the capital required for conserving the germplasm in a given region. Such studies also draw attention towards the critical components, for efficient conservation and would also lead to guide the future conservation strategies as well as in formulating cost-effective approaches. The estimation of cost of conservation helps the International Communities to allocate the appropriate financial assistance to the country for conserving its genetic resources (Gupta *et al.* 2002). Gupta *et al.* (2002), however, indicate several limitations of such estimations. Some limitations include the complex and inter-linked nature of genebank activities and use activities; characterization and evaluation based on local/traditional knowledge; changing conservation technologies associated costs; cost of sharing data with donors and users.

Farmers, especially in many developing countries, maintain traditional crop cultivars and, thus, are often referred to as the custodians of landrace genetic diversity; although some may argue that the custodianship may be a product of production practices. Since such management of on-farm diversity is directly related to their livelihood actions, most farmers maintain them only to the extent that landraces support their livelihood (generate private benefits) and address household concerns. By growing traditional varieties of crops for private benefit reasons, farmers contribute to society. This is sometimes coined

as ‘*de facto* conservation’ (Meng, 1997). Although, mainly resource-poor farmers are maintaining PGRFA *in situ* and are not compensated for their work, countries are carrying most of the costs of PGRFA conservation. Without greater international incentives to maintain such biodiversity, countries, especially diversity rich but capacity poor countries, will see little reason for retaining this diversity. International mechanisms and instruments are needed to recompensate national conservation systems for the cost involved maintaining PGRFA. Furthermore, it should be national responsibility to foster the agricultural production increase, especially in marginalised areas, and, simultaneously, to target the *in situ* conservation through an objectives-oriented approach. The combination of production increase by transforming land to high-potential area and a qualitative high, but quantitative low *in situ* conservation is needed to guarantee a sustainable agricultural development (Virchow, 1999). Wale (2011) attempted to estimate on-farm conservation costs based on household-level financial opportunity costs which, in turn, are estimated using sorghum and wheat household survey data from Ethiopia. The results suggest that opportunity costs need to be responsive to agricultural development opportunities, crop types and farmers’ characteristics which will all affect the national level conservation costs. Farmers have to be contextually targeted (for on-farm conservation) and treated based on their attribute profiles. Different levels and types of compensation schemes might be required for different groups. Institutionalizing on-farm conservation and optimizing costs calls for fulfilling farmers’ expectations based on the opportunity costs they forego (Wale, 2011). On-farm conservation is an important component of the global strategy to conserve crop genetic resources, though the structure of costs and benefits from on-farm conservation differ from those associated with *ex situ* conservation in genebanks. A fundamental problem that affects the design of policies to encourage on-farm conservation is that crop genetic diversity is an impure public good, meaning that it has both private and public economic attributes (Smale *et al.*, 2004).

The available information suggests that in most cases the costs of conservation are little understood. The costs of running conservation organizations/agencies may be estimated from their annual budgets, but it may not give a correct picture as such budgets may include several collateral costs that may be unrelated to conservation efforts. In addition, actual *in situ*/on-farm conservation programmes/projects in many countries may be *ad hoc*

and may not be institutionalized. Thus, estimating costs of *in situ* conservation of PGR may be very difficult, if not impossible. A better understanding of costs of conservation is necessary to better strategize conservation efforts and may even be important in valuation of PGR, if such valuation is considered necessary for developing policies that cover conservation efforts. In addition, a poor understanding of cost of conservation of PGR can contribute to certain sections of society for looking at PGR purely in terms of their present economic returns.

Value of Plant Genetic Resources

The value of genetic diversity, in its various forms (*i.e.* tangible, intangible etc.), has been extensively discussed in literature (Pearce and Moran, 1994; Brush and Meng, 1998; Evenson *et al.*, 1998; Gollin and Evenson, 1998; Rao and Evenson, 1998; Simpson and Sedjo, 1998; Smale, 2006; Swanson, 1998; Rausser and Small, 2011). Methods employed to estimate value of biodiversity may include one or a combination of various econometric methods that may include: 1. willingness to pay for on-farm diversity; 2. contingent valuation measure; 3. hedonic pricing; 4. other hedonic approaches; 5. option values; and 6. production losses averted. However, the economic valuation of many aspects of agricultural biodiversity remains problematic as these not only have direct value in terms of food and nutrition, but also have indirect uses which include adaptation to low input conditions, co-adaptive complexes, yield stability (reduction of risk), aesthetic value and meeting religious and socio-cultural needs. For crop varieties, three different types of value are distinguished: direct, indirect and option value (Brown, 1990; Brush, 2000; OECD, 2002; Swanson, 1996). Direct or use value is the simplest and most obvious one that refers to the harvest and uses of crop varieties by farmers (Smale *et al.*, 2004). Indirect value refers to the environmental services or ecological health the crop varieties contribute to, but which farmers may not observe or notice (Hajjar *et al.*, 2007). Option value refers to the future use of crop varieties (Krutilla, 1967). From the farmers' perspective, the latter two values of crop varieties are secondary, whereas for conservationists the option value is of paramount importance. Nunes and van den Bergh (2001) evaluated the notion and application of economic theories and monetary valuation of biodiversity and concluded that most available economic value estimates only provided incomplete picture. See Drucker *et al.* (2005) for an exhaustive review of literature.

In general terms, agricultural biodiversity provides

many goods and services of environmental, economic, social and cultural importance; these environmental goods and services also contribute to sustainable livelihoods in a number of ways (Cromwell *et al.*, 2001). The economic value of such goods and services is not well captured by market prices because they are not traded (Brown, 1990) but are valued by local communities often in marginal areas where markets are weak or not present (Smale, 2006). A number studies have been underway to determine the economic bases of farmers' decisions and benefits when using local crop varieties (Smale *et al.*, 2004). These studies provide a more concrete understanding of the public and private values that farmers' crop varieties embody. They are: (1) 'private' values in the harvest the farmer enjoys, either directly as food or feed, or indirectly through the cash obtained by selling the produce and purchasing other items; and (2) 'public' values in its contribution to the genetic diversity from which future generations of farmers and consumers will also benefit. The genetic diversity attributes of crop diversity are not fully captured by markets (Brown, 1990) and generally require public investments to provide farmers enough economic incentives to continue growing them. Economic value is important, however, this can be highly contextual and there have to be trade-offs, and the value system varies within the local context and culture (Sthapit *et al.*, 2008). Thus, an understanding local culture is essential to visualize the value of PGR and may be difficult or even unethical to look at their value purely in economic terms. However, in these days when every aspect of human activity is measured in terms of economics, it may be difficult to stay away from the questions with regard to economic value of PGR.

Plant genetic resources or agricultural biodiversity in general provides goods with: (1) option value (Brush *et al.*, 1992; Rao & Evenson, 1998); (2) direct use value (Johns & Sthapit, 2004); and (3) exploration value (Wilson, 1988; Rausser and Small, 2011). Another classification includes use value, their option value, and their intrinsic value (Dasgupta, 2001). The services offered by agricultural biodiversity can also be categorized into three values: (1) option value (Swanson, 1996); (2) direct use value (Smale, 2006); and (3) indirect use value (Hajjar *et al.*, 2007). (see Table 1). However, it is important to note that any discussion, despite various pressures to put a value on PGR must be tempered taking into account the intrinsic value of biodiversity for local livelihoods and the multiple benefits generated from its use (Table 2). Agricultural ecosystems are completely managed by

Table 1. Goods and services provided by plant genetic resources

Goods	Option value	Adaptive traits
		Mass selection Parents for breeding Sources of resistance to biotic and abiotic stresses
		Food Wild Uncultivated Cultivated
		Nutrition Wild Uncultivated Cultivated
	Direct use value	Other Utilities Medicines Timber Energy Utensils/equipment Fodder Natural dyes
	Exploration value (bioprospecting)	Pharmaceuticals Industrial products
Services	Option value	Portfolio value Exploration value Use of multiple species/varieties to manage risk Alternate energy
	Direct use value	Dietary diversity Food habits and preferences Religious and research needs Aesthetic value Recreation/agrotourism
	Indirect use value*	Ecosystem services Soil retention Pollination Pest management Regulation of natural predators Nutrient recycling
		Carbon sequestration Hydrologic regimes Shade and shelter Nitrogen fixation

*Note: Indirect value of plant genetic resources is its contribution as a part of larger agricultural biodiversity in given system and realization of these services would depend on how much 'volume' it occupies in a system.

humans and are reported provide services food, fibre, and fuel as per the Millennium Ecosystem Assessment. Provision of these services depends on supporting and regulating services as inputs to production (e.g., soil fertility and pollination, etc.). Agriculture also receives ecosystem disservices that reduce productivity or increase production costs for example, herbivory and competition for water and nutrients by undesired species (Zhang *et al.* 2007). Hence, it is important take into account the how adequately the agricultural ecosystems are managed and upon the diversity, composition, and functioning of remaining natural ecosystems in the landscape. Managing agricultural landscapes to provide sufficient supporting and regulating ecosystem services and fewer disservices will require research that is policy-relevant, multi-disciplinary and collaborative. Some of the agricultural

Table 2. Plant species and species useful to humans

Use/classification	Plant species
Total number of described species	250,000
Edible species	30,000
Cultivated species	7,000
Species important on national scale	120
Making up 90% of world's calories	30

Source: FAO, State of the World's Plant Genetic Resources for Food and Agriculture (1997)

ecosystem disservices include: habitat loss, nutrient run-off, pesticide poisoning of non-target species etc. Zhang *et al.* (2007) discussed how ecosystem services contribute to agricultural productivity and how ecosystem disservices detract from it. They describe the major services and disservices as well as their key mediators and discuss outstanding issues in regard to improving the management of ecosystem services and disservices to agriculture.

Studies on Valuation of PGR

Farmers' Perspective

There has been very little economics research carried out to understand the value of rapidly eroding local cultivars/landraces to the farmers who grow them. This is partly because such varieties are typically found in marginal, isolated environments, where they are traded outside of formal markets (Smale and King, 2005). In addition, economists have only recently challenged the commonly-held assumption that local varieties will inevitably be replaced by modern varieties over time (Brush *et al.*, 1992; Meng, 1997).

Sthapit *et al.* (2008) discussed three case studies from Nepal and Vietnam in three typical livelihood scenarios: (1) uncultivated and wild food; (2) home gardens; and (3) diversity within species in larger ecosystems. They attempted to demonstrate the scenarios, the value of genetic diversity. They found that there was a common pattern in how farmers valued genetic diversity. The results illustrated that the rationale of managing a large number of cultivars at household levels depending on the value assigned to them based on: (1) the contribution to food security or for the market (income generation), (2) socio-cultural (traditions, religious rituals) purposes, (3) specific abiotic co-adaptive traits (such as being adapted to swamp soils, poor soils, drought), and (4) specific use values to particular families. The degree to which genetic diversity is used and valued by farmers could be measured in the proportion and size of the population planted within the fields of households in a community. These studies revealed that genetic resources are one of the few resources available to resource-poor farmers to ensure their livelihoods and income. However, economic evaluation of these in terms of actual monetary value may be untenable as such an analysis would change the perspective with which valuation exercise may be carried out.

Poudel and Johnsen (2009) carried out a study in Nepal that uses the contingent valuation method to document the economic value of crop genetic resources based on the farmers' willingness to pay for conservation. The study concluded that the rice producing farmers in Kaski district of Nepal were on average willing to pay USD 4.18 for *in situ* conservation and USD 2.20 for *ex situ* conservation of rice landraces per landrace per annum. The respondents were willing to contribute more for *in situ* than *ex situ* conservation because of the additional effect of direct use and direct involvement of

the farmers in *in situ* conservation. The values obtained in this study are quantified indications of the value placed by the farming community on the crop genetic resources, specifically rice landraces. As such, they are useful for cost benefit analysis and for debate and decision-making on conservation strategies. The study may contribute to drawing the attention of the policy makers in formulation of appropriate policy mechanisms, raising public and political awareness of the importance of the issue, and helping to set conservation priorities.

Value of Agrobiodiversity in Research Development

Biodiversity prospecting, the search for valuable compounds from plants (and other organisms, mainly wild ones) has been considered as a potential source of finance for biodiversity conservation. However, it has been debated whether revenues from bioprospecting could be large enough to offset the opportunity costs of PGR conservation. Simpson *et al.* (1996) argued that the returns to holding genetic resource assets are unlikely to be large enough to create significant conservation incentives. The claim is based on a model of the research process in which firms sample without replacement from a large set of research leads, incurring a fixed cost per draw. The authors pose the question: supposing that each lead carries a fixed probability of yielding a breakthrough, how much would a private firm be willing to pay to prevent the collection of leads from becoming slightly smaller? In other words, what is the value of the marginal research opportunity, in this R&D process?

Formal analysis confirms what intuition suggests: if the original collection is sufficiently large, then one additional lead is likely either to be infertile (if the probability of success per test is very low) or redundant (if the probability of success is sufficiently high). Given that the number of species in the world is very large indeed, the expected return to the "marginal species" is likely to be vanishingly small. It will, then, exert no genuine incentive towards conservation, in the context of a market for genetic resources. Extensions to cases in which discoveries vary in quality, or in which success rates covary according to an average degree of genetic distance (Polasky and Solow, 1995), generate somewhat higher values, but do not alter the substance of this conclusion. Leads of unusual promise then command information rents, associated with their role in reducing the costs of search. When genetic materials are abundant, information rents are virtually unaffected by increases in the profitability of product discovery, and

decline as technology improvements lower search costs. Numerical simulation results suggest that, under plausible conditions, the bioprospecting value of certain genetic resources could be large enough to support market-based conservation of biodiversity (Rausser and Small, 2011).

Generally the value of genetic resources for R&D is placed within the framework of discussions concerning sustainability. Sarr *et al.* (2008) assess the extent to which society is able to invest now in order to prepare for future risks and uncertainties in the arrival of biological problems and they discuss different approaches to valuation within this setting. Weitzman's approach to measurement is seen to be one that considers society's current objectives and information to be little relevant to future risks and uncertainties (Weitzman, 1998). They further note that Sedjo, Simpson and Reids' search-theoretic perspective (Simpson *et al.*, 1996) is seen to reduce future uncertainties to highly tractable and known problems and that Goeschl and Swanson's biotechnological approach (Goeschl and Swanson, 2002) also constrains the problem to be one without any real uncertainty, and focuses on the need to maintain genetic resources in order to maintain control over the problem. They note that Kassir and Lasserre (2004) place uncertainty at the core of the problem, and assess the extent to which additional value is added by this feature. In sum all of the approaches to the problem evince a pessimism regarding the capacity of future technological change automatically to resolve these problems. Given this, the value of genetic resources depends on beliefs concerning the ability of current objectives to anticipate future risks and uncertainties (Sarr *et al.*, 2008). The question remains whose belief can be regarded as strongest and does it match with the needs of farmers whose livelihoods depend on PGR/agrobiodiversity that is being valued.

Value of Plant Genetic Resources Based on the Use in Crop Improvement

Many genebanks around the globe conserve several thousands of germplasm accessions. One of the major weaknesses of our conservation efforts has been full characterization and evaluation of the PGR conserved and document information on the useful traits identified in particular accessions. This makes it very difficult to place a value on such PGR and begs the question—what is the expected benefit from using an additional, unimproved genebank accession in crop breeding (Zohrabian *et al.*, 2003)? Typically, plant breeders can deduce little about what these accessions have to offer from the existing data describing them. Zohrabian *et al.* (2003) tried to

answer this question by combining search theory with a maximum entropy approach, which is particularly suitable for analysis with sparse data. They estimated the marginal value of utilizing prebreeding materials contained in the U.S. National Plant Germplasm System. Data were drawn from trials to screen 573 recently acquired accessions that test for susceptibility to soybean cyst nematode. The present discounted value of benefit streams in the United States was estimated with areas planted to soybean and its prices. The present value of the expected gross research benefits is estimated at about \$36,000 to \$61,000, which implies that the benefit-cost ratio for investing in an additional accession to prevent losses from a single pest is in the range of 36 to 61. The size of benefits is sensitive to changes in area planted to the crop and to the discount rate because of the time lag between investment in the research and the stream of earnings. The magnitude is also affected by the economic value of the crop, the severity of damage caused by the disease, and the likelihood of future outbreaks requiring a new search. The findings of this study indicate that the lower-bound benefits from utilizing a marginal accession are higher than the upper-bound costs of acquiring and conserving it, justifying the expansion of the U.S. soybean collection.

A single wild relative of the tomato contributed genetic resources that increased the solids content of processing tomatoes by 2.4%. This has been worth US\$ 250 million a year in the state of California alone, because it reduces energy needs in processing (Stolton *et al.*, 2006). Three different wild peanuts have been used to breed commercial varieties resistant to root knot nematodes. It is helping to save peanut growers around the world an estimated \$100 million a year (<http://www.unep.org/documents.multilingual/default.asp?DocumentID=399&ArticleID=4542&l=en>).

As one of the use values, genetic diversity available to us in PGR has economic value related to the potential benefits it can bring through the breeding of new varieties of global crops. Through crop improvement programmes (of which plant breeding is an essential component) useful genetic traits can be incorporated into existing plant cultivars, for instance in order to increase yields, improve the quality of the crop, or breed disease resistance. Plant breeding based on traits derived from crop wild relatives is quite common for most global crops, and makes an important contribution to increasing global welfare (Morris and Heisey, 2003). As noted earlier, the economic value of genetic diversity is widely recognized, however, there

are relatively few experiences with the actual valuation of PGR. Hein and Gatzweiler (2006) carried out an analysis of the economic value of *Coffea arabica* genetic resources contained in highland forests of Ethiopia. The valuation was based on an assessment of the potential benefits and costs of the use of *C. arabica* genetic information in breeding programmes for improved coffee cultivars. The method is based on the assumption that the value of coffee genetic information equals the benefits that can be obtained from applying this information in a breeding programme. The study considered the breeding for three types of improved cultivars: increased pest and disease resistance, low caffeine content and increased yields. Costs and benefits are compared for a 30 years discounting period, and result in a net present value of coffee genetic resources of 1458 and 420 million US\$, at discount rates of 5% and 10%, respectively. The value estimate is prone to considerable uncertainty, with major sources of uncertainty being the length of breeding programmes required to transfer valuable genetic information into new coffee cultivars, and the potential adoption rate of such enhanced cultivars. Nevertheless, the study demonstrated the high economic value of genetic resources, and it underlines the need for urgent action to halt the currently ongoing, rapid deforestation of Ethiopian highland forests.

More examples of PGR contribution to crop improvement in crops like wheat, maize etc can be found in Hoisington *et al.* (1999). Also see Box in Esquinas-Alcázar (2005) and Evenson *et al.*, 1998).

Value of Plant Genetic Resources Conserved in Genebanks

Broadly speaking, PGR can be conserved *ex situ* (out of their place of origin) by any one of several technical means, or managed *in situ* (in their place of origin), on farms or in wild reserves. Economics is a utilitarian discipline focusing on human society rather than biological systems. The economic value of PGR, therefore, derives from human use, although human use can refer not only to food, fibre, and medicinal production but also to aesthetic, ecosystem, and social-support functions (Brown, 1991).

The theory of valuing and managing PGRs is reasonably well understood and has been surveyed before. These genetic resources are an impure public good, and markets typically do not give the right incentives for conservation to the farmers, herders, hunters, and gatherers whose actions may have a large impact on the conservation of species, landraces, breeds, and varieties. There is

thus *prima facie* support for public actions that promote conservation (Gollin and Evenson, 2003). Simpson *et al.* (1996) show that the marginal value of large collections gets very small, because if a trait is common, a marginal accession will seldom be useful, and if it is rare, it will be difficult to collect. However, this can change with any chance discovery within genebank accessions which can make the value of conserved accessions soar.

With the progress that is being made in molecular biology and molecular tools that are becoming available, in the future, collections may be screened for the presence of new alleles at a given locus (Graner *et al.*, 2004)). These alleles could later be assayed for their functional value. This approach would require the prediction of a gene's phenotype from its DNA sequence, a capacity that is still to be reached. However, recent advances in the analysis of linkage disequilibrium may help identify genes underlying traits of interest by association mapping (Rafalski, 2002). This approach obviates the requirement for experimental populations, and genetic studies could be performed directly on the plant material available at a genebank. The time span from identifying a target gene to its deployment in a breeding programme might be reduced, thus, further increasing the value of germplasm collections. Developing countries are not able to take advantage of the full range of biotechnology tools to harness the value of their genetic resources and efforts must be made to bridge the gap that is widening in this field of speciality.

Valuing Biodiversity – Public Perception

Determining value of biodiversity in general, of which PGR is a subset, may not tell us directly the value of PGR but they are indicative of their value in a boarder context. Even with fairly well established theoretical basis for estimating the value of biodiversity in economic terms, research efforts have yet to provide a comprehensive assessment of the value attached to the components of biological diversity such as anthropocentric measures (*e.g.* cuteness, charisma, and rarity) and ecological measures (*e.g.* keystone species and flagship species). Christie *et al.* (2006) addressed this issue of valuing the ecological and anthropocentric diversity of biological resources. Their study also stands out in that it is one of the few studies that attempt to value the diversity of biodiversity. They attempted to, rather than simply estimating the value of a biological resource such as a particular species or habitat, explored in detail values for the ecological and anthropocentric concepts that can be used to define and describe the diversity that exists within biological resources. Policy makers may

benefit from information on the economic value of different actions aimed at biodiversity protection, but also on which aspects of biodiversity are most valued by taxpayers. Stated preference methods can provide both types of value estimates, but implementing these methods is difficult in this particular case since the general public has a rather low level of understanding of what biodiversity is and why it matters. In this study authors made use of a novel way of conveying information to respondents, information which is consistent with ecological understanding of what aspects of biodiversity might be considered. Authors then used choice experiments to estimate the relative values people place on these attributes, and contingent valuation to look at the value of specific policy programmes. The study concluded that the public had positive values for biodiversity, but may be indifferent as to how biodiversity is actually protected. Christie *et al.* (2006) also investigated the extent to which valuation workshop approaches to data collection could overcome some of the possible information problems associated with the valuation of complex goods, such as diversity of biodiversity. The key conclusion was that the additional opportunities for information exchange and group discussion in the workshops helped to reduce the variability of value estimates. How policy makers might choose to use such information is something that was not addressed in their study. One option could be to use economics to set overall budgets for biodiversity conservation, but ask ecologists to determine how this money could be utilized on the ground. Another option could be to use the kind of evidence presented to use more economic information in this targeting different conservation actions. Some economists might argue that, in a world of scarce resources and conflicting demands, some information on public preferences for biodiversity conservation is better than no information if society wishes to make sensible and politically-inclusive choices.

Changes in climate and environment are altering selection pressures on natural plant populations, but, it is difficult to predict the novel selection pressures to which populations will be exposed. As noted earlier, there is heavy reliance on plant genetic diversity for future crop security in agriculture and industry, but the implications of genetic diversity for natural populations receives less attention. Jumpt *et al.* (2008) examined the links between the genetic diversity of natural populations and aspects of plant performance and fitness. They argue that accumulating evidence demonstrates the future benefit or 'option value' of genetic diversity within natural

populations when subject to anthropogenic environmental changes. Consequently, the loss of that diversity will hinder their ability to adapt to changing environments and is, therefore, of serious concern. Bosselmann *et al.* (2008) showed that the economic value of genetic diversity in forests goes beyond the risk reducing effects and includes, *e.g.* option values when several clones are mixed in the same forest stand.

Climate change is pacing new demands on agrobiodiversity and there is a need for change in conservation use efforts and attitudes towards it; along with valuing it for the future. As noted earlier, the concerns for economic evaluation place a bit too high value on their current and immediate future. Thus, a good question to ask is how these various changes will affect different *in situ* conservation efforts of landraces and wild species. Although, ecosystems have adapted to changing conditions in the past, current changes are occurring at rates not seen historically. In general, the faster the climate changes, the greater the impact on people and ecosystems. There is a significant research gap in understanding the genetic capacity to adapt to climate change (Ramanatha Rao, 2009). This appears to be corroborated by the recent fluxes in the food prices and collapsing production systems are a reminder of how rapidly climate change can affect global food markets erasing geographical borders with a common pain: how do we feed ourselves (Havalgi, 2009)? This changing scenario may have serious implications on the methods used for the valuation of PGR. Plant breeders, farmers and food production systems, including monocultures all depend on the wide genetic base of the wild relatives to develop crops that adapt and produce well under different climatic conditions, especially when the changes are occurring dramatically and drastically as they are now. Agricultural biodiversity, however, is under severe threat due to habitat loss and environmental degradation, exacerbated by climate change, leading to significant loss of these critical genetic resources, threatening global food security. Placing further stress on it through funding restrictions due to improperly estimated value and inflated costs of conservation can further impede the conservation efforts. The use and conservation of agrobiodiversity is the central means in assuring adaptation of humanity to climate change challenges and to provide global food security. Agricultural trading policies, systems and organizations are critical in providing means to trade, recognize and reward farmers working as stewards of agricultural biodiversity. For

farmers, policy makers and governments to realize the critical role of agrobiodiversity in climate change, and for paving a path for use of agrobiodiversity as an essential adaptation tool; it is critical that the agrobiodiversity should wear the mantle of economic success capable of bargaining for its care-takers. This requires changes in our thinking on placing a definite value on agrobiodiversity. However, some of this problem can be overcome by putting a price on agrobiodiversity used and conserved by the farmers and designing ways for payment and trade of agroecosystem services such as control of natural enemy population, genetic source for insect, disease or drought tolerance and others. Havalgi (2009) strongly argues that farmers and farming communities must benefit and be able to trade through agrobiodiversity conservation credits for their needs without compromising on conservation goals. The role of trade and policies that govern trade are critical here. It is this role of trade in agrobiodiversity conservation that will be explored in this paper. Putting a price or value on agrobiodiversity through taxation or share-and-trade systems is a starting point. Given the urgency of early and widely covered agrobiodiversity conservation and rescue interventions, it is critical that agrobiodiversity share-trade programmes be understood and monitored carefully.

Limits of Economic Valuation of Biodiversity of Plant Genetic Resources

We have seen so far various ways to view and estimate economic value of PGR and biodiversity. The value of PGR appears to vary greatly depending on the values perspective, economic theory adapted and assumptions made. In practice, monetary valuation of biotic resources by the concept of total economic value is a powerful tool for a rational treatment of this fraction of natural capital and for its conservation. Beyond methodological limits to monetarisation with regard to its marginal character there are also moral limits. Adopting the weakest and least controversial assumptions regarding both human dependence on biodiversity and environmental ethics, one is led to the conclusion that the impossibility of communicating with future generations forbids us to value biodiversity only in monetary terms. Fairness towards future demands that we consider conservation as a constraint on economic activity (Hampicke, 1999). As noted earlier, PGR basically are irreplaceable and it is essential that we should be concerned with their conservation, at species level, genepool level or at the ecosystem level and genetic diversity is a natural defence

mechanism against the genetic vulnerability, which has been built into the genetic structure of traditional cultivars. The adoption of biodiversity-based practices for agriculture, however, is partly based on the provision of ecosystem goods and services, since individual farmers typically react to the private use value of biodiversity, not the 'external' benefits of conservation that accrue to the wider society, a society that often ignores the small farmer. Evaluating the actual value associated with goods and services provided by agrobiodiversity, especially to the farmers, requires better communication between ecologists and economists, and the realization of the consequences of either overrating its value based on 'received wisdom' about potential services, or underrating it by only acknowledging its future option or quasi-option value. Partnerships between researchers, farmers, and other stakeholders to integrate ecological and socioeconomic research help evaluate ecosystem services, the tradeoffs of different management scenarios, and the potential for recognition or rewards for provision of ecosystem services (Jackson *et al.*, 2007).

Genetic resources for food and agriculture are the biological basis of world food and nutrition security; and they directly or indirectly support the livelihoods of over 2.5 billion people. For resource-poor farmers, adaptive animal breeds, crop varieties and cultivars adapted to particular micro-niches, stresses or uses are the main resources available to maintain or increase production and provide a secure livelihood. During the last decade, there have been significant number of studies that attempt to estimate the economic value on PGR. However, as noted earlier it is difficult to value many other aspects of agricultural biodiversity as these have both direct and indirect values in terms of qualitative traits such as food, nutrition and environmental uses that include adaptation to low input conditions, co-adaptive complexes, yield stability and the consequent reduction of risk, specific niche adaptation, and in meeting socio-cultural needs. These values vary according the context and location and to outguess the value that the poor farmers place on agrobiodiversity available for their livelihoods seems to be unethical. Together, the direct and indirect values of genetic resources for resource-poor farmers are expressed in a range of options in the form of the crop varieties and species they use for managing changing environments (Sthapit *et al.*, 2008). Given this premise, viewing their value in purely monetary terms may not be right strategy. After all there are not strategies for the conservation of

the so called high economic value items like gold, rare minerals etc. It must also be noted that the current value of agrobiodiversity estimates generally tend to be low. If when the private value of a good rises, potential owners will agitate to change property rules so that it becomes easier for them to seize the added value.

Concluding Remarks

Plant genetic resources are the raw material used by plant breeders to create improved crop cultivars. Due to socio-economic-cultural complexities involved, it is exceedingly difficult to ascribe a purely economic value to any particular PGR. While the market value of a new variety of rice or wheat is fairly easy to calculate, it is almost impossible to estimate the value of any one characteristic derived from an individual accession would always be, at best, an estimate based on several assumptions and would heavily depend on one's perspective. At the end of the debate, the question that would loom large is – what use can we put such an estimate to which may turn out to be purely and estimate with large range of plus or minus. No doubt, it can help the conservationists to argue for more funding for PGR conservation, research and use efforts. However, is it necessary to make any such argument for PGR conservation and use – on which all of our current needs for food and other needs depend? I leave it at that and for the reader to decide on the future course of action.

References

- Anon (1973) Genetic vulnerability of Crops. A world wide problem of raising concern. *Agrl. Sci. Rev.* **11**: 49–55.
- Bosselmann AS, JB Jacobsen, ED Kjær (2008) Climate change, uncertainty and the economic value of genetic diversity: A pilot study on methodologies. Forest & Landscape Working Papers No. 31-2008. Forest & Landscape Denmark, Hørsholm, 58p.
- Brown GM (1990) Valuing genetic resources. In: GH Orians, GM Brown, WE Kunin and JE Swierzbinski (eds.) *Preservation and Valuation of Biological Resources*, Seattle: University of Washington Press, pp 203–226.
- Brown WL (1983) Genetic diversity and genetic vulnerability an appraisal. *Econ. Bot.* **37**: 4–12.
- Brush SB (2000) Genes in the Field: On-Farm Conservation of Crop Diversity. Canada: IDRC; Rome: IPGRI, pp 3–26.
- Brush SB and E Meng (1998) Farmers' valuation and conservation of crop genetic resources. *GRACE* **45**: 139–150.
- Brush SB, JE Taylor MR Bellon (1992) Technology adoption and biological diversity in Andean potato agriculture. *J. Dev. Econ.* **39**: 365–387.
- Chang TT (1994) The biodiversity crisis in Asian crop production and remedial measures. In: CI Peng and CH Chou (eds.) *Biodiversity and Terrestrial Ecosystems*. Institute of Botany, Academia Sinica, Monograph Series No. 14, Taipei. pp 25–41.
- Christie M., N Hanley, J Warren, K Murphy, R Wright and T Hyde (2006) Valuing the diversity of biodiversity. *Ecol. Econ.* **58**: 304–317.
- Cromwell E, D Cooper and P Mulvany (2001) Agriculture, biodiversity and livelihoods: Issues and entry points for development agencies. In: I Koziell and J Saunders (eds.) *Living off Biodiversity: Exploring Livelihoods and Biodiversity Issues in Natural Resources Management*. London, UK: International Institute for Environment and Development, pp 79–112.
- Dasgupta P (2001) Economic Value of Biodiversity, Overview In: SA Levin (ed.). *Encyclopedia of Biodiversity*. pp 291–304.
- Drucker AG, S Melinda and P Zambrano (2005) Valuation and Sustainable Management of Crop and Livestock Biodiversity: A Review of Applied Economics Literature. Published for the CGIAR System-wide Genetic Resources Programme (SGRP) by the International Food Policy Research Institute (IFPRI), the International Plant Genetic Resources (IPGRI), and the International Livestock Research Institute (ILRI).
- Evenson RE, D Gollin and V Santaniello (1998) *Agricultural Values of Plant Genetic Resources*. Wallingford, UK: FAO and CAB, pp 1–25.
- Esquinas-Alcázar J (2005) Protecting crop genetic diversity for food security: political, ethical and technical challenges. *Nature Reviews/Genetics* **6**: 947–953.
- Gollin D and RE Evenson (1998) Breeding values of rice genetic resources. In RE Evenson, D Gollin and V Santaniello (eds.) *Agricultural Values of Plant Genetic Resources*. Wallingford, UK: FAO and CAB, pp 179–196.
- Gollin D and R Evenson (2003) Valuing animal genetic resources: lessons from plant genetic resources. *Ecol. Econ.* **45**: 353–363.
- Graner A, KJ Dehmer, T Thiel and A Börner (2004) Plant genetic resources: benefits and implications of using molecular markers. In: M Carmen de Vicente (ed.) *The Evolving Role of Genebanks in the Fast-developing Field of Molecular Genetics*. IPGRI, Rome, pp 26–32.
- Goeschl T and T Swanson (2002) Social value of biodiversity for R&D. *Envtl. Resou. Econ.* **22**: 477–504.
- Gupta AK, S Saxena, C Vikas, B Gosh Shrabani, S Riya and N Jain (2002) Cost of conservation of agrobiodiversity. IIMA Working Papers WP2002-05-03, Indian Institute of Management, Ahmedabad, Research and Publication Department.
- Hajjar R, DI Jarvis and B Gemmill-Herren (2007) The utility of crop genetic diversity in maintaining ecosystem services. *Agric. Ecosyst. Envt.* **123**: 261–270.
- Hampicke U (1999) The limits to economic valuation of biodiversity. *Intl. J. Social Econ.* **26**: 158–173.
- Harlan JR (1992) *Crops and Man*, 2ed. American Society of Agronomy, Inc. Madison, WI.
- Havalgi N (2009) Implication for International Trade on Agrobiodiversity Conservation and Food Security in

- Climate Change Scenario. http://www.nccr-climate.unibe.ch/conferences/climate_policies/working_papers/Havaligi.pdf.
- Heina L and F Gatzweiler (2006) The economic value of coffee (*Coffea arabica*) genetic resources. *Ecol. Econ.* **60**: 176–185.
- Hoisington, DM Khairallah, T Reeves, JM Ribaut, B Skovmand, S Taba and M Warburton (1999) Plant genetic resources: What can they contribute toward increased crop productivity? *Proc. Natl. Acad. Sci. USA* **96**: 5937–5943.
- International Technical Conference on Plant Genetic Resources (ITCPGR) (1996) Current expenditures for the conservation and utilisation of plant genetic resources for food and agriculture”, Document: ITCPG/96/Inf/1, FAO, Rome.
- Jacksona LE, U Pascualb and T Hodgkin (2007) Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agric. Ecosys. Envt.* **121**: 196–210.
- Johns T and BR Sthapit (2004) Biocultural diversity in the sustainability of developing country food systems. *Food Nutrition Bull.* **25**: 143–155.
- Jump AS, R Marchan1 and J Peñuelas (2008) Environmental change and the option value of genetic diversity. *Trends in Plant Sci.* **14**(1): 51–58.
- Kassar I and P Lasserre (2004) Species preservation and biodiversity value: a real options approach. *J. Envt. Econ. Manag.* **48**: 857–879.
- Krutilla JV (1967) Conservation reconsidered. *Am. Econ. Rev.* **57**: 777–786.
- Meng EC (1997). Land allocation and in-situ conservation of crop genetic resources: The case of wheat landraces in Turkey, PhD Thesis, University of California.
- Morris ML and PW Heisey (2003) Estimating the benefits of plant breeding research: methodological issues and practical challenges. *Agri. Econ.* **29**: 241–252.
- Munasinghe M and E Lutz (1993) Environment economics and valuation in development decision making. Environment Working Paper No. 51, The World Bank, Washington, DC.
- National Research Council (1972) Genetic Vulnerability of Major Crops. National Academy of Sciences. Washington DC.
- Nunes PALD and JCJM van den Bergh (2001) Economic valuation of biodiversity: sense or nonsense? *Ecological Econ.* **39**: 203–222.
- OECD (2002) Handbook of Biodiversity Valuation. A Guide for Policy Makers. Paris, France: Organization for Economic Cooperation and Development.
- Pearce D and DMoran (1994) The economic value of biodiversity. Earthscan Publications, London.
- Pearce DW, BE Barbier, A Markandya, S Barrett, RK Turner and T Swanson (1991) Blueprint 2, Earthscan, London.
- Polasky S and A Solow (1995). On the value of a collection of species. *J. Envt. Econ. Manag.* **29**: 298–303.
- Rafalski A (2002) Applications of single nucleotide polymorphisms in crop genetics. *Curr. Opinion Pl. Biol.* **5**: 94–100.
- Ramanatha Rao V (2009) *In situ/on-farm conservation of crop biodiversity*. *Indian J. Gen. Pl. Breed.* **69**: 284–293.
- Rao KPC and RE Evenson (1998) Varietal trait values for rice in India. In: RE Evenson, D Gollin and V Santaniello (eds.) *Agricultural Values of Plant Genetic Resources*, Wallingford, UK: FAO and CAB, pp 151–156.
- Rausser GC and AA Small (2011) Valuing research leads: Bioprospecting and the conservation of genetic resources. *J. Political Economy* **108**(1): 173–206.
- Rubenstein KD, P Heisey, R Shoemaker, J Sullivan and G Frisvold (2005) Crop Genetic Resources—An Economic Appraisal. A Report from the Economic Research Service, USDA, 39p.
- Sajse PE (2003) Agrobiodiversity and sustainable development: what, why and for whom? In: Xu Jiancho and Stephen Mikesell (eds). Proceedings of the III Symposium on MMSEA 25-28 August 2002, Lijang. PR China, Kunming.
- Simpson DR, RA Sedjo and JW Reid (1996) Valuing biodiversity for use in pharmaceutical research. *J. Political Economy* **104**: 163–185.
- Simpson RD and RA Sedjo (1998) The value of genetic resources for use in agricultural improvement. In: RE Evenson, D Gollin and V Santaniello (eds.) *Agricultural Values of Plant Genetic Resources* Wallingford, UK: FAO and CAB, pp 55–66.
- Smale M (2006) Valuing Crop Biodiversity On-Farm Genetic Resources and Economic Change. UK: CABI.
- Smale M, M Bellon, D Jarvis and BR Sthapit (2004) Economic concepts for designing policies to conserve crop genetic resources on-farms. *GRACE* **51**: 121–135.
- Smale M and A King (2005) What is Diversity Worth to Farmers? Research at Glance series – Briefs 13-18. I
- Stolton S, N Maxted, B Ford-Lloyd, B, S Kell and N Dudley (2006) Food Stores: Using protected areas to secure crop diversity. WWF and University of Birmingham, Gland, Switzerland and Birmingham, UK.
- Sthapit BR, R Rana, P Eyzaguirre and D Jarvis (2008) The value of plant genetic diversity to resource-poor farmers in Nepal and Vietnam. *Intl. J. Agri. Sust.* **6**: 148–166.
- Swanson T (1996) Global values of biological diversity. *PGR Newslet.* **105**: 1–7.
- Virchow D (1999) Conservation of plant genetic resources for food and agriculture: main actors and the costs to bear. *Intl. J. Social Econ.* **26**: 1144–1161.
- von Braun J (1994) Genes and biodiversity: new scarcities and rights challenge agricultural economics research. *Quarterly J. Intl. Agri.* **4**: 345–348.
- Wale E (2011) Costing on-farm conservation of crop diversity: The case of sorghum and wheat in Ethiopia and implications for policy. *Afr. J. Agri. Res.* **6**: 401–406.
- Wilson EO (1988) Biodiversity. Washington, DC: National Academy Press.
- Weitzman ML (1998) The Noah’s ark problem. *Econometrica* **66**: 1279–1298.
- Zhang W, TH Rickettsb, C Kremenc, K Carneyd and SM Swintona (2007) Ecosystem services and dis-services to agriculture. *Ecol. Econ.* **64**: 253–260.
- Zohrabian A, G Traxler, S Caudill and M Smale (2003) The marginal value of an accession. Biotechnology and Genetic Resource Policies – What is a Genebank Worth? Brief 9. International Food Policy Research Institute, Washington.

Reproductive Ecology and Conservation of Plant Genetic Resources of the Wild

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Habitat degradation and overexploitation have threatened the sustainability of our plant genetic resources (PGR) growing in the wild. In the absence of any effective conservation efforts, many of them would become extinct in the coming years. Sustainability of any species depends on its successful reproduction and recruitment of new individuals to the population. The stability of the species is threatened when it experiences major constraint(s) in one or several reproductive events. Thus, for successful conservation and management of any vulnerable species, knowledge on reproductive ecology is essential. In the absence of such data any conservation efforts would remain arbitrary and largely ineffective. Amongst the reproductive events, pollination, seed dispersal and seedling establishment are the most critical aspects and a failure in any of them makes the species vulnerable. Identification of reproductive constraints, if any and their effective mitigation are necessary to conserve or recover vulnerable species. Unfortunately, there is hardly any information on reproductive ecology of our wild PGR. It is important to generate data on reproductive ecology to make our conservation efforts more effective and successful. Knowledge on reproductive ecology is also important to monitor the success or failure of any conservation programme.

Key Words: Habitat degradation, Overexploitation, Plant genetic resources, Pollination, Reproductive constraints, Seed dispersal, Seedling recruitment, Vulnerable species

Introduction

Biodiversity includes all heritable variations at all levels of organization (Wilson, 1997). India is bestowed with a vast biodiversity (Bawa, 2010; Uma Shaanker *et al.*, 2010). Although we cover only 2% of the land area, our biodiversity is about 7.5%. India shares four of the 34 biodiversity hotspots with the neighboring countries: i) Western Ghats and Sri Lanka, ii) Himalayas, iii) Indo-Burma (Northeast India south of Brahmaputra, Myanmar, Thailand, Laos, Vietnam and Southern part of China) and iv) Sundaland (Andaman and Nicobar Islands, Malaysia and Indonesia). About one third of our species of higher plants are endemic.

Plant genetic resources (PGR) generally refer to all those plant species being used and also those that have potential use for human needs. Apart from cultivated agri-horticultural species, land races and their wild relatives, PGR includes forest species used for wood as well as those wild species which are the sources of non-wood forest products such as gums, resins, medicines, dyes, biopesticides, bamboos and rattans (Biswas, 2004; Gautam, 2004). Indian subcontinent is the centre of diversification and domestication of a range of economically useful wild plant species. They comprise 3000 species of edible value, 4000 species of medicinal value, 500 fibre-yielding species, 400 fodder species, 300 gum, resin and dye yielding species and 100 species of aromatic and essential oil-yielding

species (Pandey and Arora, 2004). These wild PGR are the repository of novel genes for nutrition, resistance to biotic and abiotic stresses, and a range of medicinal and industrial uses. A large number of economically important naturalized and domesticated species introduced from other countries also form an important component of our PGR (Gautam, 2004). Plant genetic resources are fundamental to human welfare and their effective management is crucial for conservation of genetic variability needed for further improvement in the productivity and quality of crops and other plant-based products needed to satisfy human needs in the coming decades (Dhillon *et al.*, 2004). Thus, a diverse array of plant species needs to be conserved and managed for the present and future use of mankind. The National Bureau of Plant Genetic Resources (NBPGR) is the nodal agency for the management of PGR in India; it has made remarkable progress in *ex situ* conservation of both cultivated and wild species of agri-horticultural importance (Singh *et al.*, 2004).

A large number of species which are being harvested from the wild and also those which have the potential to provide future human needs have to be conserved and effectively managed *in situ* (within their natural habitats) (Dhillon *et al.*, 2004; Abraham *et al.*, 2004; Biswas, 2004). Habitat degradation and/or overexploitation have enormously increased vulnerability of our PGR of the wild in recent decades (Murali *et al.*, 1996; Bekker and

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Berendse, 1999; Pares *et al.*, 2003; Rodriguez-Cabal *et al.*, 2007; Peres, 2010; Bennett and Saunders, 2010; Laurance, 2010; Tandon *et al.*, 2010; Sodhi and Ehrlich, 2010). This is particularly true for tropical forests which harbor most of the world's biological diversity and genetic resources (Herrera and Pellmyr, 2002; Roubik *et al.*, 2005, Dennis *et al.*, 2007; Ghauzoli and Sheil, 2010). Some of the causative factors for habitat degradation are: encroachment of forests for agri-horticulture, logging, urbanization and industrialization. As the livelihood of a large number of people in developing countries depends on forests; a range of non-wood forest species are collected extensively from the forests for their livelihood. Increasing population pressure combined with rising standards of living over the years have resulted in overexploitation of wild PGR in our forests and a large number of species have been pushed into vulnerable category (The IUCN Red List of Threatened Species 2008, series of volumes on Red Data Book of Indian Plants since 1987 by the Botanical Survey of India, see also Ravikumar and Ved, 2000; Rao *et al.*, 2003; Pandravada *et al.*, 2004).

A general principal for effective conservation and management of any species is that more we know about the biology of the species, better is the rate of success. A major area of biology which has direct relevance to the conservation of vulnerable plant species is reproductive ecology. This article highlights some aspects of reproductive ecology which are relevant for effective conservation and management of vulnerable, endemic and endangered wild PGR.

Causes for Species Vulnerability

The stability of any wild species essentially depends on its effective reproduction and recruitment of new individuals to sustain populations. Both habitat degradation and overexploitation eventually affect the ability of the species to reproduce and/or to recruit new individuals (Bond, 1994; Robertson *et al.*, 1999; Wilcock and Neiland, 2002; Kwack and Bekker, 2006). Such reproductive constraints gradually result in deaths exceeding births in the populations. When this continues, there is a gradual decline in population size. Continuous reduction in population size leads to eventual extinction of the population/species. In some species, reproductive failure often leads to adaptation to inbreeding/vegetative propagation as a means of reproductive assurance. Although this may ensure short-time survival of the species, it eventually leads to:

- loss of genetic variability

- inbreeding depression
- loss of evolutionary potential to cope with changed habitat and
- eventual extinction of the population.

Reproductive Ecology – Basic Aspects

Reproductive ecology covers a broad spectrum of events involved in reproduction of an organism (Shivanna, 2003) and their interaction with biotic and abiotic components of the environment. Effective conservation measures for vulnerable species depend on our understanding of the nature of threats to the sustainability of the species and their effective remediation. As reproduction and recruitment are the major threats in the final analysis of species stability, generation of baseline data on reproductive ecology is a pre-requisite for effective management of our genetic resources.

The following are the major reproductive events in flowering plants:

- Phenology
- Floral morphology and sexuality
- Pollen and pistil biology
- Pollination ecology
- Pollen-pistil interaction and the breeding system
- Seed biology (seed production, dispersal and viability)
- Seedling recruitment

Although all these aspects are important for a comprehensive understanding of the reproductive ecology of the species, some of the most important areas which are relevant for conservation of PGR are: pollination ecology, breeding system, seed biology and seedling recruitment. The following pages give a brief account of these areas and their relevance for conservation of vulnerable species.

Pollination Ecology

Pollination is the transfer of pollen from the anther to the stigma. Pollination ecology is the study of pollen transfer from the anther to the stigma through an understanding of interactions between plants and pollinators in relation to the prevailing habitat (Jones and Little, 1983; Herrero and Pellmyr, 2002; Roubik *et al.*, 2005). Except in parthenocarpic and apomictic species which are pseudogamous (endosperm development with out fertilization), pollination is an essential requirement for fruit and seed set. Only a small proportion of wild species depend on wind or water for pollination; a vast majority of

them depend on animals for pollination. Flowers exhibit an amazing variety of sizes, shapes, colours, arrangements, scents, and sexual systems to attract various animals to the flowers to achieve pollination. Non-mobility is one of the major limitations of plants to move their genes across space; diversification of flowers seems to be necessary to attract various animals to move their genes. Amongst animals, insects are the major pollinators; of these, bees, beetles, moths, butterflies and flies are the most common pollinators. Pollination in animal-pollinated species is largely mutualistic between plants and animals that result in reciprocal benefits to both the partners. It is a form of 'biological barter' in which plants exchange their resources such as pollen and nectar with the pollination services of animals. This mutualism is highly complex, dynamic and varies greatly in time and space. It has become highly vulnerable in recent years as a result of habitat loss.

An understanding of pollination ecology of a species needs familiarity with the phenology (timing of various reproductive events, their duration and intensity) of the species, structural features of flowers and sexuality. Depending on the origin of pollen, pollination is categorized into the following three types:

Autogamy – transfer of pollen from the anther to the stigma of the same flower. **Geitonogamy** – transfer of pollen from the anther to the stigma of another flower of the same plant or of another plant of the same clone (ramet).

Geitonogamy – transfer of pollen from the anther to the stigma of a different plant (not of clonal origin, genet).

The first two represent self-pollination leading to inbreeding and the third represents cross-pollination. Identification of pollinator(s), their efficiency and pollination limitation, if any, under natural habitats are important components of pollination ecology which determine the extent of success of seed set.

Pollination Limitation

Pollination is a major constraint for optimal seed set in many vulnerable species. Pollination limitation (reduction in seed production by inadequate pollination) is wide spread and also of high magnitude (Burd, 1994; Larson and Barrett, 2000; Wilcock and Neiland, 2002; Knight *et al.*, 2005). When compared to temperate species, tropical rain forests are characterized by longer distances between conspecific plants, higher incidence of self-incompatibility, dependence of a fewer pollinators and lower incidence of vegetative propagation (Wilcock and Neiland, 2002).

These features make them more vulnerable to pollination failure when compared to temperate species.

Pollination limitation not only reduces seed set, but also the quality of offspring by reducing pollen competition among gametes (Corlett, 2007). Pollination limitation may be the result of several ecological disturbances such as habitat fragmentation, presence of co-flowering plant species and introduction of alien species (Wilcock and Neiland, 2002; Knight *et al.*, 2005; Kolb, 2005; Aguilar *et al.*, 2006). Pollination limitation is more prevalent in specialized plant species which depend on just one or a few animal species for pollination services. Vulnerable species generally occur in specialized or fragmented habitats in sparse populations. These features amplify pollination limitation; as the distance between plants increases, the resources available for pollinators decreases, leading to a decline of animals involved in pollination (Wilcock and Neiland, 2002). When the plant species happen to have special sexual features such as dioecy and self-incompatibility, which make them depend entirely on cross-pollination for seed set, pollination failure would further intensify. Detailed information on pollination limitation is necessary to come up with an effective strategy to overcome the limitation (Spira, 2001). Significant reduction in recruitment as a result of pollination failure compromises evolutionary adaptability and thus their eventual survival prospects. Pollination can be a limitation even in wind-pollinated species when population density of plant species becomes low (Wilcock and Neiland, 2002).

Pollination Ecology and Release of Genetically Modified Plants

One of the major concerns for the release of genetically modified plants (GMP) has been the possibility of pollen flow from GMP to wild relatives and their introgression into wild populations (Armstrong *et al.*, 2005). Regulatory authorities need extensive data on the biology of GMP (Craig *et al.*, 2008). Of these, pollination ecology of the GMP and their wild relatives is an important component (Marvier, 2008) to rule out the possibility of escape of engineered gene(s) to the wild before permitting GMPs for field trials and their eventual release for cultivation. Every new transgenic organism requires a great deal of research in assessing the following four basic aspects (Armstrong *et al.*, Craig *et al.*, 2008; 2005; Marvier, 2008):

- i) Potential of hybridization of transgenics with wild relatives

- ii) Rate of hybridization
- iii) Opportunities for backcrossing and introgression of transgenes into the wild relatives
- iv) Ecological impacts of transgenes in wild populations.

Thus detailed knowledge on various aspects of pollination ecology and its consequences is important before transgenics are released. Assessment of these aspects of GMP involves research into the following aspects of reproductive biology:

- spatial and temporal distribution of other cultivars and wild relatives in the area where the transgenics are grown
- flowering phenology of transgenics and their wild relatives
- temporal details of pollen viability of transgenic plants
- temporal details of stigma receptivity of the transgenics and related species growing in the area
- details of pollination ecology and pollen flow of transgenic plants through biotic and abiotic means
- compatibility relationships between the transgenics and other cultivars/wild species
- details of hybrid seed development, hybrid seedling establishment and potential of development of backcross seeds with wild populations.

Pollination Ecology and Crop Introduction

Knowledge on pollination ecology is important in crop domestication and introduction. Crop introduction to other areas/countries has been one of the approaches for exploitation of genetic resources. When crops are introduced into areas where natural pollinators are absent, introduction of pollinators is one of the effective options for assured pollination. Oil palm (*Elaeis guineensis*), a native of Africa and Central South America, is pollinated by wind as well as many insects particularly weevils. Oil palm was introduced to Malaysia and Indonesia where its pollinators were absent. During the initial years, the yields were low because of inadequate pollination. Introduction of weevil, *Elaeidobius kamerunicus*, the pollinator of oil palm, from Cameroon to Malaysia during 1960s has markedly increased the yield (Syed *et al.*, 1982). Now oil palm is one of the most important crops in these countries.

In India also, there are many crops which can be introduced to other areas and exploited. For example, *Indian J. Plant Genet. Resour.* 25(1): 75–84 (2012)

Amomum subulatum (large cardamom) is an important cash crop in the North-East particularly in Sikkim, Bhutan, Nepal and Darjeeling areas of West Bengal. Bumblebee is the principal pollinator. Attempts are being made by the Spice Board to introduce this crop to cardamom growing belt of Kerala. Although the plant grows well and flowers profusely, it does not set fruits. Even in the plains of Karnataka (elevation ca 600 msl) *A. subulatum* grows well and flowers but does not set fruits (personal observations). Lack of fruit set in Kerala and Karnataka seems to be due to the absence of the pollinator. It is therefore necessary to study the details of pollination ecology to identify the problems, if any, and develop technology to mitigate the problem before the crop is introduced.

Breeding System

Breeding system is the mode of transmission of genes from one generation to the next through sexual reproduction. It largely reflects the extent of selfing/crossing (Richards, 1986). Genetic variation is the basis of evolution; it enables the species to cope with changed habitat and its establishment when migrated to new areas. Genetic variation is assessed on the basis of the extent of heterozygosity in the population. This is dependent on a number of reproductive traits particularly the sexuality of the species (bisexual/unisexual flowers, monoecious/dioecious plants) and the breeding system (extent of selfing/crossing).

Flowering plants have evolved the following devices to encourage outbreeding and discourage inbreeding:

Dichogamy: Temporal separation of pollen release and stigma receptivity.

Protandry: Anthers release pollen before stigma becomes receptive.

Protogyny: Stigma is receptive before pollen release.

Herkogamy: Spatial separation of the anthers and the stigma.

Self-incompatibility: Self-pollinations do not result in fertilization because of inhibition of pollen germination or pollen tube growth in the pistil.

Dicliny: Flowers are unisexual.

Monoecious: Male and female flowers are borne on the same plant.

Dioecious: Male and female flowers are borne on different plants.

Of these, self-incompatibility and dioecy prevent

inbreeding completely. In a majority of other species it is a combination of selfing and crossing, although the extent of each varies greatly between and within the species. An understanding of the breeding system of the species is important not only for conservation but also for domestication and introduction of the species to newer areas.

The breeding system of the species (self-compatible/self-incompatible) has a marked effect on its vulnerability to pollination limitation in fragmented, low density populations (Aizen and Feinsinger, 1984; Kery *et al.*, 2000, Aizen *et al.*, 2002; Lennartsson, 2002). In India, recent studies of Nayak and Devidar (2010) on ten species in the Pondicherry region of southern India have clearly shown a higher level of pollination limitation leading to lower fruit set in self-incompatible species when compared to self-compatible species. This is because self-compatible species are less dependent on pollinators. Further, the sapling and adult densities in self-compatible species were significantly higher than those in self-incompatible species in fragmented habitats indicating that lower fruit set as a result of pollination limitation would lead to lower rate of recruitment. This should be true for dioecious species also. For an effective management of species in fragmented populations we must be aware of the breeding system of the species.

Seed Biology

Seeds provide the species a means not only for increasing genetic diversity (through cross-pollination) but also for independent dispersal which enables the species to establish in new environments (Turner, 2001; Fenner and Thompson, 2005; Dennis *et al.*, 2007). Seed production, therefore, is an essential reproductive event for the long-term stability and spread of the species. Seed biology is, therefore, yet another important aspect of reproductive ecology which has relevance to conservation biology (Khurana and Singh, 2001; Corlett, 2007). Some of the important aspects of seed biology are: seed production and their dispersal, viability of seeds in the soil seed bank and seedling recruitment (Hall and Lulow, 1997; Bustamante and Simonetti, 2000).

Seed Production and Dispersal

Only a small proportion of flowers develop into mature fruits particularly in tree species. There is great variation between species in the extent of fruit and seed set. This seems to be an adaptation to provision a reserve of flowers that can be used under optimal conditions but

discarded with minimum cost under suboptimal conditions. Depending on the available resources, the plant can also terminate developing fruits before investing for their full development. The failure of flowers developing into fruits is due to a combination of factors such as pollination limitation, genetic defects, resource limitation, and predation of flowers and young fruits. Both seed limitation (arrival of very few seeds to potential regeneration sites suitable for establishment) and establishment limitation (lack of availability of suitable microsites for seedling establishment) (Nathan and Muller-Landau, 2000; Dalling *et al.*, 2002; Svenning and Wright, 2005; Norghauer and Newery, 2010) play a critical role in sustainability of populations.

Dispersal of seeds is one of the most critical aspects of reproductive ecology; it is an important step for the recruitment and spatial distribution of plant populations. Seed dispersal provides many advantages to plants: escape from specialist predators and pathogens prevalent under the parent, prevention of competition between parent and offsprings and between siblings, and location of seeds in safe sites where they can successfully germinate and establish seedlings (Fenner and Thompson, 2005; Ghazoul and Sheil, 2010). Thus, seed dispersal enables plants to escape from sources of mortality that are concentrated around parents, and increases the probability of colonizing suitable habitats (Dennis *et al.*, 2007).

In general, a majority of seeds fall below the parent plant. A small proportion of them are dispersed away from the plant. Fruits and seeds have adopted a range of devices for effective dispersal. Animals are the major seed dispersers. Because of anthropogenic disturbances as a result of direct persecution (hunting or trapping of species and collection of live animals for pet trade) and land-use changes, many seed dispersers have become endangered in tropical forests. Some of them have almost been eliminated from many of their natural ranges. This is particularly true for large birds, large fruit bats, primates, civets and terrestrial frugivores which are the major dispersers of large-fruited plant species (Dennis *et al.*, 2007).

Although extensive studies have been carried out on seed dispersal in the Neotropics and tropics of Africa, Australia and the Far East (Dennis *et al.*, 2007; Corlett 2007), only a beginning has been made in tropical forests in India. The proportion of animal dispersed species range between 68 to 78% (Datta and Rawat, 2008; Tadwalkar *et al.*, 2012). Birds followed by mammals are the major animal dispersers (Ganesh and Devidar, 2001). The

density of animal-dispersed species tends to decrease in disturbed habitats as a result of dispersal limitation since animal dispersers are more severely affected by forest fragmentation. However, the density of species which are not dependent on animals for dispersal tends to increase in such habitats (Tadwalkar *et al.*, 2012).

Viability of Seeds in Soil Seed Bank

The period for which seeds remain viable varies greatly, from a few weeks to several years. Although we have extensive data on seed viability and storage of cultivated species, there is hardly any information on PGR growing in the wild. After dispersal from the parent plant, seeds fall on the surface of the soil. They may germinate soon after dispersal or remain dormant for varying periods before germination. Some of them get covered with leaf litter and eventually get buried in surface layers of the soil. The seeds present on or in the soil form the soil seed bank. For the sustainability of the PGR in the wild, viability of soil seed bank is more important than their viability under laboratory conditions. Considerable information is available on soil seed banks of temperate species (Thompson *et al.*, 1997). Occasionally, soil seed bank may contain seeds of plants which are no more growing in the region. An interesting example of longevity of soil seed bank is *Nelumbo nucifera*. Several seeds recovered from dried bed of an earlier lake in North-East China germinated and radioactive carbon dating of the oldest germinated seed showed that it is 1288 ± 250 years old (Shen-Miller *et al.*, 1995).

Seed persistence in the soil seed bank is a critical trait for species with very low fecundity and those which require more exact conditions for germination and seedling establishing (Gallery *et al.*, 2007). Unfortunately, there is very little information on seed banks of tropical region. A majority of tree species in Western Ghats show fruiting during pre-monsoon drier months or monsoon period. Of the 185 species studied for their fruiting behavior in Northern Western Ghats (Tadwalkar *et al.*, 2012), 64% of the species showed fruiting in the pre-monsoon period (February-May). The seeds of those species which fruit pre-monsoon or during the monsoon months are exposed to monsoon wet season which is suitable for seed germination and seedling establishment before the ensuing drier months. The fruiting synchrony with the wet monsoon months appears to be an adaptation for successful seedling recruitment. Seeds of many species in Western Ghats (for example, *Dysoxylum malabaricum*, *Vateria indica* and several species of *Syzygium*, our unpublished

observations), which are shed during the monsoon period germinate within a few days after dispersal and their seedlings are established before the onset of post-monsoon drier months. Seeds of these species are refractory and loose viability within weeks after shedding. Such species do not contribute to the soil seed bank. If they miss the monsoon season, there is zero recruitment. Many of these species also show flowering in alternate years making seedling recruitment more critical. It is, therefore, important to know seed viability in the soil seed bank for effective management or restoration of the species.

Seedling Establishment

Seedling establishment is the final hurdle in a series of reproductive events culminating in the recruitment of new individual. A large proportion of seeds may not germinate as they may not land on suitable microsites. Even when they germinate, seedling mortality is high in wild species. Competition from other seedlings and from surrounding vegetation, herbivory, and infestation by insects, fungi and other microbes are the major causes for seedling mortality. Abiotic hazards for seedling survival include physical damage due to fall of branches, fire and lack of moisture. Detailed information on seed dispersal, seed viability in the soil and constraints for seedling recruitment is necessary for developing effective strategy to conserve and manage the species (Corlett, 2007).

Several studies have indicated that recruitment is the major limitation for population sustainability in several non-wood forest resources of Madhya Pradesh, India. *Sterculia urens*, the source of gum karaya (Indian tragacanth), is an important non-wood forest product of India. It is a source of income to the tribals and the rural poor living around the forests. Secretion of the gum requires wounding of the bark. The tappers use crude method of tapping causing serious injury to the plants. The trees eventually die after repeated and unscientific tapping for several years. Owing to steady increase in the export demand for gum karaya, *S. urens* is over-exploited. Death of old trees and lack of seedling recruitment in the natural habitats have resulted in a large-scale reduction in the populations of *S. urens*. Detailed studies (Sunnichan *et al.*, 2004) on reproductive ecology have shown that there are no major constraints in pollination and seed production in this species.

However, recruitment seems to be the major constraint (Sunnichan, 1998; Tandon *et al.*, 2010) for sustainability of the populations of *S. urens*. A large number of vigorously

growing seedlings appear under the canopy of parent trees during the monsoon. The seedlings develop underground tubers and the shoot dries up during October–November. A new shoot comes up from the tuber in the next monsoon season and grows for 2–3 months before drying up again. This cycle of shoot death and sprouting of new shoot is repeated for another year before a permanent shoot comes up. The tuber enlarges during each year of shoot growth and sustains early growth of the permanent shoot. However, the tubers are dug up from the forest soil by the surrounding villagers and are cooked and eaten as food or pounded and used to relieve constipation and to facilitate childbirth. Wild herbivores also dig up some tubers and consume them. Harsh drought conditions prevailing during summer may also result in drying up of some of the tubers. Eventually no new adult is added to the population. In another overexploited gum-resin yielding species, *Boswellia serrata* (Sunnichan *et al.*, 2005; Tandon *et al.*, 2010), the source of ‘salai guggul’, also seed production is satisfactory but seedling recruitment is the major constraint for sustainability of the populations.

Apart from habitat degradation and overexploitation, global warming is an additional factor which is going to play a major role in sustainability of PGR in the future. Limited data available has already shown that global warming affects flowering phenology and induces species migration (Fitter and Fitter, 2002; Jump and Penuelas, 2005; Lovejoy and Hannah 2005; Miller-Rushing and Primack, 2008; Thuiller *et al.*, 2008; Lovejoy, 2010). Such changes are likely to bring about decoupling of plant-animal mutualisms which are likely to have serious consequences on the sustainability of the species. Understanding the details of spatial and temporal variation in plant-animal mutualisms is necessary to predict the long term effects of global warming.

Conservation Approaches

Conservation involves a) preservation (of what exists) and b) recovery (of populations of endangered species to a sustainable level). In recent years, conservation efforts are being increasingly directed towards habitats and ecosystems, rather than individual species. Establishing protected areas/reserves has been the main approach to conserve and recover the habitat and the populations. Although a large number of protected areas have been established in India, there is hardly any management to check whether it is effective at conserving biodiversity particularly of vulnerable species.

If overexploitation is the only cause for vulnerability of the species, conservation approach is straightforward and involves controlling the harvest from the vulnerable species to a sustainable level. But this approach is difficult to implement and monitor particularly in developing countries because of population pressure. Landscape protection may not be effective in those species in which reproduction or recruitment is seriously compromised due to other reasons. Many of these approaches are species-specific and situation-specific. Effective mitigation of reproductive constraints depends on the availability of detailed information on reproductive ecology of the species. When vulnerability is because of the inbreeding depression, introduction of cross-compatible genotypes may be an effective approach to increase heterozygosity of the population. Also, establishment of new populations at suitable habitats using several cross-compatible genotypes would also be effective in mitigating the constraints (Wilcock and Neiland, 2002). In some species, it may require reintroduction of missing pollinators or dispersal agents, or the reinforcement of depleted populations or reintroduction of populations in suitable habitats. Manual seed dispersal and planting of nursery raised seedlings is an effective approach for reinforcement or reintroduction of populations. The success rate of artificial seed dispersal is relatively low, as a result of seed predation and other post-dispersal processes. Planting of nursery-raised seedlings avoids most of these problems (Corlett, 2007). Another approach to conserve PGR being harvested in the wild such as medicinal plants and sources of other non-wood forest products is to bring them under cultivation for sustainable harvest so that the pressure on the wild germplasm is reduced.

Although there is considerable information on the details of reproductive events on species of Neotropics and the tropics of Africa, Australia and the Far East (Bawa and Hadley, 1990; Turner, 2001; Herrera and Pellmyr, 2002; Roubik *et al.* 2005, Dennis *et al.*, 2007), there is hardly any information on reproductive ecology on species of the Indian tropical forests. Therefore, the species-specific conservation approaches mentioned above would largely remain theoretical for India's conservation programme because of our ignorance on reproductive ecology and reproductive constraints, if any, of our vulnerable species. Generation of data on reproductive ecology particularly plant-animal interactions is, therefore, urgently needed for effective formulation and implementation of our conservation programmes. In the absence of such data our

conservation efforts would remain arbitrary and largely ineffective.

Concluding Remarks

A perusal of recent books and reviews on conservation biology indicates that scientific conservation attempts made and also some of the successes reported so far are animal-centric (Hayward, 2009; Sodhi *et al.*, 2011). There are hardly any success stories on conservation of plant species. It is apparent that several reproductive constraints, particularly pollination limitation, seed limitation and establishment limitation play a critical role in sustainability of the wild populations of PGR. It is important to understand whether any of these limitations are prevalent in the vulnerable species, and if so, the processes and consequences of such limitations for effective conservation and management. Conservation success depends on the quality and quantity of research component on the focal species. Lack of adequate information on reproductive ecology in general and plant-animal interactions in particular, has been the major limitation to formulate and implement effective conservation programmes. Studies on reproductive ecology are important not only for understanding the cause(s) for species vulnerability and its conservation but also to monitor the success or failure of any conservation programme. Such information is also needed in assessment of the risks the species is exposed to and their ability for long-time survival without intervention. Conservation efforts need to be proactive and should be initiated much before the species becomes critically endangered for a reasonable success.

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References

- Abraham Z, M Latha, S Biju and SL Narayanan (2004) Changing pattern of plant biodiversity in Southern Western Ghats. In: BS Dhillon, RK Tyagi, A Lal and S Saxena (eds) *Plant Genetic Resource Management*, Narosa Publishing House, New Delhi, pp113-135.
- Aguilar R, L Ashworth, L Galetto and MA Aizen (2006) Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. *Ecol. Lett.* **9**: 968-980.
- Aizen MA and P Feinsinger (1994) Forest fragmentation, pollination, and plant reproduction in a Chaco dry forest, Argentina. *Ecology* **75**: 330-351.
- Aizen MA, L Ashworth and L Galetto (2002) Reproductive success in fragmented habitats: do compatibility systems and pollination specialization matter? *J. Veg. Sci.* **13**: 885-892.
- Armstrong TT, RG Fitzjohn, LE Newstrom *et al.* (2005) Transgenic *Indian J. Plant Genet. Resour.* **25**(1): 75-84 (2012)
- escape. What potential for crop-wild hybridization? *Mol. Ecol.* **14**: 2111-2132.
- Bawa KS (2010) Cataloguing life in India: the taxonomic imperative. *Curr. Sci.* **98**: 151-154.
- Bawa KS and M Hadley (eds) (1990) *Reproductive Ecology of Tropical Forest Plants*. UNESCO, Paris and Parthenon Publishing Group, Carnforth.
- Bakker JP and F Berendse (1999) Constraints in the restoration of ecological diversity in grasslands and heathland communities. *Trends Ecol. Evol.* **14**: 63-68
- Bennett AF and DA Saunders (2010) Habitat fragmentation and landscape change. In: NS Sodhi and PR Ehrlich (eds) *Conservation Biology for All*. Oxford Univ Press, New York, pp 88-106.
- Biswas S (2004) *In situ* conservation: A multidisciplinary participatory task. In: BS Dhillon, RK Tyagi, A Lal and S Saxena (eds) *Plant Genetic Resource Management*, Narosa Publishing House, New Delhi, pp 205-219.
- Bond WJ (1994) Do mutualisms matter? Assessing the impact of pollinator and disperser disruption on plant extinction. *Philos. Trans. R. Soc. London, Biol. Sci.* **344**: 83-90.
- Burd M (1994) Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. *Bot. Rev.* **60**: 83-139.
- Bustamante RO and J Simonetti (2000) Seed predation and seedling recruitment in plants: the effect of the distance between parents. *Plant Ecol.* **147**: 173-183.
- Corlett RT (2007) Pollination or seed dispersal: which should we worry about most? In: AJ Dennis, EW Schupp, RJ Green and DA Wescott (eds) *Seed Dispersal: Theory and its Application in a Changing World*. CAB International, Wallingford, UK, pp 523-544.
- Craig W, M Tepfer, G Degrassi and D Ripandelli (2008) An overview of general features of risk assessments of genetically modified crops. *Euphytica* **164**: 853-880.
- Dalling JW, HC Muller-Landau, SJ Wright and SP Huell (2002) Role of dispersal in the recruitment limitation of Neotropical pioneer species. *J. Ecol.* **90**: 714-727.
- Datta A and GS Rawat (2008) Dispersal modes and spatial patterns of tree species in a tropical forest in Arunachal Pradesh, northeast India. *Trop. Cons. Sci.* **1**: 163-185.
- Dennis AJ, EW Schupp, RJ Green and DA Wescott (eds) (2007) *Seed Dispersal: Theory and its Application in a Changing World*. CAB International, Wallingford, UK.
- Dhillon BS, RK Tyagi, A Lal and S Saxena (eds) (2004) *Plant Genetic Resource Management*. Narosa Publishing House, New Delhi.
- Fenner M and K. Thompson (2005) *The Ecology of Seeds*. Cambridge Univ. Press, Cambridge.
- Fitter AH and RS Fitter (2002) Rapid changes in flowering time in British plants. *Science* **296**: 1689-1691.
- Gallery RE, JW Dalling, T Wolfe and AE Arnold (2007) The influence of seed source, habitat and fungi on *Cecropia* seed survival in two neotropical forests. In: AJ Dennis, EW Schupp, RJ Green and DA Wescott (eds) *Seed Dispersal: Theory and*

- its Application in a Changing World. CAB International, Wallingford, UK, pp 479-498.
- Ganesh T and P Davidar (2001) Dispersal modes of tree species in the wet forests of southern Western Ghats. *Curr. Sci.* **80**: 394-399.
- Gautam PL (2004) Trends in plant genetic resource management. In: BS Dhillon, RK Tyagi, A Lal and S Saxena (eds) *Plant Genetic Resource Management*, Narosa Publishing House, New Delhi. pp 18-30.
- Ghazoul J and D Sheil (2010) *Tropical Rain Forest Ecology, Diversity, and Conservation*. Oxford Univ. Press, Oxford, New York
- Hall KD and ME Lulow (1997) Effects of species, habitat, and distance from edge of post-dispersal seed predation in a tropical rain forest. *Biotropica* **29**: 459-468.
- Herrera CM and O Pellmyr (eds) (2002) *Plant-animal Interactions: An Evolutionary Approach*. Blackwell Publ. Co., MA, USA
- Hayward MW (2009) Conservation management for the past, present and future. *Biodiv. Cons.* **18**: 765-775.
- Jones CU and RJ Little (eds) (1983) *Handbook of Experimental Pollination Biology*. Van Nostrand Reinhold Inc., New York.
- Jump A and J Penuelas (2005) Running to stand still: adaptation and the response of plants to rapid climate change. *Ecol. Lett.* **8**: 1010-20
- Kery K, D Matthies and H-H Spillmann (2000) Reduced fecundity and offspring performance in small populations of the declining grassland plants *Primula veris* and *Gentiana lutea*. *J. Ecol.* **88**: 17-30.
- Khurana E and JS Singh (2001) Ecology of tree seed and seedlings: Implications for tropical forest conservation and restoration. *Curr. Sci.* **80**: 748-757.
- Knight TM, JA Steets, JC Vamosi, SJ Mazer *et al.* (2005) Pollen limitation of plant reproduction: pattern and process. *Ann. Rev. Ecol. Evol. Syst.* **36**: 467-497.
- Kolb A (2005) Reduced reproductive success and offspring survival in fragmented populations of the forest herb *Phyteuma spicatum*. *J. Ecol.* **93**: 1226-1237.
- Kwak MM and RM Bekker (2006) Ecology of plant reproduction: Extinction risks and restoration perspectives of rare plant species. In: NM Waser and J Ollerton (eds) *Plant-Pollinator Interactions: From Specialization to Generalization*, Univ. Chicago Press, Chicago, pp 362-386.
- Larson BMH and SCH Barrett (2000) A comparative analysis of pollen limitation in flowering plants. *Biol. J. Linn. Soc.* **69**: 503-520.
- Laurance WF (2010) Habitat destruction: death by a thousand cuts. In: NS Sodhi and PR Ehrlich (eds) *Conservation Biology for All*. Oxford Univ. Press, New York, pp 73-87.
- Lennartsson T (2002) Extinction thresholds and disrupted plant-pollinator interactions in fragmented plant populations. *Ecology* **83**: 3060-3072.
- Lovejoy TE and L Hannah (eds) (2005). *Climate change and Biodiversity*. Yale Univ. Press, New Haven.
- Lovejoy TE (2010) Climate change. In: NS Sodhi and PR Ehrlich (eds), *Conservation Biology for All*. Oxford Univ. Press, New York, pp 153-162.
- Marvier M (2008) Implication of transgenic escape for conservation. In: SP Carroll and CW Fox (eds), *Conservation Biology: Evolution in Action*, Oxford Univ. Press, Oxford and New York pp 297-307.
- Murali KS, Uma Shankar, R Uma Shaanker, KN Ganeshaiah and KS Bawa (1996) Extraction of non-timber forest products in the forests of Biligiri Rangan Hills, India. 2. Impact of NTFP extraction on regeneration, population structure and species composition. *Eco. Bot.* **50**: 252-269.
- Miller-Rushing A and RB Primack (2008) Global warming and flowering times in Thoreau's Concord: a community perspective. *Ecology* **89**: 332-341.
- Nayak KG and P Davidar (2010) Pollinator limitation and the effect of breeding systems on plant reproduction in forest fragments. *Acta Oecologica* **36**: 191-196.
- Nathan R and HC Muller-Landau (2000) Spatial pattern of seed dispersal, their determinants and consequences. *Trends Ecol. Evol.* **15**: 278-285.
- Norhauer JM and DM Newery (2010) Recruitment limitation after mast-seeding in two African rain forest trees. *Ecology* **91**: 2303-2312.
- Pandey A and PK Arora (2004) Potential of domestication of wild species in the Indian gene centre. In: BS Dhillon, RK Tyagi, A Lal and S Saxena (eds) *Plant Genetic Resource Management*, Narosa Publishing House, New Delhi, pp 56-78.
- Pandravada SR, N Sivaraj and KS Varaprasad (2004) The changing pattern of plant biodiversity in the Eastern Ghats. In: BS Dhillon, RK Tyagi, A Lal and S Saxena (eds) *Plant Genetic Resource Management*, Narosa Publishing House, New Delhi, pp 136-152.
- Peres CA (2010) Overharvesting In: NS Sodhi and PR Ehrlich (eds) *Conservation Biology for All*. Oxford Univ. Press, New York, pp 107-130.
- Peres CA, C Baider, PA Zuidema, LHO Wadt *et al.* (2003) Demographic threats to the sustainability of Brazil nut exploitation. *Science* **302**: 2112-2114.
- Rao CK, BL Geetha and G Suresh (2003) *Red List of Threatened Vascular Plant Species in India: Compiled from the 1997 IUCN Red List of Threatened Plants*. ENVIS, Botanical Survey of India, Ministry of Environment & Forests, Kolkata.
- Ravikumar K and DK Ved (2000) *100 Red Listed Medicinal Plants of Conservation Concern in Southern India: Illustrated Field Guide*. Foundation for Revitalization of Local Health Traditions, Bangalore.
- Richards AJ (1986) *Plant Breeding Systems*. Allen and Unwin, London.
- Roertson AW, D Kelly, JJ Ladly and AD Sparrow (1999). Effects of pollinator loss on endemic New Zealand mistletoes (Loranthaceae). *Cons. Biol.* **13**: 499-508.
- Rodriguez-Cabal MA, MA Aizen and AJ Novaro (2007) Habitat fragmentation disrupts plant-disperser mutualism in the temperate forest of South America. *Biol. Cons.* **139**: 195-202.

- Roubik DW, Sakai S and Karim AAH (eds) (2005) *Pollination Ecology and the Rain Forest: Sarawak Studies*, Springer, New York.
- Shen-Miller J, MB Mudgett, JW Schopf, S Clarke and R Berger (1995) Exceptional longevity and robust growth: ancient sacred lotus from China. *Am. J. Bot.* **82**: 1367-1380.
- Shivanna KR (2003) *Pollen Biology and Biotechnology*. Science Publishers, Enfield, USA (Special Indian Edition: Oxford-IBH Publishers, New Delhi).
- Singh AK, RK Tyagi and K Rao (2004) *Ex situ* approaches for conservation of plant genetic resources: achievements and challenges. In: BS Dhillon, RK Tyagi, A Lal and S Saxena (eds) *Plant Genetic Resource Management*, Narosa Publishing House, New Delhi, pp 179-193.
- Sodhi NS and PR Ehrlich (eds) (2010) *Conservation Biology for All*. Oxford Univ. Press, New York.
- Sodhi NS, R Butler, WF Laurance and L Gibson (2011) Conservation successes at micro-, meso- and macroscales *Trends Ecol. Evol.* doi:10.1016/j.tree.2011.07.002
- Spira TP (2001) Plant-pollinator interactions: a threatened mutualism with implications for the ecology and management of rare plants. *Natural Areas J.* **21**: 78-88.
- Sunnichan VG (1998) Reproductive biology of two forest trees of India: *Sterculia urens* (gum karaya) and *Boswellia serrata* (salai guggul). Ph.D. Thesis, Univ. Delhi, Delhi.
- Sunnichan VG, HY Mohan Ram and KR Shivanna (2004) Floral sexuality and breeding system in gum karaya tree, *Sterculia urens*. *Plant Syst. Evol.* **244**: 201-218.
- Sunnichan VG, HY Mohan Ram and KR Shivanna (2005) Reproductive biology of *Boswellia serrata*, the source of salai guggul, an important gum-resin. *Bot. J. Linnean Soc.* **147**: 73-82.
- Svenning J and SJ Wright (2005) Seed limitation in a Panamanian forest. *J. Ecol.* **93**: 853-862.
- Syed RA, IH Low and RHV Corley (1982) Insect pollination of oil palm: Introduction, establishment and pollinating efficiency of *Elaeidobius kamerunicus* Faust. *Malaysia Planter, Kuala Lumpur* **58**: 547-561.
- Tadwalkar MD, AM Joglekar, M Mhaskar, RB Kanade *et al.* (2012) Dispersal modes of woody species from the northern Western Ghats, India. *Tropical Ecol.* **53**: 53-67.
- Tandon R, KR Shivanna and HY Mohan Ram (2010) Reproductive biology of some gum producing Indian desert plants. In: Ramawat KG (ed) *Desert Plants: Biology and Biotechnology*, Springer-Verlag, Berlin, Heidelberg, New York, pp 178-197.
- Thompson K, JP Bakker and RM Bekker (1997) *The Soil Seed Banks of North-West Europe: Methodology, Density and Longevity*. Cambridge Univ. Press, Cambridge.
- Thuiller W, C Albert, M Araujo, PM Berry *et al.* (2008). Predicting global change impacts on plant species' distributions: Future challenges. *Perspectives in Plant Ecol. Evol. Syst.* **9**: 137-52.
- Turner IM (2001) *The Ecology of Seeds in Tropical Rain Forests*. Cambridge Univ. Press, Cambridge.
- Uma Shaanker R, RK Chandrashekara and KN Ganeshaiah (2010) Biodiversity in India: documentation, utilization and conservation. In: HY Mohan Ram and PN Tandon (eds), *Science in India, Achievements and Aspirations, 75 years of the Academy*, Indian National Science Academy, New Delhi, pp 160-175.
- Wilcock C and R Neiland (2002) Pollination failure in plants: why it happens and when it matters. *Trends Plant Sci.* **7**: 270-277.
- Wilson EO (1997) Introduction In: ML Reaka-Kudla, DE Wilson and EO Wilson (eds) (1997) *Biodiversity II: Understanding and Protecting our Biological Resources*. Joseph Henry Press, Wash DC., pp 1-3.

The Patterns of Use and Determinants of Crop Diversity by Pearl Millet (*Pennisetum glaucum* (L.) R. Br.) Farmers in Rajasthan

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The aim of this paper is to understand the determinants of on-farm diversity of pearl millet (*Pennisetum glaucum* (L.) R. Br.) farmers in Rajasthan, in terms of: the patterns of use of intra-specific diversity, the characteristics of both the agricultural systems and the farmers who conserve agro-biodiversity, as well as the factors that motivate farmers to grow a diverse crop. Two hundred pearl millet farming households in the 10 largest pearl millet producing districts of Rajasthan were surveyed using structured interviews about household socio-economics and use of crop genetic diversity. This analysis shows that landrace cultivation has decreased in the last ten years. Additionally, an asset-based poverty index, was created in order to classify households into three poverty groups. It was found that affluent farmers maintain a greater degree of varietal diversity on farm than poorer farmers. Irrigation and income are key determinants which affect these patterns of on-farm diversity.

Key Words: Agro-biodiversity, Conservation, Intra-specific diversity, Pearl millet, Rajasthan

Introduction

It is estimated that over 1.3 billion rural people are dependent on small-scale farming in developing countries (Mazoyer, 2001). Some of these small farmers have adopted high-yielding varieties, which successfully increased production as long as inputs were also available. The Green Revolution was based on a simplification of agricultural systems and reduction of diversity, with a replacement of the environmental services, which diversity previously provided, by irrigation, fertilizers, and pesticides. However, some farmers are unable to access inputs necessary for this type of cultivation. In marginal areas, prone to consistent crop failures, the potential benefits gained by increasing investments in agricultural inputs often outweigh the costs of crop loss.

Genetic diversity can provide resistance to the abiotic stresses common in marginal environments and reduce vulnerability to pests and diseases, increasing the resilience of harvests and reducing risks for resource-poor farmers (Jarvis *et al.*, 2006; Zhu *et al.*, 2000; Di Falco and Perrings, 2005). India is the largest pearl millet producing country in the world. It is cultivated on approximately nine million hectares producing over nine million tons per year (Khairwal *et al.*, 2010). Rajasthan is the largest pearl millet producing state in India accounting for 51% of the total area under pearl millet cultivation and 36%

of total production (Khairwal *et al.*, 2010). Nevertheless, productivity levels (yield per ha) in Rajasthan are among the lowest nationwide due to the climatic and edaphic challenges inherent to this mostly arid desert agro-ecological environment. Pearl millet is an important crop not just for the economy and for food security, but also on a global level for biodiversity conservation. There are an estimated 200 distinct Pearl millet landraces grown by farmers in Rajasthan, especially in the rain fed areas where high yielding varieties and hybrids do not perform well. Nevertheless, much of this genetic diversity has been lost because of persistent drought, crop replacement by more profitable crops, and out crossing from hybrid cultivars planted in close proximity to landraces. Due to its ability to withstand drought and high temperatures, its low water requirement, and high nutrient content, pearl millet is likely to become an important crop for the future.

Within the context of pearl millet, a number of research studies have shown that under marginal conditions landrace materials performed better than conventionally bred materials (Yadav and Bidinger, 2007; 2008; Bidinger *et al.*, 2008; Yadav and Weltzien, 2000; Witcombe and Weltzien, 1989). Pearl millet farmers in Rajasthan provide an interesting example of an agricultural scenario in flux where many farmers are now transitioning to the use of hybrid varieties. Nevertheless, in a marginal region such

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as Rajasthan where more than 90% of the pearl millet area is under rainfed management it is unclear whether the improved hybrid varieties would perform better than the use of landraces and the cultivation of a diverse crop.

Despite the fact that diversity can function to increase crop yields in marginal areas, much crop diversity has been lost from Rajasthan pearl millet farmers' fields in recent decades due to crop failure from continual drought, variety replacement, and out crossing (Khairwal, 2004; Brush, 1991; Harlan, 1992). However, there are still many farmers which continue to maintain genetic diversity on-farm. Several different factors that go beyond just yield motivate these "stewards of diversity" to maintain on-farm diversity, including: market or subsistence orientation, income diversification, agro-ecological heterogeneity, socio-economic characteristics, agricultural systems, and farmer's preferences (Joshi and Bauer, 2006).

The determinants of on-farm diversity have been the subject of a number of studies. Rana *et al.* (2007) on their work with rice diversity in Nepal illustrate through multiple regression analyses that number of parcels of land, livestock number, number of rice ecosystems, agro-ecology (altitude), and use of chemical fertilizer have a significant positive influence on landrace diversity on-farm. Benin *et al.* (2003) found that a combination of factors including community agro-ecology, access to markets, and the characteristics of farms and households affect inter- and intra-specific diversity. Some key variables that positively affect crop diversity on farms in Mexico were market isolation, environmental heterogeneity, and generational effects (Van Dusen and Taylor, 2005). Van Dusen and Taylor (2005) also concluded that the principal "stewards of diversity" were not only poor and isolated farmers, but also older farmers. It has also been recognized that the physical characteristics of farms, soil conditions, and household demographics had a significant impact on crop diversity and area allocation (Abay *et al.*, 2009; Almekinders *et al.*, 1994). Additionally, it was confirmed by studies of millets in southern India that farmers make their variety selections based on market prices, the policy environment, and the risks associated with drought (Nagarajan and Smale, 2005; Nagarajan *et al.*, 2005). It is generally been identified that market integration has a negative impact on varietal diversity on-farm (Benin *et al.*, 2003; Van Dusen and Taylor, 2005). As farmers become more oriented towards producing surpluses for sale on the market, they may be selecting only a few varieties with traits for high yield instead of a range of traditional

varieties that provided many other useful traits. Knowing the reasons that farmers choose to cultivate diverse crops is important in creating appropriate policies and projects which incentivize diversity as an important production strategy.

The aim of this paper is to understand the determinants of on-farm diversity of pearl millet farmers in Rajasthan, in terms of: (1) the patterns of use of intra-specific diversity, (2) the characteristics of both the agricultural systems as well as the farmers who conserve agro-biodiversity, and (3) the factors that motivate farmers to grow diverse crops. By looking at these three aspects, we hope to assess the determinants of crop diversification and to understand the implications of these determinants in the context of conventional agro-biodiversity conservation wisdom.

1. Methods and Data Collection

We chose to analyze pearl millet (*Pennisetum glaucum* (L.) R. Br.) in Rajasthan for several reasons: it is an important crop on an economic level regionally, nationally, and globally; it plays an important role in regional food security; India is a secondary center of diversity for pearl millet, especially Rajasthan; and due to its physiology of being highly drought tolerant and heat resistant, it has potential to become an even more important cereal crop for the future in light of climate change (Brunken *et al.*, 1977; Lane and Jarvis, 2007).

Rajasthan state is a marginal zone for agricultural production. Pearl millet is generally cultivated in regions that receive approximately 150-700 mm of rainfall annually (Commissionerate of Agriculture-Rajasthan, 2010), which is concentrated between the months of June and September during the annual monsoon season. Much of this rain often comes in only a few (1-3) heavy rainfall events, which can be erratic and unpredictable. The extreme temperatures during the Kharif (monsoon) growing season from (July to October), can range from approximately 28 to 46°C, in combination with sandy soils, and prolonged periods of drought, create an environment where few rain fed crops will survive. Pearl millet plays an equally important role for both grain and fodder in semi-arid environments worldwide, especially in Rajasthan, where livestock production is an important element of the agricultural system. Although pearl millet is one of the hardiest drought tolerant crops, it is estimated that harvest failure can be as high as 80% in most years (RP Jangir, personal communication).

Survey and Collection of Data

In order to assess the agricultural scenario surrounding pearl millet cultivation in India we surveyed 200 pearl millet farming households in the 10 largest pearl millet producing districts of Rajasthan based on total area under cultivation (Commissionerate of Agriculture-Rajasthan, 2010) (see Map 1). The study area encompasses 3 agroecological zones according to the system presented by Sehgal *et al.* (1992): the Western Zone: 2.1: Western Plain, hot arid, length of growing period less than 60 days; the Central Zone: 2.3: Rajasthan Bagar/SW Punjab plain, hot arid with deep loamy desert soils, length of growing period 60-90 days; and the Eastern Zone: 4.1: North Punjab Plain/Rajasthan Upland, hot semi-arid with deep loamy soils, length of growing period 90-120 days.

Map 1 presents the location of Rajasthan and Districts surveyed during the present study. One group of 4-5 villages (panchayat) was randomly selected after selecting 1 tehsil (groups of panchayats) at random. Twenty farmers from each panchayat were surveyed from a total of 116 villages in an attempt to spread our samples among as many villages of each panchayat selected as possible. Due to a lack of information about the number of households in a particular village and the prevalence of dhanis (farmsteads separated from the urban center), two-stage cluster sampling was used to select all households in the villages that fell along random transects.

Data were collected from February to June 2010 through structured in-person interviews at farmer's

respective households and farms. The survey instrument was initially pre-tested and modified based on the responses from 20 farmers. It was designed to solicit responses about: 1) general demographics, 2) household socioeconomics, 3) use of crop genetic diversity over time, 4) farmer's perceptions of the value of diversity, varieties, and character traits, 5) seed supply, 6) seed replacement, 7) agricultural extension, and 8) climate change. The analysis presented here utilizes primarily data generated from the first 4 sections of the questionnaire.

Using the Principal Component Analysis (PCA) statistical procedure a household poverty level used as a proxy for welfare was created, following Irungu (2002), Zeller *et al.* (2006) and Gotor and Irungu (2010). A set of six simple, reliable, verifiable and quantifiable poverty indicators from Rajasthan was used (Table 1) and one principal component was extracted, which explained over 43% of the total variance in the 6 variables and was interpreted as measuring poverty. The lower the score the poorer the household was. This helped us to understand the segment of the population which maintained the highest amount of intra-specific diversity on farm as well as conserved landraces.

Communalities and Component Matrix of the Poverty Index Model

Table 1 summarises the variables selected in the final model alongside their respective communalities and component loadings. Using the poverty index values, all households were ranked and then categorized into three terciles. The third lowest scoring households were categorised as the "poorest", the next as the "poor" and the highest scorers as "not so poor".

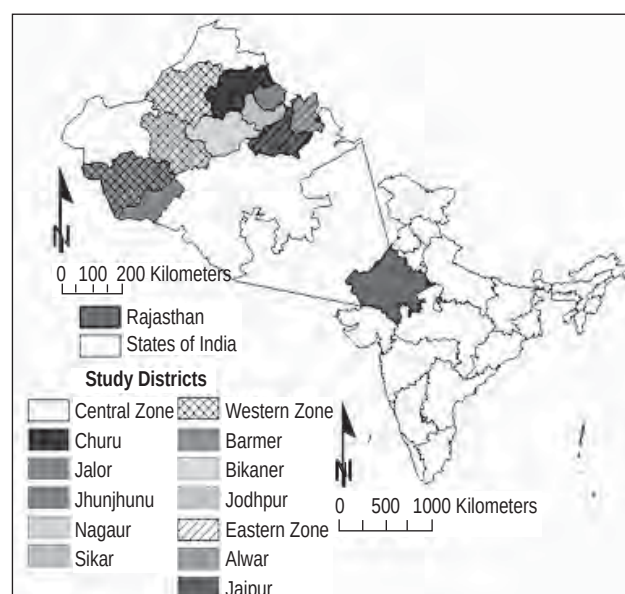
Table 1. Communalities and component matrix of the poverty index model

	Communalities		Component 1
	Initial	Extraction	Rotated
Level of education	1.000	.815	.187
Quantity of land owned	1.000	.611	.720
Quantity of land irrigated	1.000	.700	.836
Number of cows owned	1.000	.246	.262
Number of buffalos owned	1.000	.441	.662
Total income from agricultural production	1.000	.722	.845
KMO and Bartlett test	.719		
Total Variance Explained	42.610		
Significance Level	.000		

NB:

a) Extraction Method: Principal Component Analysis

b) The model had a Kaiser-Meyer-Olkin (KMO) value of 0.719 and the Bartlett test of Specificity was significant at less than 1% level



Map 1: Location of Rajasthan and Districts Surveyed

Results and Discussion

The Patterns of Use of Intra-specific Diversity

This survey revealed that over the course of three years between 2008-2010 farmers grew a total of 51 distinct pearl millet seed lots during the Kharif (monsoon) season. For purposes of simplicity we split pearl millet varieties into four major classes of seed varieties: public hybrids, private hybrids, landraces, and other. Public hybrids are those varieties that are developed by public sector research institutes and multiplied by the Rajasthan State Seed Corporation (RSSC) using hybrid seed production methods. Some of these varieties are also produced by private seed companies under licensing agreements between the state and the private company responsible for the seed production. Private varieties are those varieties developed and produced by private companies. Many of these varieties are developed by multi-national corporations under the auspices of their nationally recognized entity. However, in India there are regional-based private seed companies that are increasingly becoming integrated in the seed supply and production system. Landraces refer to any of a number of traditional farmer developed varieties, which are commonly traded informally and known to be locally adapted, heterogeneous populations, with various distinct phenotypic characteristics. The “other” category refers to advanced generation hybrids, composite varieties, which are populations or landrace selections that have been conventionally bred without hybrid technologies, or commercial grain that has been purchased from the market. Details regarding these categories and the varieties that are included therein can be found in Annex 1.

Trend (percentage) in the Cultivation of Pearl Millet Varieties 2000, 2008-2010

Figure 1 illustrates the trend (percentage) in the use of the four types of pearl millet varieties. Over the period 2000 to 2008, there has been an increase in the use of hybrid varieties with a concomitant decrease in the use of landrace varieties (Fig. 1), but thereafter no significant changes have been observed. Pearl millet farmers in Rajasthan still heavily rely on landrace varieties in order to cope with the marginal, drought-prone environment prevalent in this region. Nevertheless, over the last 10 years the predominance of landrace varieties has decreased. It is suspected that the genetic purity of landrace seed lots is uncertain in many locations where hybrids are frequently cultivated. Since this study did not rely on genetic or morphological characterization of each individual seed

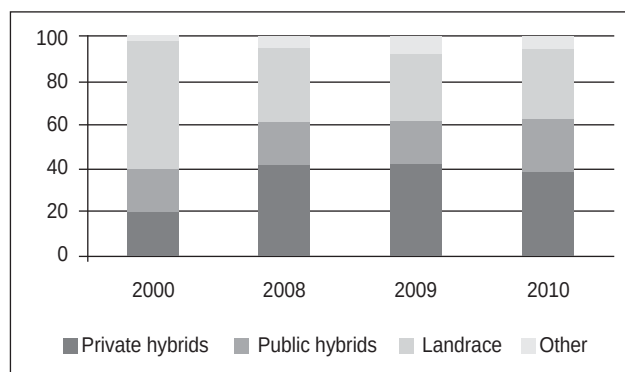


Fig. 1: Trend (percentage) in the cultivation of pearl millet varieties 200, 2008-2010

lot, as has been performed in similar studies (vom Brocke, 2003; Abay et al., 2009), the exact varietal identification cannot be definitively ascertained. The definitive categorization of highly cross pollinating crops, such as pearl millet, by farmers as landraces is difficult because of the genetic plasticity that is exhibited from year to year. Many farmers may claim to be growing *desi* (landraces), but in reality they may be growing advanced generation hybrids that have taken on the phenotypical qualities of a landrace due to cross pollination and natural changes in gene frequencies occurring from one generation to the next. Therefore, it is expected that the proportion of farmers claiming to cultivate pure *desi* landrace varieties that are in fact actually growing pure landrace varieties may be much less (Fig. 2).

Number of Farmers Reporting Use and Availability of Landrace Seed in All Districts

Figure 2 shows the extent to which landrace varieties are available to farmers in all districts surveyed. In all districts except in Jalore, farmers tend to use landraces where available. However, a smaller proportion of farmers actually utilize the available landraces. Despite the fact that many varieties are acquired by farmers over time, it is only a few key varieties which are utilized on a large scale. Landraces are the most important type of variety due to their cultivation over an extensive area and frequent presence on farm. However, private hybrids although not cultivated on as much land area, are more frequently found on farms than landraces. Public hybrids are cultivated on fewer farms, but over a larger area than private hybrids.

Relative Importance of the Four Types of Pearl Millet Varieties

The relative importance of these variety types is illustrated in Fig. 3. Of the over 50 varieties recorded by the study,

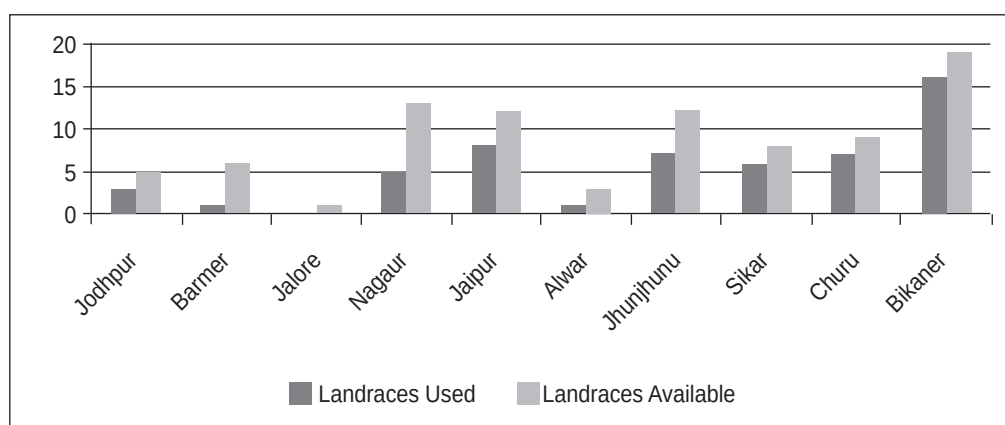


Fig. 2: Number of farmers reporting use and availability of landrace seed in all districts

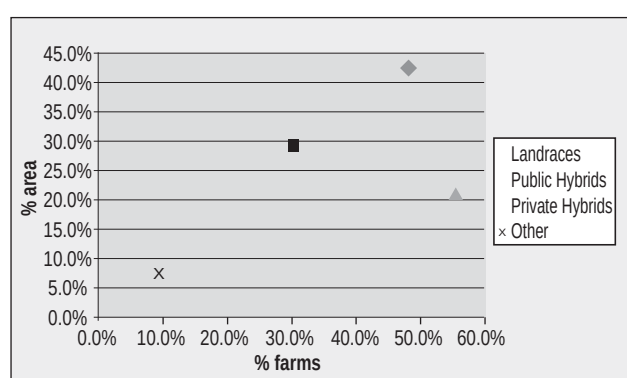


Fig. 3: Relative importance of the four types of pearl millet varieties

six varieties were of larger relative importance than the rest based on frequency of use and area under cultivation: Desi (the common name in India given to any of a large array of landraces), HHB-67 (a public hybrid), Pioneer 86 M 52 (a private hybrid), Pro Agro 9444 (a private hybrid), Jakhra (a landrace), and JK 26 (a private hybrid) (See Annex 1 for more details). The popularity of these varieties demonstrates the fact that farmers are responding to diverse needs. They use landraces and HHB-67 to mitigate the risks and problems associated with frequent drought periods; they use the private hybrids (Pioneer, ProAgro, and JK) in ideal conditions (*i.e.* irrigation and fertilizer) for high yields; and they use Jakhra for dual purpose of high fodder and grain yields. It is important to note that it has been shown that farmers can not often easily distinguish the variety that they have grown over a long span of time (Tripp and Pal, 1998). However, we were able to overcome this problem through our expert enumerators who used diagnostic methods in order to ascertain the identity of each variety and by asking farmers to show us their seed bags from the previous seasons. Nevertheless, in some cases, such as for regionally marketed varieties,

it was not always possible to ascertain the identity of a particular seed lot.

Characteristics of Farmers and Agricultural Systems

Figure 4 represents the distribution of the households into the three groups according to the districts surveyed. The percentage of farms where a particular combination of intra-specific diversity was used is graphically represented according to the 3 poverty groups in Fig. 5. This disaggregation of the data was carried out in order to understand not only what type of farmer was utilizing a certain type of variety, but to also assess the ways in which farmers utilize different types of varieties in order to meet their needs and demands for particular traits (see Annex 2 for more details). Four combinations of varietal use was found in this study: The use of only landraces, the use of only hybrids, the use of a combination of hybrids and landraces, and the exclusive use of other varieties not including hybrids or landraces.

Number of Farmers Growing a Particular Varietal Combination across Poverty Groups

There is a distinct dichotomy between the poorest and not so poor farmers, but the dichotomy between hybrid and landrace farmers is not as clear. The majority of not so poor farmers are growing hybrid varieties, whereas the poorest farmers are more likely to grow landraces. The poor category shows a transition from the poorest to the not so poor in that the poor are using fewer landraces and more hybrids than the poorest group, but they are using fewer hybrids and more landraces than the not so poor group (Fig. 5). Nevertheless, many farmers in all poverty groups concurrently grow hybrid varieties as well as landraces (27%).

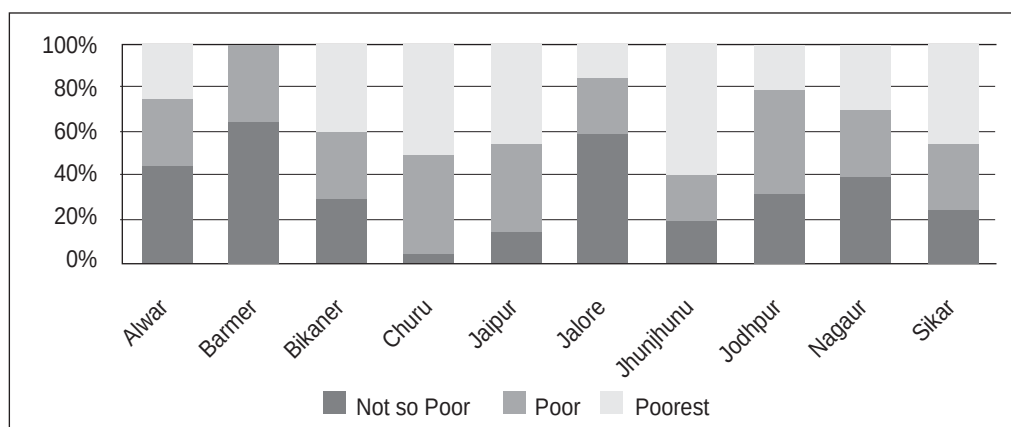


Fig. 4: Poverty Index: Cross-tabulation of survey districts versus relative poverty groups

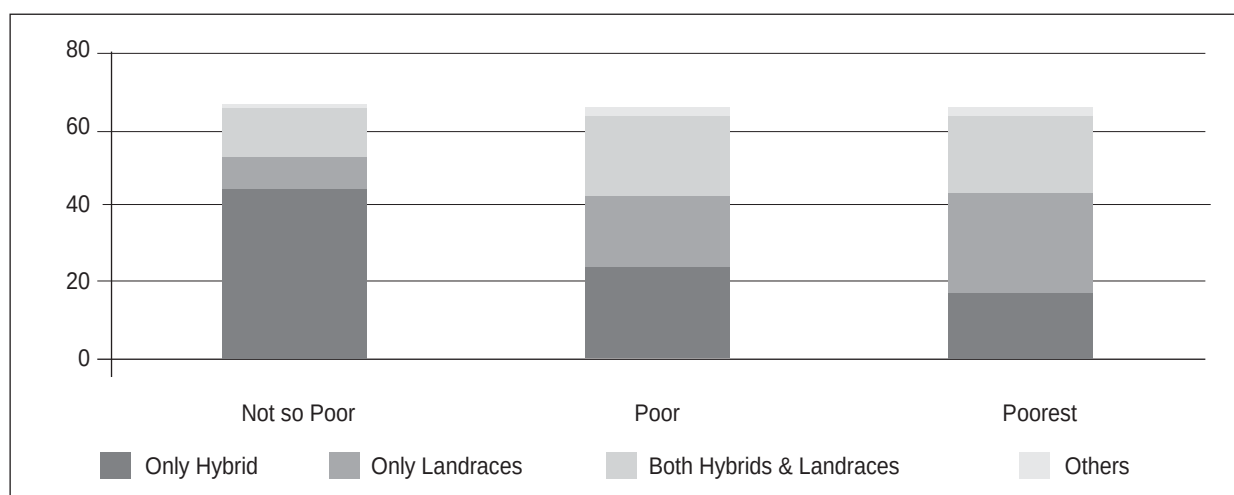


Fig. 5: Number of farmers growing a particular varietal combination across poverty groups

A significant degree of variation exists among the relative diversity cultivated by each of the poverty groups. This variation among diversity as measured by total number of varieties in a village (community richness) and evenness (Simpson Index) is shown in Tables 2 and 3.

Distribution of Community Richness and Evenness according to Poverty Group

As expected there were significant observable differences between the levels of diversity between each of the poverty groups. However these differences were somewhat counter intuitive. We expected to see less diversity in the not so poor farmers whom are largely believed to have adopted simplified agricultural systems via monoculture and mechanization brought on by modernized agricultural

practices. However, we found that the poor and not so poor farmers were cultivating the most diversity both with regards to richness and evenness. Since many poor and not so poor farmers have either disposable income or access to irrigation they can afford to purchase and cultivate the large array of hybrid varieties available on the market, which generally have a high water requirement. Therefore, due to the availability of more options the poor or not so poor farmer is more likely to have higher on-farm intra-specific diversity than the poorest farmers, who often practice farming in rainfed conditions (Tables 2 and 3).

The Factors that Motivate Farmers to Grow Diverse Crops

Understanding the reasons that farmers choose to grow a

Table 2. Distribution of community richness according to poverty group

Level of Community Richness	% Farmers Not So Poor	% Farmers Poor	% Farmers Poorest
Low Richness (1-4)	23.1	22.1	26.6
Medium Richness (5-9)	9.5	12.6	5.5
Medium High Richness (10-14)	0.0	1.0	1.0
High Richness (14-18)	1.0	0.0	0.0

Pearson Chi-Square Test show that between the not so poor there are significant difference among districts and the Richness index at 10%

Pearson Chi-Square Test show that between the poorest there are significant difference among districts and the Richness index at 5%

Table 3. Distribution of evenness according to poverty group

Simpson Index	% Farmers Not So Poor	% Farmers Poor	% Farmers Poorest
Low Diversity (0-0.33)	23.6	21.1	26.6
Medium Diversity (0.34-0.66)	9.0	12.1	5.5
High Diversity (0.67-1)	1.0	0.0	1.0

Pearson Chi- Square Test show that between the poorest there are significant difference among districts and the Simpson index at 10%

particular variety or a combination of varieties is at the core of our assessment of the patterns of use of intra-specific diversity. Farmers that cultivated multiple pearl millet varieties were asked about the reasons for cultivating several varieties concurrently. Table 4 summarizes these findings with higher yields being the most common response, followed by each has different use, and then by cultural preferences.

Table 4. Pearl millet farmers' reasons for growing multiple varieties simultaneously

Rationale	Number of Farmers
minimize risk	6
higher yields	63
each has different use	26
Experimentation	11
each is adapted to different conditions	6
fits into crop cycle	6
cultural preferences	17

The farmers' responses underscore the importance of diversity as a mechanism for not only meeting the multiple needs of farmers, but also for increasing agricultural production. While there was some overlap to the responses, farmers recognized that each variety reacts differently season to season depending on environmental conditions and, therefore, planting more varieties assures that yields will be stabilized and maximized in comparison to growing a single variety. Nevertheless, it cannot be concluded on this evidence alone that all farmers react in similar ways based on shared knowledge. For that reason, in order to more fully understand the determinants of varietal diversity, we performed a regression analysis with some of the more compelling variables as per our understanding and the knowledge gained through the work of the previously cited authors (Abay *et al.*, 2009;

Almekinders *et al.*, 1994; Nagarajan and Smale, 2005; Nagarajan *et al.*, 2005; Joshi and Bauer, 2006; Benin *et al.*, 2003; Van Dusen and Taylor, 2005; Rana *et al.*, 2007).

Determinants of Intra-specific Diversity within Pearl Millet in the Monsoon Season through Linear Regression

A multivariate linear regression analysis is presented subsequently using household species richness and evenness (Simpson index) as dependant variables to aid in the understanding of the determinants of on farm crop diversity in pearl millet (Table 5). The interpretation of these results will inform decisions with regards to the most effective ways to enhance and encourage the use of diversity by farmers. The regression analysis shows a strongly significant relationship between many of the variables of our poverty index (land irrigated, land owned, livestock, and total income from agricultural production) and both simple household species richness and the Simpson index. The strength of this relationship indicates that the wealthier a farmer is, the more varieties he will grow during the main pearl millet cultivation season. We disaggregated the poverty index in order to understand how each of its components influence diversity; however, other models we constructed which incorporated the poverty index as an independent variable of diversity showed strong and significant relationships. As these more wealthy farmers transition to growing more hybrid varieties they are also diversifying the varieties they grow. In many cases they recognize the importance of growing multiple varieties in order to increase yields although they also are motivated to diversify for many other reasons (Table 4).

Additionally, according to our model several factors

Table 5. Determinants of intra-specific diversity within pearl millet in the monsoon season through linear regression.

	Simpson Index			Richness Index		
	Beta	t	Sig.	Beta	t	Sig.
(Constant)		2.723	.007		6.944	.000
Level of education	.017	.231	.817	.016	.223	.824
Quantity of land owned	-.122	-.866	.388	-.247	-1.778	.077
Quantity of land irrigated	.279	2.761	.006	.311	3.114	.002
Total income from agricultural production	.122	1.170	.243	.172	1.678	.095
Percent income from pearl millet	.005	.068	.946	-.019	-.249	.804
Area under pearl millet cultivation	.181	1.578	.116	.233	2.056	.041
Livestock units owned	-.131	-1.781	.077	-.111	-1.533	.127
Age of head of household	-.115	-1.619	.107	-.111	-1.574	.117
Agroecology of farm	-.007	-.089	.929	.067	.840	.402
Quantity of land with loamy soil	-.032	-.371	.711	-.020	-.239	.811
Distance to major market	-.131	-1.856	.065	-.109	-1.562	.120
Number of extension visits per year	.144	2.041	.043	.097	1.392	.166
R ²	.163			.182		
P-value	.001			.000		

played a lesser, but still significant role in determining on farm diversity. Distance to markets and the intervention provided by extension agents had varying, but significant effects on on-farm diversity. As would be expected as the number of extension visits increased, on-farm diversity increased. This result points to the effectiveness of agricultural extension as a change agent, when it is present and available to farmers. Contrary to many studies our research points to the positive influence of markets on varietal diversity. As market integration increased (*i.e.* the distance to markets decreased), varietal diversity increased. In the context of pearl millet in Rajasthan where the market for hybrid varieties is well developed and seed is available at a local level this would seem logical. Farmers have a larger selection of varieties that is easily accessible. Therefore, not so poor farmers with access to irrigation (who account for the largest proportion of on farm diversity) can experiment with new varieties easily and in doing so increase diversity on their farms. Improved varietal development and seed supply systems have made hybrid varieties more readily available at the market. Their relatively superior performance, with regards to grain yield under favorable conditions, has made them more popular among not so poor farmers that have access to irrigation and disposable income. However, for rainfed farmers where drought is a recurring cause of crop failure there is little interest in investment in fertilizers or new varieties as the risk of failure is too great. It is important to point out that HHB-67 and its derivatives have played an important role of filling the niche mostly held by landraces: that of a rainfed variety which will produce even in the most marginal of conditions.

Although the variance explained by the R² values is

relatively low, the p-value of the ANOVA analysis is highly significant (Table 5). Our model is consistent with the previously articulated analysis of the relationships between the dependant and independent variables. Therefore we are apt to accept the conclusions of the determinant causes (*i.e.* irrigation, income, etc.) of diversity as identified by the regression analysis. The variation in R² values does indicate that these factors cannot alone determine the on-farm diversity of pearl millet farmers in Rajasthan, but several of the relationships are highly significant and for that reason we accept the validity of the relationships in light of the problem associated with the adjusted R² values.

Conclusions

As discussed previously, there have been many suggestions put forth to explain the causal factors of variation in on farm diversity (Rana *et al.*, 2007; Joshi and Bauer, 2006; Van Dusen and Taylor, 2005; Nagarajan and Smale, 2005; Abay *et al.*, 2009; Almekinders *et al.*, 1994). Each agricultural system and the socio-economic scenario in which it is embedded have specific factors which influence farmers' decisions on crop selection and the use of varietal diversity. It is important to recognize that there are different factors which are unique to each crop and socio-economic context which control the use of diversity in agricultural systems and no single universal factor controls this variation. Despite the fact that our model of the determinants of intra-specific diversity incorporates many of the causal factors that these previous authors describe, it does not perfectly explain what determines intra-specific diversity. Many of the factors mentioned by these authors in fact have seemingly little impact upon the choices made by pearl millet farmers in Rajasthan.

Nevertheless, this study and the corresponding analyses do add to the body of knowledge about the influence that certain factors may have on agro-biodiversity.

In particular, two causal factors seem to be strongly affecting farmers' decisions regarding the cultivation of multiple varieties: irrigation and income. The availability of irrigation allows farmers to utilize new hybrid varieties, which have mostly been bred for favorable conditions. The availability and use of these new hybrids increases diversity on farm and allows farmers to choose between different options available at the market. The lack of use of hybrids by the poorest farmers is likely the result of the lack of availability of suitable varieties for rainfed agricultural systems and the lack of focus of breeding programs on the needs of the marginal small scale farmer. Income is also a function of the availability of irrigation, as farmers with irrigation can also produce crops during the winter season. These winter crops such as wheat and mustard provide the majority of agricultural income to irrigated farmers in Rajasthan. Nevertheless, many irrigated farmers (27%) also grow landraces and hybrids concurrently. It seems that as income and irrigation become more readily available farmers not only are relieved of poverty, but they also diversify their agricultural systems.

It has been suggested that poor, marginalized farmers are the stewards of biological diversity and should, therefore, be targeted by intervention projects which aim to maintain on farm diversity (Van Dusen and Taylor, 2005). However, our analysis as well as others (i.e. Rana et al., 2007) show that it is not the poor farmers that conserve agro-biodiversity, but instead the affluent farmers who are maintaining a greater degree of varietal diversity on their farms. This may suggest that affluent farmers are using the many advantages of diversification to adapt agricultural systems to specific agroecological niches and to mitigate biotic and abiotic stresses to produce favorable crop yields.

Two strategies of diversification were commonly mentioned by farmers: 1) under irrigated conditions a high yielding, high water requiring hybrid was cultivated, while under rainfed conditions a landrace, composite, or short duration hybrid was cultivated, and 2) when the monsoon arrived early a late maturing variety such as a landrace or high water requiring hybrid was cultivated, and when the monsoon arrived late a short duration, "drought escaping", hybrid was cultivated. It can, therefore, be recommended to poorer farmers that they consider utilizing strategies such as these, implemented by the more affluent farmers, in

order to achieve favorable yields. These two strategies of diversification also illustrate an important point about the need for access to a diverse array of crop varieties: there is no single "silver bullet" variety which can replace the role of the many traits provided by the numerous distinct varieties known to farmers.

Ultimately the question of supporting agro-biodiversity conservation interventions for poorer farmers is just as relevant in light of these results. In order to increase agricultural production and improve the livelihoods and food security for poor farmers in marginal areas a diverse array of appropriate varieties needs to be made available and promoted. Instead of a zero sum game where biodiversity conservation and food security are considered mutually exclusive, a strategy should be forged where by using both modern and traditional varieties concurrently both food security and biodiversity conservation are improved.

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References

- Abay F, A Bjornstad, and M Smale (2009) Measuring on Farm Diversity and Determinants of Barley Diversity in Tigray: Northern Ethiopia, Momona, *Ethopian J. Sci.* **1**: 44-66.
- Almekinders CJM, N Louwaars, and G de Bruijn (1994) Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* **78**: 207-16.
- Benin S, M Smale, J Pender, B Gebremedhin, and S Ehui (2004) The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. *Agric. Econ.* **31**: 197-208.
- Bidinger FR, MM Sharma and OP Yadav (2008) Performance of landraces and hybrids of pearl millet (*Pennisetum glaucum* (L.) R. Br.) under good management in the arid zone. *Indian J. Genet.* **68**: 145-148.
- Brunken J, MJ deWet and JR Harlan (1977) The morphology and domestication of pearl millet. *Econ. Bot.* **31**: 163-174.
- Brush SB (1991) A Farmer-based Approach to Conserving Crop Germplasm. *Econ. Bot.* **45**: 153-165.
- Commissionerate of Agriculture (2010) Rajasthan Agricultural Statistics at a Glance for the Year 2008-09' Commissionerate of Agriculture, Department of Agriculture, Statistical Cell, Rajasthan, Jaipur, 147 pp.
- di Falco S and C Perrings (2005) Crop biodiversity, risk management and the implications of agricultural assistance'. *Ecol. Econ.* **55**: 459-466.

- Gotor E and C Irungu (2010) The impact of Bioversity International's African Leafy Vegetables Programme in Kenya. *Impact Assessment and Project Appraisal* **28**: 41–55
- Harlan JR (1992), Crops and Man. 2nd ed., American Society of Agronomy, Madison Wisconsin. 295p.
- Irungu C (2002) Outreach performance of Nongovernmental development organisations in Eastern Kenya. *Socio-Economic Studies on Rural Development*, vol. **131**. Kiel: Wissenschaftsverlag Vauk Kiel KG.
- Jarvis D, I Mar and L Sears (editors) (2006) Enhancing the use of crop genetic diversity to manage abiotic stress in agricultural production systems. Proceedings of a workshop, 23–27 May 2005, Budapest, Hungary. International Plant Genetic Resources Institute, Rome, Italy.
- Joshi G and S Bauer (2006) Determinants of Rice Variety Diversity on Household Farms in the Terai Region of Nepal, Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12–18, 2006.
- Khairwal IS, BS Rajpurohit, KN Rai, OP Yadav and GR Kherwa (2010) Pearl Millet Cultivation and Seed Production in Rajasthan. All India Coordinated Pearl Millet Improvement Project, Indian Council of Agricultural Research, Mandor, Jodhpur, 22p.
- Khairwal IS (2004) Project Report on Measuring and Monitoring Genetic Erosion of Pearl Millet Landraces through Participatory Approach. Report submitted to International Plant Genetic Resources Institute Regional Office for South Asia, New Delhi, 28p.
- Lane A and A Jarvis (2007) Changes in Climate will Modify the Geography of Crop Suitability: Agricultural Biodiversity can Help with Adaptation', *J. Semi-Arid Tropics* **4**(1).
- Mazoyer M (2001) Protecting Small Farmers and the Rural Poor in the Context of Globalization. FAO, Rome, Italy, 24p.
- Nagarajan L and M Smale (2005) Local seed systems and village-level determinants of millet crop diversity in marginal environments of India. Joint Publication of IFPRI/ICRISAT/FAO, Discussion Paper #135 at EPT Division, IFPRI, Washington, D.C.: International Food Policy Research Institute.
- Nagarajan L, M Smale and P Glewwe (2005) Comparing farm and village level determinants of millet diversity in marginal environments of India: The context of seed systems', Joint Publication of IFPRI/ICRISAT/FAO, Discussion Paper No. 139 (EPT Division, IFPRI). Washington, D.C.: International Food Policy Research Institute.
- Rana R, C Garforth, B Sthapit and D Jarvis (2007) Influence of socioeconomic and cultural factors in rice varietal diversity management on farm in Nepal', *Agri. Human Values* **24**: 461–472.
- Sehgal J, DK Mandal, C Mandal and S Vadivelu (1992) Agro-Ecological Regions of India. Technical Bulletin No. 24 (Second edition). National Bureau of Soil Survey & Land Use Planning, Nagpur.
- Tripp R and S Pal (1998) Information exchange in commercial seed markets in Rajasthan. Network Paper No. 83. Agricultural Research & Extension Network (ODI).
- Van Dusen E and JE Taylor (2005) Missing markets and crop diversity: evidence from Mexico. *Environ. Dev. Economics* **10**: 513–531.
- vom Brocke K, A Christinck, E Weltzien, T Presterl and HH Geiger (2003) Farmers' seed systems and management practices determine pearl millet genetic diversity patterns in semiarid regions of India. *Crop Sci.* **43**: 1680–1689.
- Witcombe JR and E Weltzien (1989) Population improvement in pearl millet (*Pennisetum glaucum* (L.) R. Br.) in India. Paper presented at Sixth International Congress of SABRAO. August 21–25, 1989, Tsukuba, Japan.
- Yadav OP and FR Bidinger (2008) Dual-purpose landraces of pearl millet (*Pennisetum glaucum*) as sources of high stover and grain yield for arid zone environments', *Plant Genet. Resour.: Characterization and Utilization* **6**: 73–78.
- Yadav OP and FR Bidinger (2007) Utilization, diversification and improvement of landraces for enhancing pearl millet productivity in arid environments. *Annals Arid Zone* **46**: 49–57.
- Yadav OP and E Weltzien (2000) Differential response of pearl millet landrace-based populations and high yielding varieties in contrasting environments. *Annals Arid Zone* **39**: 39–45.
- Zeller M, M Sharma, C Henry and C Lapenu (2006) An operational method for assessing the poverty outreach performance of development policies and projects, Results of case studies in Africa, Asia, Latin America. *World Development* **34**: 446–464.
- Zhu Y, H Chen, J Fan, Y Wang, Y Li, J Chen, JX Fan, S Yang, L Hu, H Leung, TW Mew, PS Teng, Z Wang and CC Mundt (2000) Genetic diversity and disease control in rice. *Nature* **406**: 718–722.

ANNEXES

Annex 1: Classification, description, and frequency of use of pearl millet varieties by farmers in Rajasthan

Variety Type	Name of variety	Description	Frequency of Use			
			2000	2008	2009	2010
Landrace	Ardi	landrace occurring in Jaipur district of eastern Rajasthan, 79-81 days to maturity, tall, thin stem, slender earhead	4	6	8	6
	Desi	name for any number of landrace varieties occurring throughout India, generally maturing from 70-90 days, characterized by slender earheads and thin stems, often with bristles, height ranges from short to very tall	129	71	64	70
	Dhodsar	landrace occurring in Sikar district of central Rajasthan, 82-84 days maturity, tall, long earheads, dual-purpose variety	3	3	3	2
	Jakrana	landrace commonly occurring in eastern Rajasthan, 80-85 days duration to maturity, very tall, exceptionally long earheads slightly curved at tip, a dual-purpose variety	28	22	16	18
Public Hybrid	BJ 104	public hybrid, 75-82 days duration to maturity, good basal tillering, medium tall	2	0	0	0
	BK 560	public hybrid, 85-90 days duration to maturity, medium tall, good tillering, sturdy, resistant to lodging	1	7	6	6
	GHB 538	public hybrid, early maturity, highly resistant to moisture stresses, resistant to downy mildew and lodging	0	0	2	7
	HHB 197	public hybrid, early maturity, medium tall, dark green leaves, long bristles, resistant to downy mildew	0	2	2	3
	HHB 67	public hybrid, 60-62 days duration, medium tall, thin stem, narrow leaves, escapes drought and tolerates salt stresses	16	38	37	39
	HHB 67 (I)	public hybrid, extra early maturity, highly resistant to moisture stresses, difference between precursor is that it is resistant to downy mildew	0	2	3	5
	HHB 94	public hybrid, 73-76 days duration to maturity, medium tall, compact cylindrical earheads	0	1	1	1
	ICMH 356	public hybrid, 85 days duration to maturity, medium tall, semi compact thick conical earheads	0	1	1	1
	MH 169	public hybrid, 82 days to maturity, medium tall, leaves glabrous	20	6	4	5
	MH 179	public hybrid 85-90 days, medium tall, leaves medium in width, semi-compact earheads, bristles, moderately resistant to ergot	11	1	0	0
	MH 322		2	0	0	0
Private Hybrid	AgriTech		0	0	0	1
	Asa Private Hybrid		0	2	1	1
	Auni 144		0	2	3	2
	Chambal Albela	private hybrid, developed by chambal fertilizers	0	0	1	0
	Dhanias	private hybrid, tall, high tillering, tolerant to downy mildew, stay green fodder	0	0	1	1
	Eknath 301	private hybrid, 80-85 days duration to maturity, medium tall, non-pubescent internodes, good tillering, long bristles	4	1	2	2
	Euro		0	1	0	0
	Govinda		0	1	0	0
	Gujarat 777		0	1	2	1
	JK 26	private hybrid or regional importance, 85 days to maturity, medium tall, purple pigmented nodes, conical earheads	6	17	13	11
	Mahalaxmi		2	0	1	0
	Mahyco 2210	private hybrid, medium maturity, medium tall, good tillering, compact earhead, not drought or heat tolerant	0	1	1	0
	Mahyco 6		0	0	0	1
	Mahyco Rsch Seed		0	0	1	1
	Marudhar		1	1	0	0
	Nandi 5	private hybrid, 70-75 days to maturity, medium height, resistance to downy mildew and lodging	2	1	3	1
	Nandi 52	private hybrid, 73-78 days to maturity, tall, long compact earheads, resistant to downy mildew, ergot, and lodging	1	2	1	0
	Nandi 67	private hybrid, 80-85 days to maturity, good tillering, compact cylindrical earheads, resistant to downy mildew, smut, and tolerant to lodging	1	1	0	1

Contd.

Annex 1 Contd.

Variety Type	Name of variety	Description	Frequency of Use			
			2000	2008	2009	2010
Other	Nirmal N 53		0	0	1	0
	Nirmal Seeds 1561	private hybrid, 85-90 days duration to maturity, medium tall, 4-5 tillers per plant, highly tolerant to downy mildew, long compact earhead, non bristled	0	3	1	2
	Pioneer 86 M 52	private hybrid, 78-80 days to maturity, hairy green internodes, compact cylindrical earheads	14	40	40	31
	Pioneer 86 M 64	private hybrid, 80-85 days to maturity, tall, stay green after maturity, tolerance to downy mildew	0	2	1	1
	Plasma		0	1	0	1
	ProAgro 9444	One of the most popular private hybrids throughout Rajasthan, reaching maturity in 80-88 days, highly productive with regards to grain yield, good tillering, compact conical earheads	7	26	22	18
	Sardar	private hybrid, 80-85 days to maturity, medium tall, non-lodging, glabrous, resistant to smut and downy mildew	0	0	1	1
	Sathia		1	0	0	0
	Seed Tech	private hybrid, 90-95 days to maturity, resistant to downy mildew and lodging, conical compact earheads	0	2	2	0
	SiriRam	private hybrid, 78-82 days to maturity, medium tall, stays green after maturity, compact conical earhead	3	2	3	2
	Sona 16		0	1	1	0
	Unknown Private Hybrid	Any private hybrid of unknown identity	6	10	9	17
	Uttam	private hybrid, developed by chambal fertilizers	0	0	1	0
	Commercial grain	Any variety procured from local market as grain, where no selection has taken place, this could include advanced generation hybrids, landraces, or composites	3	8	9	6
	CZP 9802	public composite, 70-72 days duration to maturity, medium tall, good tillering, narrow leaves, thin stem, drought tolerant, high stover yield	0	1	1	3
	HHB 67 F2	Second generation, HHB 67 hybrid	0	3	4	3
	MH 169 F2	Second generation, MH 169 hybrid	0	0	1	0
	Pioneer 86 M 52 F2	Second generation, Pioneer 86 M 52 hybrid	0	2	4	3
	ProAgro 9444 F2	Second generation, ProAgro 9444 hybrid	0	2	3	2
	ProAgro 9555	private hybrid, late maturity, medium tall, compact cylindrical panicles	0	1	3	2
	Raj 171	public composite, 82-85 days to maturity, tall, medium thick stem, long cylindrical semi compact earheads, resistance to downy mildew	1	0	0	0

Annex 2. Poverty index and varietal use combination according to district surveyed

	Poverty Index and Crop diversity																				
	Alwar		Barmer		Bikaner		Churu		Jaipur		Jalore		Jhunjhunu		Jodhpur		Nagaur		Sikar		Total
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n
Not so Poor	9	0.5	13	0.7	6	0.3	1	0.1	3	0.2	12	0.6	4	0.2	6	0.3	8	0.4	5	0.3	67
Just Hybrid	9	0.5	13	0.7	0	0.0	1	0.1	0	0.0	12	0.6	3	0.2	5	0.3	1	0.1	1	0.1	45
Both	0	0.0	0	0.0	2	0.1	0	0.0	2	0.1	0	0.0	0	0.0	1	0.1	4	0.2	4	0.2	13
Only landraces	0	0.0	0	0.0	4	0.2	0	0.0	1	0.1	0	0.0	1	0.1	0	0.0	2	0.1	0	0.0	8
Adv Gen	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0	1
Poor	6	0.3	7	0.4	6	0.3	9	0.5	8	0.4	5	0.3	4	0.2	9	0.5	6	0.3	6	0.3	66
Just Hybrid	6	0.3	2	0.1	0	0.0	3	0.2	0	0.0	5	0.3	0	0.0	6	0.3	1	0.1	1	0.1	24
Both	0	0.0	4	0.2	0	0.0	4	0.2	3	0.2	0	0.0	3	0.2	1	0.1	2	0.1	4	0.2	21
Only landraces	0	0.0	1	0.1	6	0.3	2	0.1	5	0.3	0	0.0	1	0.1	1	0.1	2	0.1	1	0.1	19
Adv Gen	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1	1	0.1	0	0.0	2
Poorest	5	0.3	0	0.0	8	0.4	10	0.5	9	0.5	3	0.2	12	0.6	4	0.2	6	0.3	9	0.5	66
Just Hybrid	3	0.2	0	0.0	0	0.0	0	0.0	0	0.0	3	0.2	3	0.2	3	0.2	4	0.2	2	0.1	18
Both	1	0.1	0	0.0	0	0.0	4	0.2	7	0.4	0	0.0	2	0.1	0	0.0	0	0.0	6	0.3	20
Only landraces	1	0.1	0	0.0	8	0.4	6	0.3	2	0.1	0	0.0	7	0.4	0	0.0	1	0.1	1	0.1	26
Adv Gen	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1	1	0.1	0	0.0	2
Total	20	1.0	20	1.0	20	1.0	20	1.0	20	1.0	20	1.0	20	1.0	19	1.0	20	1.0	20	1.0	199

Community Based Approach to On-farm Conservation and Sustainable Use of Agricultural Biodiversity in Asia

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On-farm conservation is a process of the continuous cultivation and management of a diverse set of populations by farmers in the agro-ecosystem where a crop has evolved. The continued evolution and adaptation of a species/cultivar, including adaptation to climate change, thus depend on continuous on farm management of local crop diversity. The paper discusses challenges of implementation of the on-farm conservation, despite significant support from the global scientific as well as civil society agencies, as the preferred method of conservation. Illustrating the insights obtained from three research case studies on crops and fruits of donor funded on-farm initiatives in Nepal and India and South East Asia, the paper aims to highlight the role and importance of community involvement for on-farm conservation of Plant Genetic Resources for Food and Agriculture (PGRFA). Community biodiversity management (CBM) emerged as an approach that is increasingly recognized as a process that contributes to on-farm conservation through the management of landscape, species and genetic diversity.

Key Words: Agricultural biodiversity, Community biodiversity management, Home garden, *In situ*/On-farm conservation, Sustainable livelihoods, Tropical fruit species

Introduction

The Convention on Biological Diversity and International Treaty on Plant Genetic Resources for Food and Agriculture both acknowledge the importance of *in situ* and on-farm conservation of agricultural biodiversity (UNEP, 1992; FAO, 1998). On-farm (*in situ*) conservation of cultivated plants refers to management of landraces/cultivars and occasionally cultivated wild relatives (as in the case of fruit species like mango) in the very place where they developed their present-day characteristics (Altieri and Merrick, 1987; Brush, 1995; Frankel *et al.*, 1975; Sthapit and Rao, 2011 in press). On-farm conservation is a highly dynamic form of plant genetic resources (PGR) management, which allows the processes of both natural and human selection to continue to act in the production system. Farmer's ability to search for new diversity, selection of new traits and exchange of selected materials with friends and relatives is the processes that allow the genetic material to evolve and change over time. This conservation method is increasingly valued for evolving new adaptive diversity and therefore, enhances farmer's capacity to cope adversity resulting

from the consequences of socio-economic and market forces and climate change.

In spite of these advantages, most agencies dealing with plant genetic resources conservation are facing the dilemma of implementing on-farm conservation of agricultural biodiversity in their national conservation programme as a functional strategy (Sthapit, Padulosi and Bhagmal, 2010). Most of globally implemented on-farm conservation projects are donor -funded with various objectives (Jarvis *et al.*, 2004; CBDC, 1994). Global *In situ* Conservation Project launched in 1995 by Bioversity (then IPGRI) was aimed to understand the scientific basis of *in situ* and on-farm conservation of agricultural biodiversity, and to strengthen capacity of national partners for implementing on-farm conservation. The Community Biodiversity Development and Conservation Programme (CBDC) is another global initiative developed by governmental and non-governmental organizations (GOs and NGOs) involved in agricultural initiatives in Africa, Asia and Latin America, in cooperation with Northern partners to promote the objectives of CBD that

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includes *in situ* and on-farm conservation of globally important biodiversity (UNEP GEF, 1992). This initiative was focused—mainly through civil societies—to strengthen the ongoing work of farming communities in conserving and developing the agricultural biodiversity that is vital to their livelihood and food security (CBDC, 1994). Since then a number of specific case studies on *in situ* and on farm conservation of agricultural biodiversity were reported from China (Yongneng, 2006), European countries (Veteläinen *et al.*, 2009), India (Bisht *et al.*, 2006; Pandey *et al.*, 2011), Italy (Negri, 2003), Ethiopia (Worede, 1997; Tsehay *et al.*, 2006), Mexico (Louette *et al.*, 1997; Rice, 2007), Philippines (Carpenter, 2005), Thailand (Rerkasem and Rerkasem, 2002), Vietnam (Hue *et al.*, 2003), but they are not clear as to how the role of farmers and their local institution on management of local crop diversity *in situ* can be consolidated. Economically emerging developing countries have seldom invested sufficient on this complementary plant genetic resources conservation approach to produce any tangible impacts. The major challenges faced by plant genetic resource conservation agencies to implement on-farm conservation are centered around i) lack of a clear understanding of the scientific basis of on-farm conservation of agricultural biodiversity and how it could be practically implemented on the ground, ii) difficulty in changing the mindset of current PGR institutional set up and staff to empower farmers and their rural institutions, iii) identifying priority region of diversity-rich regions/sites for on-farm conservation, iv) rationale for identifying the least cost conservation areas and policy trade-off between the locating diversity rich regions/sites and designating region for intensive modern agriculture, v) difficulties in identifying incentive mechanisms to support on-farm conservation of PGRFA, and vi) inadequate policy support for community based management of agricultural biodiversity as a *in situ* conservation strategy. What makes these challenges particularly complex is the fact that they are highly interlinked and dependent upon a mix of socio-cultural, economic and political factors, making on farm conservation not a purely technical intervention as it is the case in *ex situ* conservation methods but a much more complex endeavour (Ramanatha Rao, 2009; Ramanatha Rao and Sthapit, 2011 in press). This paper selected three case studies carried out in Asian region to illustrate the emerging method of consolidating role of farmer and rural institution in management of agricultural biodiversity on-farm.

Case Studies

Case 1: Strengthening Scientific Basis of *In situ* Conservation of Agricultural Biodiversity On-farm

Over the last decade, Bioversity International has worked with national, regional and local partners in eight countries (Burkina Faso, Ethiopia, Hungary, Mexico, Morocco, Nepal, Peru and Vietnam) on the maintenance and use of crop genetic diversity on farm, particularly that is found in traditional varieties (or landraces). The work involved investigating the extent and distribution of diversity in over 27 crops and exploring with farmers and rural communities the management practices used to maintain traditional varieties. The results of this collaboration have (i) provided tools to assess the amount and distribution of crop genetic diversity in production systems (ii) increased our understanding of when, where and how this diversity will be maintained, (iii) identified practices, communities and institutions that support maintenance and evolution of crop genetic diversity in production systems, and (iv) provided possible mechanisms for ensuring that the custodians of these systems and genetic materials will benefit from their actions. This international collaboration has provided significant contributions to the four elements of the Convention on Biological Diversity's Programme of Work on Agricultural Biodiversity: (i) assessment of diversity; (ii) adaptive management; (iii) capacity building; and (iv) mainstreaming (Jarvis and Hodgkin, 2008). The purpose was to strengthen the scientific basis, institutional linkages and policies that support the role of farmers in conservation and use of crop genetic diversity. Understanding the above mentioned questions provides the scientific knowledge needed not only to manage crop genetic resources on-farm, but also to develop options for better livelihoods and income that provide incentive for conservation efforts (Jarvis *et al.*, 2004, 2007; Sthapit *et al.*, 2007).

Through this partnership, countries worked together to collate datasets from biologically and culturally diverse sites from into a small number of globally applicable diversity indices to compare across farmer households and communities. Varietal data from 27 crop species from five continents were analysed to determine overall trends in crop varietal diversity on farm. Measurements of richness, evenness, and divergence showed that considerable crop genetic diversity continues to be maintained on farm, in the form of traditional crop varieties. Major staples

had higher richness and evenness than non-staple crops. Variety richness for clonal species was much higher than that of other breeding systems. Study suggested that diversity may be maintained as an insurance to meet future environmental changes or social and economic needs. Divergence estimates, measured as the proportion of community evenness displayed among farmers, underscore the importance of a large number of small farms adopting distinctly diverse varietal strategies as a major force that maintains crop genetic diversity on farm.

Studies on (i) on-farm diversity assessment, (ii) access to diversity and information, (iii) extent of use of available materials and information, and (iv) benefits obtained by the farmer or farming community from their use of local crop diversity, are necessary to identify the different ways of supporting farmers and farming communities in the maintenance of traditional varieties and crop genetic diversity within their production systems (Jarvis *et al.*, 2010). The lessons learned from the study are into two key areas. First, any analysis within the four main areas (assessment, access, use and benefit) can, and most probably will, lead to a number of different community actions. Second, the decision to implement a particular community action, and therefore its success, will depend on farmers and the farming community having the knowledge and leadership capacity to evaluate the benefits that this action will have for them. This in turn emphasizes the importance of activities of strengthening and empowering local institutions so as to enable farmers to play a greater role in the management of their resources (Subedi *et al.*, 2006; Sthapit *et al.*, 2008ab; Smith, 2009). The consolidating role of farmer and community on management of agricultural biodiversity solely depends upon the experience and deeper understanding of community empowerment and its linkage with on-farm management of PGRFA.

When local institutions are weak, involving the community and community institution in the management of agricultural biodiversity is a challenge. This requires building of knowledge, skills and practices of farmers with social system and driven by local rules and institutions. Since the farmers and their social networks play a key role in maintaining dynamic process of evolution, selection and adaptation of useful diversity in the changing climate and other external forces (Subedi *et al.*, 2003), it is important to understand that on-farm conservation is a constantly changing complex system of relations between people, plants, animals, other organisms and the environment,

continuously challenged by new problems (Brookfield, 2001). If dynamism of agricultural biodiversity constitutes of relations between people, plants, animals, other organisms and the environment, how can these relations be conserved *per se* for on-farm conservation and are there any social system/customs that support that? Often PGR agencies have difficulty to address this issue. Subedi *et al.* (2006) and Sthapit *et al.* (2008ab) used a participatory community based biodiversity management (CBM) as a method to realize the on-farm management of agricultural biodiversity.

CBM integrates knowledge and practices into social systems so that the process is dynamic and sustainable. The strategy strengthens the capacity of rural communities to make decisions on the conservation and use of biodiversity in order to secure access to and control over their resources (Subedi *et al.*, 2006; 2007). Sthapit, Shrestha and Upadhyay (2006) described a number of steps of CBM method and a set of good practices that suit to the particular context. These include: i) understanding local biodiversity, social networks and institutions, ii) enhancing community awareness and capacity building of community institutions, iii) setting up of institutional working modalities, v) consolidating community roles in planning and implementation, iv) establishing a CBM Trust Fund (payment system for community conservation efforts), v) community monitoring and evaluation, and vii) social learning and scaling up for community collective action. The CBM strategy provides an overarching structure with practices (Sthapit *et al.*, 2006; 2008ab; Subedi *et al.*, 2007) that include a number of ways to contribute to the implementation of on-farm management. Some examples are:

- Diversity and seed fairs (Adhikari *et al.*, 2006; Neuendorf, 1999);
- Community biodiversity register (Subedi *et al.*, 2006);
- Diversity blocks, diversity kits (Sthapit *et al.*, 2006) and participatory varietal selection (Joshi and Witcombe, 1996);
- Farmer and participatory plant breeding (Gyawali *et al.*, 2006; Sthapit and Jarvis, 1999; Sthapit *et al.*, 1996; Witcombe *et al.*, 1996);
- Community seed banks, strengthening social seed networks and local seed business development (Shrestha *et al.*, 2006; Subedi *et al.*, 2003);
- Value addition of local crops and varieties, and

associated product chain development (Bhandari *et al.*, 2006).

In Nepal, these community-driven practices empower farmers and community about the importance of local crop diversity and its maintenance for future crop improvement and two examples are cited below to illustrate this from the work done in Nepal during 1998-2005.

Participatory Landrace Enhancement

First, Gyawali *et al.* (2010) demonstrated how local diversity of *Jethobudho* rice can be made more competitive to so that farming community has incentive to continued cultivation of traditional cultivars and thereby supporting on-farm conservation. *Jethobudho* is an aromatic rice landrace of the Pokhara valley in middle hills of Nepal. Although local consumers are willing to pay a high price for its purchase, the landrace has a problem with quality variation. Decentralized participatory population improvement for specific market-identified traits was conducted on “*Jethobudho*” populations collected from farmers’ fields in seven geographic regions of the valley in Nepal. The preferred post harvest quality traits, field tolerance to blast and lodging, and superior post harvest quality traits of *Jethobudho* were established by a consumer market survey. These traits were used for screening the materials. 338 sub-populations of *Jethobudho* were evaluated for yield, disease, lodging resistance, and post harvest quality traits. Six accessions with similar agronomic traits, field tolerance to blast and lodging, and superior post harvest quality traits, were bulked and evaluated on-farm using participatory variety selection (PVS). The enhanced *Jethobudho* accessions were also evaluated for aroma using simple sequence repeat (SSR) and found to have unique aromatic genetic constitution. Community based seed production groups were formed, linked to the Nepal District Self Seed Sufficiency Programme (DISSPRO), and were trained to produce basic seeds (truthfully labelled) of *Jethobudho*. The National Seed Board of Nepal released the enhanced landrace in the name of “*Pokhareli Jethobudho*” in 2006, as the first bulk variety of traditional high quality aromatic rice improved through participatory plant breeding to be formally released in Nepal for general cultivation under the national seed certification scheme. Landrace improvement is shown as an important option for supporting programmes for *in situ* conservation of landraces on-farm. This example showcased evidence to policy makers how variability in local crop diversity can be capitalized to provide incentive for management diversity on-farm.

Community Seed Bank

Second example is from the high production potential area Indo-Gangetic plain of Bara district bordering to India. As part of a global on-farm crop conservation project in Nepal, community seed banks were established by the NGO Local Initiatives for Biodiversity, Research and Development (LIBIRD) and the Nepal Agriculture Research Council (Shrestha *et al.*, 2006; Sthapit *et al.*, 2007). The community seed bank in itself is managed by Agriculture Development Community Society (ADCS), a farmers’ organization. The seed bank deals with a variety of local farmer’s varieties. In addition, some rice varieties bred from traditional varieties with the technical assistance of LI-BIRD are included. In collaboration with partner organizations ADCS collects, regenerates, multiplies and promotes diversity on-farm. The diversity and knowledge gathered through different techniques, such as diversity fairs, biodiversity registration and diversity blocks, have improved farmers’ access to seeds of preferred local varieties (Table 1). To refresh seeds maintained in the seed bank and meet local demands, seeds of the crop varieties are regenerated each year. The seed bank offers local people seeds of local origin as well as preferred improved varieties, and it empowers the community with respect to conservation, use and marketing. Farmers and farmers groups frequently visit the seed bank for technical input, facilitation of saving and credit schemes, business advice and funding for small scale businesses. This place is seen as the outlet of local varieties as they are increasingly difficult to access for farmers whereas modern varieties are easy to obtain from variety of sources such as Agrovets, Extension agencies, NGOs and research stations (Shrestha *et al.*, 2006).

This strongly suggests that ADCS is becoming a key institution in the area. The most important lesson learned from the project is that most crop varieties of local origin are maintained by wealthier households. Poorer farmers use those varieties, but are unable to invest resources for the sake of conservation for future use. In this situation, the community seed bank can maintain and provide easy access of varieties preferred by small scale farmers, who often operate in marginal environments where local varieties are preferred. The amount of seed and varieties transactions of Table 1 illustrates that small holder farmers are ‘drawing’ locally adapted germplasm from CSB and multiplying them on their farm for further use. Thus, the easy access to needed seed provided by community seed banks is directly helps improve the food security of small

Table 1. Recipients of seed from CSB by socioeconomic categories

Year	Number of farmers of different socio-economic category				Number of landraces	Seed Qty. (Kg)
	Rich	Medium	Poor	Total		
2007	3 (6)	20 (41)	26 (53)	49	23	61
2006	7 (11)	25 (39)	32 (50)	64	17	78
2005	17(20)	37 (42)	33 (38)	87	23	197
2004	6 (17)	14 (40)	15 (43)	35	13	69
2003	5 (12)	19 (48)	16 (40)	40	11	87

(Figures in parenthesis indicate the percentages, Source: Seed distribution records from community seed bank, Kachorwa)

scale farmers. ADCS has also established a diversity fund, which had been effective in raising the incomes of small scale farmers, including landless households. By accepting fund rules, those who borrow from the diversity fund agree to be responsible for the regeneration of one traditional variety. The fund thus strengthens small scale businesses and contributes to conservation of traditional varieties. Most of the diversity fund loan takers have been resource poor farmers or people from socially excluded and ethnic minorities (Table 1). Most importantly, community seed bank provides a local institutional platform to access local varieties and strengthen community capacity for monitoring local diversity. The detailed methodologies of such community based approaches were published (Sthapit, Shrestha and Upadhyaya, 2006; Sthapit *et al.*, 2008ab). In the context of climate change adaptation, those practices can provide options that enhance the capacity of farming communities to adapt.

Case 2: Home Gardens in Nepal

Home gardens are reported to be the oldest agro-ecosystem that provides a bridge between the social and the biological, linking cultivated species and natural ecosystems, combining and conserving species and genetic diversity. Home garden¹ is a traditional land use practice around a homestead where many annual and perennial plant species are planted and maintained by the members of the household (HH) intended primarily for HH consumption (Shrestha *et al.*, 2002; Trinh *et al.*, 2003). There is a wealth of literature that illustrates how home gardens¹ provide a niche where people keep those plants and animals that are precious to the household for religious, cultural, health, aesthetic, ecological and economic reasons (Eyzaguirre and Linares, 2004). They are often used as a place where farmers can experiment with, introduce and domesticate useful plants. Their structural composition, and species and varietal diversity

are influenced by the socio-economic circumstances and cultural values of the users. Constant experimentation makes home gardens important reservoirs of germplasm—especially unique fruit trees and species associated with local food culture and preference (Gautam *et al.*, 2008b). These gardens therefore are not only important sources of food and nutrition, but are also important for on-farm management of a wide range of plant genetic resources not found in larger agro-ecosystems (Agnihotri *et al.*, 2004; Trinh *et al.*, 2003). The dynamic nature and multiple uses of home gardens raise several research questions about the stability of this micro-ecosystem and its role as a viable conservation unit.

The Nepal home garden project was linked closely with the Bioversity International's global home garden project that was being implemented in five countries, namely Cuba, Venezuela, Guatemala, Ghana and Vietnam during 1998–2002. The methodologies developed under this project in understanding the dynamics and role of home garden were utilized in carrying out the Nepal project.

Systematic studies on Nepalese found that the compositions of home gardens were variable and species and varietal richness were high with variable distribution across home gardens (Shrestha *et al.*, 2002; Sunwar *et al.*, 2006 and Gautam *et al.*, 2008). Although species diversity within community is large (172–342), 24 key species were identified for the study (Gautam *et al.*, 2008). There was no fixed size of a home garden. Species richness was significantly higher in vegetable followed by fodder, fruits and spices. Within each trophic level, plant species that were frequently grown in home gardens in a relatively large area by many HHs were considered the key species that were locally important for the community. Broad leaf mustard, radish, hyacinth bean, garlic, yams, Biye (*Solanum anguivi* L.), etc. were the common key species in winter season, whereas sponge gourd, pumpkin, bottle

¹ There are many terms that describe these garden production systems, the term “home garden” is preferred as it highlight the close relationship between garden and the social group residing at home.

Table 2. Impact of home garden interventions on species richness in six districts in Hill (bold) and Tarai (normal) agro-ecological zones of Nepal

District	Site	Altitude (m asl)	Shannon weaver Indices† (H')		Simpson index (λ) ††	
			Before§	After§§	Before§	After§§
Ilam	Chaulachuli	173	3.81	3.95	0.97	0.98
	Larkhe	1717	3.70	3.34	0.97	0.98
	Sumbek	1413	3.53	3.74	0.96	0.97
Gulmi	Amarpur	1180	2.57	3.87	0.91	0.98
	Hardineta	1132	2.92	3.67	0.94	0.97
Rupendehi	KhadwaBangain	120	3.25	3.76	0.93	0.97
	Siktahan	115	2.53	3.85	0.91	0.98
Jhapa	Chakchaki	95	3.49	3.83	0.96	0.97
	Duwagadhi	116	3.78	4.10	0.97	0.98
Kailai	Godawari	679	3.17	3.47	0.95	0.96
Bardiya	Taratal	167	2.99	3.68	0.94	0.97

† Shannon-Weaver Indices (H'), and † † Simpson Indices (λ) or Dominance (Shannon and Weaver, 1949; Simpson, 1949).

§ Before (2002); §§ After (2011)

gourd, taro, cucumber, chillies, etc. were the key species in summer season. Within these key species, the amount of intra-specific diversity was relatively high compared with other plant species since it is an indication of farmers' diverse needs and preferences (Gautam *et al.*, 2008; 2009). Monitoring of species richness over the years showed that richness has increased (Pudasaini *et al.*, 2011) and spatial distribution (as measured by evenness, Simpson index) was also at par showing that the home gardens species diversity was not affected by market forces and most produces are consumed for family use (Table 2).

Success of home gardens has been measured as increase in species diversity (Table 2) as it is taken as proxy indicator for dietary diversity and the increase in options in functional categories from a nutritional perspective (Pudasaini *et al.*, 2011 in press). The system provides a platform of exchange of locally important PGRFA and associated knowledge amongst farmers and in the process assists the farmer innovation at local scale. One of the important functions that home garden performs is to keep knowledge of crop and varieties and uses of diversity alive from generation to generation and serve a live school of biology for children from custodian elder farmers. However, this tradition is eroding fast and diversity and traditional knowledge on seed saving and propagation are also eroding fast.

Home gardens, though small in population size, offer not only refuge to crops that are no longer grown in larger agro-ecosystems, but also offer a method of conservation of many rare and unique components of biodiversity, which are then inherently decentralized and evolutionary. Many spices, vegetables, herbs and non-timber forest products, especially medicinal plants, are in this category. This

provides an ideal setting to promote local-level innovation. Crops for family preference, traits for multiple harvests, use of multiple plant parts, perennial growth habits, unique to local food culture are some of criteria used by farmers in species/variety selection in home garden. The crop species, such as Pidar (*T. nudiflora* L.), Kundruk (*Coccinea grandis* L.) and Poi sag (*Basella alba* L.), are strongly linked culturally to indigenous ethnic groups in Tarai (Gautam *et al.*, 2009). In this context, importance of home garden is well recognized to have bound between plant and human community.

It has been debated that the plot size and number of plants of key species in home gardens are so small that they cannot be considered an effective population size for conservation efforts (Brown, 2000). In reality, however, farmers have managed to maintain genetic diversity of cross-pollinated and self-pollinated crop varieties in home garden ecosystems by exchange of seed and knowledge as social practices. These seed exchange systems resemble the dynamics of a meta-population, where different farmer populations represent sub-populations; seed flow represents migration, and the rate of seed exchange determines extinction and colonization (Hastings and Hartison, 1994). A consideration of the populations of key species found in home gardens through the lens of meta-population theory can explain how, for example, farmers can maintain two to six distinct varieties of cross-pollinated sponge gourd in a community. Thus, from a conservation perspective, a single home garden may be insignificant, but a group of them can contribute significantly.

Home gardens seem devoted towards family well-being and nutrition but not necessarily oriented towards commercial production with the subsequent monoculture

of vegetable crops. Therefore, the size of home gardens in most countries are limited below 500m² and richness and evenness of diversity high is usually very high too (Gautam *et al.*, 2008). Being small in size, home gardens have always been neglected by policy makers for research, development and conservation programmes as it is difficult to demonstrate large-scale economic impact from home garden interventions, and there are limited technological options to offer for semi domesticated, neglected and underutilized and lesser known minor crops. This suggests that government policies, linked to the millennium development goals (MDGs) and poverty reduction strategies, and research priorities need to re-examine home gardens in the context of their value towards family welfare in particular and society, in general. Suwal *et al* (2008) also found that home gardens are entry point to reach marginalized, socially excluded small holder farmers, especially women and children.

Case 3: Cultivated and Wild Tropical Fruit Diversity

Building upon previous two case studies, the Project, "Conservation and Sustainable Use of Cultivated and Wild Tropical Fruit Tree Diversity : Promoting sustainable Livelihood, food security and ecosystem service" supported by Global Environment Facility (GEF)/UNEP and executed by Bioversity International together with ICAR, India, ICHORD, Indonesia, MARDI, Malaysia and DoA, Thailand. Tropical fruits are valued for their wide range of nutritional, health and commercial values that make them an important part of Asian culture.

The genetic diversity of tropical fruit trees in Asia is increasingly threatened – in the case of cultivated species by specialization of production systems in a few varieties and by land use changes, and in the case of wild relatives due to habitat loss and climate change. Its *ex situ* conservation is difficult because tropical fruit generally possess recalcitrant seeds that cannot be stored in conventional genebanks (Ramanatha Rao, 2009). *In situ/on farm* conservation is considered as viable low cost option, however, national partners face challenges to implement *in situ/on farm* conservation programmes from the current PGR institutions (Sthapit *et al.*, 2010; Sthapit and Singh, 2010).

The project aims to improve the conservation and use of tropical fruit tree genetic diversity in Asia by strengthening the capacity of farmers, local communities and institutions to implement community-based

management of local fruit tree diversity in home gardens and orchards, and to enhance the *in situ* conservation of their wild relatives in forests. These conservation goals are to be achieved by documenting the available diversity and related knowledge, identifying and promoting good practices, enhancing the livelihoods of farmers who conserve genetic resources of tropical fruit trees, and building local, national and regional capacity to provide assistance, monitoring and policy support.

The project focuses on two globally important tropical fruit species such as *Citrus* spp. and *Mangifera* spp. and two regionally important species *Garcinia* spp. and *Nephelium* spp. as well as their wild relatives. The four countries- India, Indonesia, Malaysia and Thailand-which are located in the centre of diversity of these species-, are participating in the project. Within four countries, a total of 22 sites and 36 communities and over 15,000 households are directly involved. The study sites are located from a wide range of the production systems as traditionally tropical fruits diversity are managed in a in natural forest, protected areas, buffer zones, home gardens, semi-commercial and commercial orchards.

In the context of cultivated fruit diversity, if topical fruit tree genetic resources (including landraces) are to be conserved on-farm, this should be the result of farmers' production activities directed to improve his/her livelihood. This means on-farm conservation efforts must be carried out within the framework of farmer's livelihood needs. The project is using community-based approach to strengthen capacity of farmers, local communities and institutions to improve conservation of tropical fruit tree genetic resources and sustainably use the genetic resources of target crops and their wild relatives.

Wild fruit genetic resources are increasingly becoming valuable for breeding, genomics and commercial fruit nurseries (*e.g.* rootstocks) programmes. Wild relatives of tropical fruit species may offer desirable traits that are not available in cultivated varieties, but "wilds" often also have traits that are highly undesirable. Advances in comparative genomics and marker-assisted breeding facilitate the inclusion of the valued traits from wild materials in plant breeding programs. As technologies advance, wild plant genetic resources will become even more valuable for future research developments (Volk and Richards, 2011).

To achieve *in situ* (on-farm) conservation, community biodiversity management (CBM) method is employed to empower farming communities to manage their

agricultural biodiversity collectively and intentionally, thereby seeking sustainability in conservation. The basic principle of the CBM method is legitimizing the role of locals on the following:

- building on local resources, skill, knowledge, practice, innovation & natural assets (local use of genetic diversity and blending new acquired knowledge and science),
- empowering community and local institutions for sustainable biodiversity management and better governance (social organizations),
- diversifying biodiversity based livelihood options by mobilizing social, human and natural assets (capitalizing sustainable livelihood assets),
- promoting good governance for biodiversity management and eco-friendly approaches, and
- providing a platform for social learning for collective actions (social learning institutions) to save and use agricultural biodiversity.

The methodology is designed in such a way that locals lead the process and make decision of management and use of agricultural biodiversity (Smith, 2009). Fig. 1 illustrates key steps of community-based management of

agricultural biodiversity that employed in the conservation and sustainable use of tropical fruit tree diversity.

The project builds capacity of frontline staff and local institutions (self-help group, CBOs, women groups etc) why studies on (i) on-farm diversity assessment, (ii) access to diversity and information, (iii) extent of use of available materials and information, and (iv) benefits obtained by the farmer or farming community from their use of local crop diversity, are necessary to identify the different ways to support farmers and farming communities in the maintenance of crop genetic diversity within their production systems. Using participatory research method and creating platform of farmer and research sharing and learning, farmer and local institutions build local capacity to assess on-farm diversity, identify elite materials and improve access of useful diversity and make community action plans for deriving benefits from their conservation efforts of fruit tree diversity.

On-farm Diversity Assessment

A participatory four cell analysis method was used to assess preliminary amount and distribution of citrus, mango, rambutan and mangosteen species diversity in 36 communities from India, Indonesia, Malaysia and Thailand (Sthapit *et al.*, 2006). Baseline measurements of richness

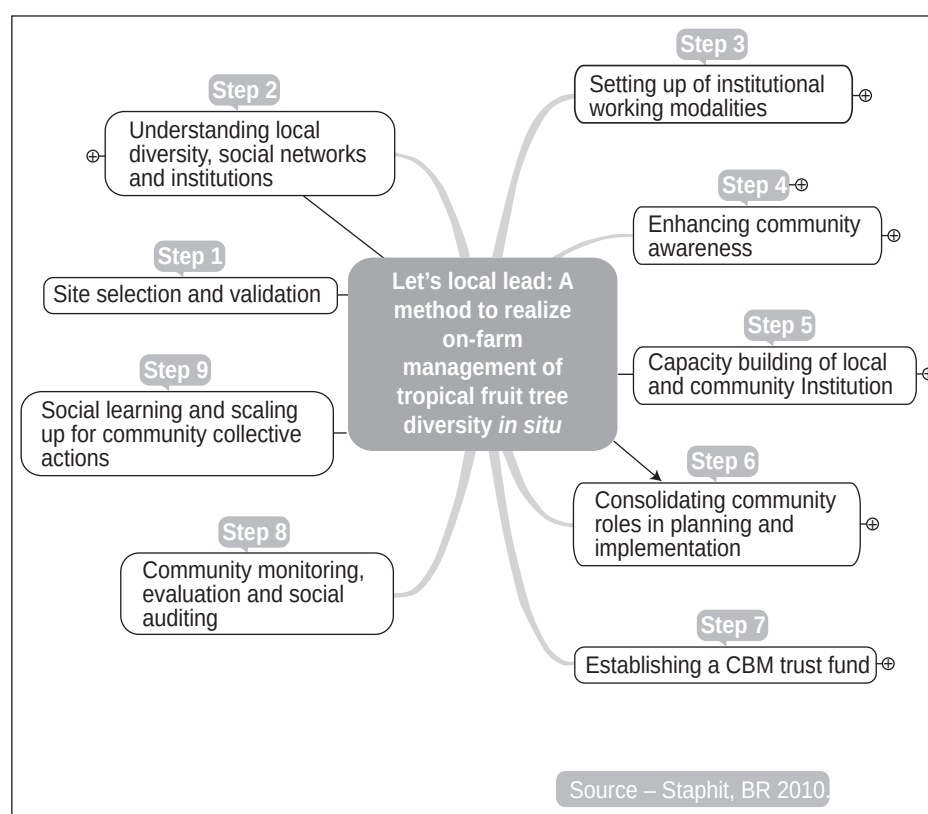


Table 3. Community richness of target fruit tree diversity (as measured by names using FCA method)

Site	Community	Total fruit HH#	<i>Mangifera</i> diversity	<i>Citrus</i> diversity	<i>Garcinia</i> diversity
Amravati	Bargaon	150	7	8	0
	Jarud	1301	6	6	0
	Nagziri	20	2	5	0
Chittor	Bangarupalyam	245	23	5	0
	Polakala	900	21	3	0
	Talupulapalli	160	25	4	0
Malihabad	Gopramau	475	14	2	0
	Kasmandi Kalam	285	40	2	0
	Mohammed Nagar Talukedari	225	11	2	0
	Sarsanda	230	8	2	0
Pusa	Dhobgama	250	20	3	0
	Jagdishpur	60	27	3	0
	Mahmada	160	26	6	0
	Murliyachak	55	13	3	0
	Gonsar	251	47	6	3
Sirsi	Koligar	320	27	6	3
	Kulibeedu	220	17	7	5
	Kumta	374	22	2	2
Total	18	5681	2-47*	5-8	2-5

*Besides, a large amount of seedling variability was observed and is being documented.

and evenness showed that considerable fruit tree diversity continues to be maintained on-farm in orchards, home gardens and natural ecosystems. Table 3 shows on-farm diversity of mango, citrus and *Garcinia* in India and are being maintained for various purposes.

Information generated by these focus group discussions (FGD) are used to have deeper understanding of the local context and analyze both natural, human and social assets in developing a set of livelihood action plans that farming community believe priorities intervention. This process - though looks to be a pragmatic approach - aims to enhance knowledge and skills of farming communities and local institutions on key issues of maintenance of local crop diversity and potential threats of not addressing those issues at the local platform so that the local communities are empowered in making decision related to their own genetic resources. In this iterative process of knowledge sharing of traditional and scientific multi-disciplinary and multi-sectoral professionals, a common heuristic understanding of agricultural biodiversity is assessed at the community level and facilitates the process of choosing appropriate intervention. Such process is graphically illustrated in Fig. 2. The choice of interventions that support on-farm management of local crop diversity may vary with the

context and interest of farmers and therefore, we need local institution that provide a platform for actors and farmers to discuss, debate and identify key practices that help the process to be continued so evolutionary process of on-farm and *in situ* conservation are continued or at least does not intervene the process. This requires deeper understanding evolutionary ecology, population genetics and social science.

Access to Diversity

Cultivated tropical and sub-tropical fruit tree species have generally been selected to suit the environment in which it is cultivated or selected naturally to satisfy the particular needs of its growers and users; such as colour, flavour and taste. Farmers have several good reasons for maintaining and using diverse traditional fruit tree diversity in home gardens or orchards for their own welfare and benefit. Deeper understanding of farmers and consumers preference and making available to farmers is essential for choosing options of interventions (Fig. 2). These options vary with the specific context. We have found six broad context of management of tropical fruit diversity in Asia. First those regions, where local fruit diversity and associated traditional knowledge, do not exist should be

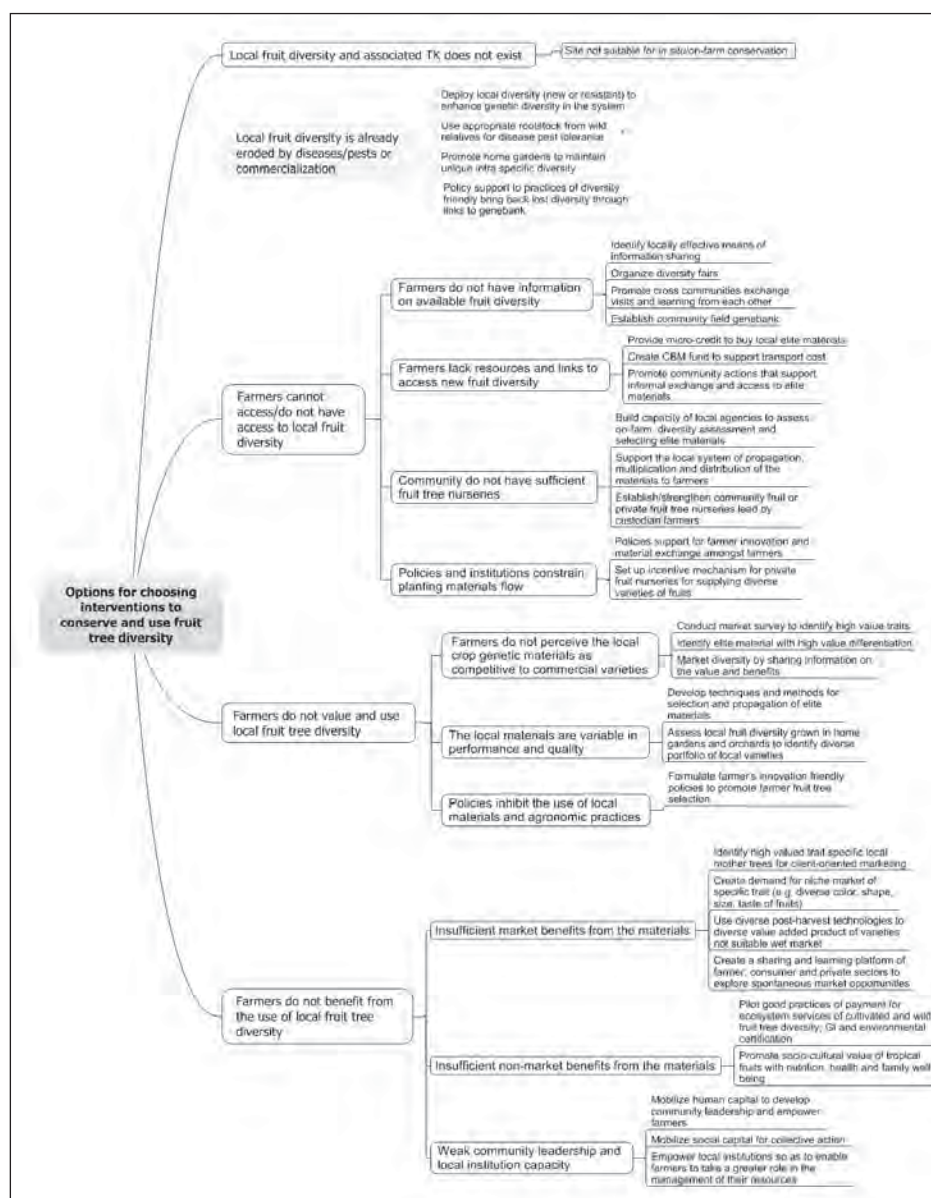


Fig. 2: Options of interventions for conservation and sustainable use of fruit tree diversity led by the local institution

selected for on-farm/in situ conservation. Second, the context where local fruit diversity is already eroded by commercialization of monoculture production system and thereby rapid decline of diseases/pests, for example, decline of Nagpur mandarin orchards in Amravati. Third, the context where farmers cannot access or do not have access to local fruit diversity. On-farm diversity assessment in the project sites identified a wide of range of unique and commercially high value traits. Knowledge and information on such valuable genetic materials are limited to few custodian farmers and are under threat to genetic erosion because of increasing deployment of youth in non-agriculture enterprises and pushing a single

option to farmer by aggressive extension messages. Figure 2 illustrates number of options available for such context specific problems. Fourth, the context where farmers do not value and use local fruit tree diversity. This context is great threat and barrier to conservation of fruit tree diversity so it is essential to demonstrate that useful elite materials can be selected from the local fruit diversity and use diversity for marketing so that the value of specific traits are appreciated by community. Finally, the context in which farmers do not benefit from use of local fruit diversity and production, there are serious threats of replacing traditional fruit orchards by commercial commodity crops. In Nai Tao, Nong Sri Chan communities

of Southern Thailand, east java of Indonesia, and Kota Belud and Yen communities of Malaysia, farmers are not getting benefits from cultivation of native high value fruits as the monetary benefits from industrial crops such as rubber, oil palm and cassava are much higher because of government subsidies. In these areas a strong local institution is required to mobilize social, human and natural capitals for creating monetary and non-monetary benefits to the community. The project identified a total of 33 good practices that can be piloted as set of interventions to suit these situations. Jarvis *et al.* (2011) has also documented a number of such interventions in recent publication.

In past the world has invested lot to collect and conserve for future use by plant breeder rather than developing mechanism to make germplasm accessible to poor and needy people. Sthapit and Ramanatha Rao (2009) argued that the benefit of such rich diversity can be capitalized by simple grassroots breeding method¹. It could be carried out by community-based organizations and private/community nurseries at a local level who can implement the activities on a large scale in order to maximize the benefits from locally available useful diversity. The project realizes that there is immediate urgency to demonstrate the value of local fruit diversity by identifying high value traits, and improve access to farming community by rapid selection, characterization and multiplication efforts from the extant diversity.

Access to seed or planting material diversity requires people having adequate land (natural capital), income (financial capital) or connections (social capital) to purchase or barter for the varieties they need (Sperling *et al.*, 2008). There may be pressure from both formal extension services and community peers against obtaining and using planting materials of local varieties. Often, value of locally available local fruit tree diversity is not known to all community and potential markets because of lack of information sharing mechanisms. In India, Indonesia and Malaysia, fruit diversity fairs were organized at regular intervals for locating new diversity and promoting exchanging of planting materials. On farm management of agricultural biodiversity (e.g. seed/planting materials) can be conceptualized as open, dynamic and decentralized genetic systems since they are the crop populations that farmers manage, and which result from farmers' seed selection practices, the flows of seed among them, and

farmers' production and utilization strategies (Bellon, 2010). Interventions like traditional mango eating feast, diversity fairs, cross communities' exchange visits etc can assist to break such social barriers. In addition, organizing such events by local institutions in participation of research institutions provide platform for farmers and researchers to locate unique and useful diversity and arrange/negotiate/transact the materials on preferred terms.

This process might improve access of germplasm. Participatory techniques such diversity fair followed by four-cell analysis researchers have identified 10 clones of *Citrus grandis*, 8 clones of *Mangifera indica*, 2 clones of *Nephelium* spp. (*lappaceum* and *ramboutan-ake*) and 2 clones of *Garcinia atroviridis* and *G. forbesii* from all four countries that have favourable traits, such as quality traits. These selected varieties are propagated by the community and sold/distributed for further promotion and conservation.

Use

The use of the traditional fruit diversity by farmers might often be increased (i) if there were more information on the characteristics (eco-physiological, adaptive, quality traits) or uses of these materials, (ii) if the materials themselves were enhanced, or (iii) if the agronomic management of the materials were improved. Farmers may perceive that traditional fruit varieties are not competitive with other options because of a lack of characterization and evaluation information on the varieties, or because of a lack of information on appropriate management methods. Four cell analysis in the community with key FGD groups helps to disseminate information as default manner. Unique and high value traits can be characterized, evaluated and made available to larger impact groups by small investment. The relevance of such work in on-farm management of fruit orchards and home gardens is great as there is lack of fruit breeding work in these neglected perennial crops and time required to produce outputs is long and expensive. To date Indian researchers have identified unique and high value traits of farmer's managed fruit trees in orchards and home gardens. This includes 10 elite materials of mango, 2 pummelo and 1 *Garcinia indica* for further multiplication and use by the community. At least 5 elite materials are already characterized and submitted for official registration

1 Grassroots breeding (GB) is defined as a simple step in the plant breeding process which enhances the capacity of grassroots institutions and farmers to assess existing diversity, select niche-specific plant material, multiply and produce sufficient quality seed and distribute it within the community (Sthapit and Ramanatha Rao, 2009).

in the name of farmers at NBPGR and PPV &FRA. Identified clones are being multiplied with farmers to provide direct benefits to the impact groups as the part of community action plans to provide incentive mechanism for conservation of valuable diversity. Community based organizations (CBOs) like farmer organizations, women groups or self-help groups are established or strengthened in all 36 communities for the implementation of local action plans. Research has shown that improving markets and quality of indigenous fruit and products would be a major driver for increased investment by the private sector in the production and commercialization of indigenous fruit trees.

Conclusions

It is important to note that on-farm conservation *per se* is not a panacea. It is neither recommended as a universal practice nor a feasible method in all circumstances. It has a place and a time, as on-farm conservation can be transient and subject to change over time and that provides the major link with *ex situ* conservation. Sustainable on-farm conservation is possible only when farmers, communities, and national institutions perceive benefits in terms of social, economic and environmental services. Once we understand that the farmer management of local crop diversity is a primarily livelihoods option for rural communities, and then cost of on-farm conservation is much cheaper than *ex situ*. In the process of farming, farmers not only derive social, economic and environmental benefits from local genetic resources but also the evolutionary potential of these genetic resources. In order to ensure that communities have platform for social learning and local organizations are equipped to make decision about the management of on-farm local crop diversity, government agencies and donors must collaborate directly with them about their specific requirement and let the local lead to save agricultural biodiversity. CBM is therefore ensure that communities have the knowledge and skills and appropriate decision making capacity to manage the agricultural biodiversity to cope any adversity situation and opportunities.

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Reference

- Adhikari A, RB Rana, R Gautam, A Subedi, MP Upadhyay, P Chaudhary, I Paudel, D Rijal, B Sthapit (2006) Diversity Fair: Promoting exchange of knowledge and germplasm. In: BR Sthapit, PK Shrestha and MP Upadhyay (eds.) *Good practices: On-farm management of agricultural biodiversity in Nepal*, NARC, LI-BIRD, IPGRI and IDRC
- Agnihotri RK, S Sharma, M Joshi and LMS Paini (2004) Crop diversity in home gardens of the Kumaun region of central Himalaya, India. *Plant Genet. Resour. Newsl.* **138**: 23–28.
- Altieri MA and LC Merrick (1987) *In situ* conservation of crop genetic resources through maintenance of traditional farming systems. *Econ. Bot.* **41**: 86–96.
- Bisht IS, KS Rao, DC Bhandari, S Nautiyal, RK Maikhuri and BS Dhillon (2006) A suitable site for *in situ* (on-farm) management of plant diversity in traditional agro-ecosystems of Western Himalaya in Uttaranchal State: A case study. *Genet. Resour. Crop Evol.* DOI 10.1007/s10722-005-4432-5.
- Bellon M (2010) Do we need crop landraces for the future? Realizing the global option value of *in situ* conservation. In: A Kontoleon, U Pascual and M Smale (eds.). *Agrobiodiversity and Economic Development*, Routledge, USA.
- Bellon MR, J Berthaud, M Smale, JA Aguirre, S Taba, F Aragon, J Diaz and H Castro (2003) Participatory landrace selection for on-farm conservation: A example from the Central Valleys of Oaxaca, Mexico. *Genet. Resour. Crop Evol.* **50**: 401–416.
- Bhandari B, P Shrestha, RB Rana, A Subedi, D Gauchan, D Rijal, T Sapkota, MP Upadhyay, B Sthapit (2006) Value addition of local crop diversity. In: Sthapit, BR, Shrestha PK and Upadhyay MP 2006 (eds.). *Good practices: On-farm management of agricultural biodiversity in Nepal*, NARC, LI-BIRD, IPGRI and IDRC
- Brookfield H (2001) Exploring agrobiodiversity. New York NY, Columbia University Press, US.
- Brown AHD (2000) The genetic structure of crop landraces and the challenge to conserve them *in situ* on farms. In: SB Brush, (eds.), *Genes in the Field*. pp. 29–48. IDRC/ International Plant Genetic Resources Institute, Rome, Italy.
- Brush SB (1995) *In situ* conservation of landraces in centers of crop diversity. *Crop Science* **35**: 346–354.
- Carpenter D (2005) The *in situ* conservation of rice plant genetic diversity: A case study from a Philippine barangay. *Agriculture and Human Values* **22**: 421–434.
- CBDC (1994) <http://www.cbdcprogram.org>
- Doring TH, S Knapp, G Kovacs, K Murphy and MS Wolfe (2011) Evolutional Plant Breeding in Cereals-Into a New Era. *Sustainability* 2011 3:1944–1971; doi: 10.3390/sus3101944
- Eyzaguirre P and OF Linares (2004) Home gardens and agrobiodiversity, pp. 296, Smithsonian Books, Washington.
- FAO (1998) The State of The World's Plant Genetic Resources for Food and Agriculture. Rome: FAO.
- FAO (2009) FAOSTAT, accessed on 10 June 2009 (<http://faostat.fao.org/site/567/default.aspx#ancor>).

- FAO (2010) Status of World Report II of Plant Genetic Resources for Food and Agriculture, Rome, Italy
- Frankel OH, AHD Brown and JJ Burdon (1975) The Conservation of Plant Biodiversity. Cambridge: CUP.
- Gauchan D, BR Sthapit and DI Jarvis (2003) Agrobiodiversity conservation on-farm: Nepal's contribution to a scientific basis for policy recommendations. IPGRI, Rome.
- Gautam R, BR Sthapit, A Subedi, D Poudel, P Shrestha and P Eyzaguirre (2008) Home gardens management of key species in Nepal: A way to maximize the use of useful diversity for the well being of poor farmers. *Plant Genetic Resources Characterization and Utilization* 1-12. doi.10.1017/S1479262108110930
- Gautam R, S Sunwar, A Subedi, PK Shrestha and BR Sthapit (2009) Home gardens and their roles in domestication of wild and uncultivated plant genetic resources in Nepal. In: H Jaenicke, J Ganry, I Höschle-Zeledon and R Kahane (eds.) *Underutilized Plants for Food, Nutrition, Income and Sustainable Development*. Proceedings of International Symposium held in Arusha, Tanzania, 3-7 March 2008. *Acta Horticulturae* 806. International Society for Horticultural Science. Leuven, Belgium. 739 pp.
- Gyawali S, BR Sthapit, B Bhandari, J Bajracharya, PK Shrestha, MP Upadhyay and D Jarvis (2010) Participatory crop improvement and formal release of *Jethobudho* rice landrace in Nepal. *Euphytica* DOI 10.1007/s10681-010-213-0
- Hastings A and S Hartison (1994) Metapopulation dynamics and genetics. *Annu. Rev. Ecol. Syst.* **25**: 167-88.
- Hue N, L Trinh, N Ha, B Sthapit and D Jarvis (2003) Taro cultivar diversity in three ecotopes of North Vietnam. In: HD Tuan, N Hue, BR Sthapit, DI and Jarvis (eds.) *On-Farm Management of Agricultural Biodiversity in Vietnam*. Proceedings of a symposium, December 6–12, 2001, Hanoi, Vietnam. International Plant Genetic Resources Institute, Rome, Italy.
- Jarvis D, Toby Hodgkin, BR Sthapit, Carlo Fadda and Isabel Lopez-Noriega (2010) A Heuristic Framework for Identifying Multiple Ways of Supporting the Conservation and Use of Traditional Crop Varieties within the Agricultural Production System. *Critical Rev. Plant Sci.* 1-49.
- Jarvis Devra I, Anthony HD Brown, Pham Hong Cuong, Luis Collado-Panduro, Luis Latourniere-Moreno, Sanjay Gyawali, Tesema Tanto, Mahamadou Sawadogo, Istvan Mar, Mohammed Sadiki, Nguyen Thi Ngoc Hue, Luis Arias-Reyes, Didier Balma, Jwala Bajracharya, Fernando Castillo, Deepak Rijal, Loubna Belqadi, Ram Rana, Seddik Saidi, Jeremy Ouedraogo, Roger Zangre, Rhrib Oum Keltoum, Jose Luis Chavez, Daniel Schoen, Bhuwon Sthapit, Paola de Santis, Carlo Fadda and Toby Hodgkin (2008) A global perspective of the richness and evenness of traditional crop genetic diversity maintained by farming communities. *Proceedings of the National Academy of Sciences PNAS (USA)*:1-6; www.pnas.org/cgi/doi/10.1073/pnas.0800607105.
- Jarvis DI, C Padoch and HD Cooper (eds.) (2007) Managing biodiversity in agricultural ecosystems. Columbia University Press, New York, USA, Bioversity International, Rome, Italy. 492p.
- Jarvis DI, V Zoes, D Nares and T Hodgkin (2004) On-farm management of crop genetic diversity and the convention on biological diversity's programme of work on agricultural biodiversity. *Plant Genet. Resour. Newsl.* **138**: 5-17.
- Jarvis DI and T Hodgkin (2008) The maintenance of crop genetic diversity on farm: Supporting the Convention on Biological Diversity's Programme of Work on Agricultural Biodiversity. *Biodiversity* 23-28.
- Jarvis DI and T Hodgkin (2000) Farmer decision making and genetic diversity: linking multidisciplinary research to implementation on-farm. In: Brush, SB (ed.) *Genes in the Field: On-Farm Conservation of Crop Diversity*. Lewis Publishers, Boca Raton, FL, USA, pp 261-278.
- Joshi A and JR Witcombe (1996) Farmer Participatory Crop Improvement. II. Participatory Variety Selection, A Case Study in India. *Exp. Agri.* **32**: 461-477.
- Louette D, A Charrier and J Berthaud (1997) *In situ* conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. *Eco. Bot.* **51**: 20-38.
- Negri V (2003) Landraces in central Italy: where and why they are conserved and perspectives for their on-farm conservation. *Genet. Resour. Crop Evol.* **50**: 871-885.
- Neuendorf O (1999) Seed fairs: creating awareness of a rich heritage. *LEISA Magazine* **15**: 24-25.
- Pandey A, IS Bisht, KV Bhat and PS Mehta (2011) Role informal seed system in promoting landrace diversity and their on-farm conservation: a case study of rice in Indian Himalayas. *Genet. Resour. Crop Evol.* **58**: 1213-1224.
- Shrestha P, A Subedi, S Sthapit, D Rijal, SR Gupta and BR Sthapit (2006) Community seed bank: Reliable and effective option for agricultural biodiversity conservation. Good practice No. 10. In: BR Sthapit, P Shrestha and M Upadhyay (eds.) *Good practices. On-farm management of agricultural biodiversity in Nepal*. Kathmandu, NARC, LI-BIRD, IPGRI and IDRC, Nepal.
- Shrestha P, R Gautam, RB Rana and BR Sthapit (2002) Homegardens in Nepal: status and scope for research and development. In: JW Watson and PB Eyzaguirre (eds.) *Home Gardens and In Situ Conservation of Plant Genetic Resources in Farming Systems*. Proceeding of the Second International Home Gardens Workshops, 17–19 July 2001, Witzenhausen, Federal Republic of Germany. Rome: IPGRI, pp 105-124.
- Smith RJ (2009) Let the local lead to save biodiversity. *Nature* **462**: 280-281.
- Sperling L, HD Cooper and T Remington (2008) Moving towards more effective seed aid. *J. Dev. Stud.* **44**: 586-612.
- Sthapit BR, S Padulosi and B Mal (2010) Role of *in situ* conservation and underutilized crops in the wake of climate change. *Indian J. Plant Genet. Resour.* **23**: 145-156.
- Sthapit BR and IP Singh (2010) On-farm conservation of citrus diversity. In: *Proceedings of National seminar on Citrus Biodiversity for Livelihood and Nutritional Security*, 4-5 October 2010, Nagpur, India, pp. 139-149. National Research centre for Citrus, Indian Society of Citriculture, Nagpur, ICAR.

- Sthapit BR and VR Rao (2009) Consolidating Community's Role In Local Crop Development by Promoting Farmer Innovation to Maximise the Use of Local Crop Diversity for the Well-Being of People. *Acta Hort.* (ISHS) 806:669-676; http://www.actahort.org/books/806/806_83.htm.
- Sthapit BR, PK Shrestha, A Subedi, P Shrestha and MP Upadhyay and PE Eyzaguirre (2008a) Mobilizing and empowering community in biodiversity management. In: MH Thijssen, Z Bishaw, A Beshir and WS de Boef (eds.) (2008). *Farmer's varieties and seeds. Supporting informal seed supply in Ethiopia*. Wageningen, Wageningen International, The Netherlands, pp.160-166.
- Sthapit BR, A Subedi, P Shrestha, PK Shrestha and MP Upadhyay (2008b) Practices supporting community management of farmers' varieties. 2008. In: MH Thijssen, Z Bishaw, A Beshir, WS de Boef (eds.), *Farmer's varieties and seeds. Supporting informal seed supply in Ethiopia*. Wageningen International, Wageningen, The Netherlands, pp 166-171.
- Sthapit BR, RB Rana, PE Eyzaguirre and DI Jarvis (2008c) The value of plant genetic diversity to resource-poor farmers in Nepal and Vietnam. *Int. J. Agric. Sustain.* **6**: 148-166.
- Sthapit BR, D Gauchan, A Subedi and D Jarvis (eds.) (2007) On-farm management of agricultural biodiversity on-farm in Nepal: Lessons learned. Proc of a national workshop, 18-19 July 2006, Kathmandu, Nepal.
- Sthapit B, PK Shrestha and MP Upadhyay (eds.) (2006) Good practices: On-farm management of agricultural biodiversity in Nepal. NARC, LI-BIRD, International Plant Genetic Resources Institute and IDRC, Kathmandu, Nepal.
- Sthapit B, P Shrestha, KP Baral, A Subedi, J Bajracharya, RB Yadav (2006) Diversity block: Assessing and demonstrating local crop diversity. In: BR Sthapit, PK Shrestha and MP Upadhyay 2006. *Good practices: On-farm management of agricultural biodiversity in Nepal*, NARC, LI-BIRD, IPGRI and IDRC.
- Sthapit B, R Gautam, S Gyawali, BK Joshi, A Subedi, RB Yadav, P Chaudhary, D Rijal (2006) Diversity kits: Deploying new diversity to farmers. In: BR Sthapit, PK Shrestha and MP Upadhyay 2006. *Good practices: On-farm management of agricultural biodiversity in Nepal*, NARC, LI-BIRD, IPGRI and IDRC.
- Sthapit BR and D Jarvis (1999) PPB for on-farm conservation. *ILEA*, 15 No ¾.
- Sthapit BR, KD Joshi and JR Witcombe (1996) Farmer Participatory Crop Improvement. III. Participatory Plant Breeding, A Case Study for Rice in Nepal. *Exp. Agric.* **32**: 479-496.
- Subedi A, B Sthapit, D Rijal, D Gauchan, MP Upadhyay, PK Shrestha (2006) Community Biodiversity Register: Consolidating community role in management of agricultural biodiversity. In: BR Sthapit, PK Shrestha and MP Upadhyay 2006. *Good practices: On-farm management of agricultural biodiversity in Nepal*, NARC, LI-BIRD, IPGRI and IDRC.
- Subedi A, Pitamber Shrestha, P Shrestha, R Gautam, MP Upadhyay, R Rana, P Eyzaguirre and B Sthapit (2007) Community biodiversity management: Empowering the community to manage and mobilise agricultural biodiversity. In: BR Sthapit, D Gauchan, A Subedi and D Jarvis (eds). *On-farm management of agricultural biodiversity on-farm in Nepal: Lessons learned*. Proc of a national workshop, 18-19 July 2006, Kathmandu, Nepal, pp. 121-126.
- Subedi A, P Chaudhary, B Baniya, R Rana, P Tiwari, D Rijal, D Jarvis and B Sthapit (2003) Who Maintains Crop Genetic Diversity and How: Implications for On-farm Conservation and Utilization. *Culture & Agri.* **25**: 41-50.
- Suwal R, BR Regmi, B Sthapit and A Shrestha (2008) Home gardens are within the reach of marginalized people (24 September 2008), *LEISA* 24.3 September 2008, p 34.
- Tsehaye Y, T Berg, B Tsegaye and T Tanto (2006) Farmers' management of finger millet (*Eleusine coracana* L.) diversity in Tigray, Ethiopia, and implications for on-farm conservation. *Biodivers. Conserv.* **15**: 4289-4308.
- Trinh LN, JW Watson, NN Hue, NN De, NV Minh, P Chu, BR Sthapit and PB Eyzaguirre (2003) Agrobiodiversity conservation home gardens management of key species and development in Vietnamese home gardens. *Agri. Ecosystems Environ.* **2033**: 1-28.
- Ramanatha Rao V (2009) *In situ/on-farm conservation of crop biodiversity*. *Indian J. Genet. Plant Breed.* **69**: 284-293.
- Ramanatha Rao and BR Sthapit (2011) Conservation of Tropical Plant Genetic Resources – *In situ* Approach . In: HF Chin, BM Reed and NM Noor *Conservation of Tropical Plant Species* (eds.) Springer Science and Business Media, LLC. NY, USA
- Rice E (2007) Conservation in a changing world: in situ conservation of the giant maize of Jala. *Genet. Resour. Crop Evol.* **54**: 701-713.
- Rerkasem B and K Rerkasem (2002) Agrodiversity for *in situ* conservation of Thailand's Native Rice Germplasm. *CMU Journal* **1**: 129-145.
- UNEP (1992) Convention on Biological Diversity. Nairobi, United Nations Environment Programme.
- van Dusen, ME (2003) A meta-population approach to farmer seed system. http://are.berkeley.edu/courses/envres_seminar/s2003/VanDusenAbstract.pdf.
- Veteläinen M, V Negri and N Macted (2009) European landraces on-farm conservation, management and use. *Bioversity Technical Bulletin No. 15*. Bioversity International, Rome, Italy.
- Volk GM and CM Richards (2011) Horticulture value of wild genetic resources-Introduction to the Workshop. *Hort. Sci.* **46**: 1436-1437.
- Worede M (1997) Ethiopian *in situ* conservation. In: Plant Genetic Conservation: The *In situ* Approach. pp. 290-301. Macted, N., Ford-Lloyd, BV and Hawkes G (eds) Chapman and Hall Ltd. London, UK.
- Witcombe JR, A Joshi, KD Joshi and BR Sthapit (1996) Farmer Participatory Crop Improvement. I: Varietal Selection and Breeding Methods and their Impact on Biodiversity. *Exp. Agri.* **32**: 445-460.
- YongNeng Fu, Guo HuiJun, Chen AiGuo and Cui JinYun (2006) Household differentiation and on-farm conservation of biodiversity by indigenous households in Xishuangbanna, China. *Biodivers. Conserv.* **15**: 2687-2703.

Mini Core Collections for Enhanced Utilization of Genetic Resources in Crop Improvement

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Plant genetic resources form the raw material for developing high yielding cultivars. About 7.4 million accessions of various economically important crops have been conserved globally. Since the large size of germplasm collections hampers the assessment of their genetic worth, the 'mini core collection concept' was postulated and developed at ICRISAT. The mini core serves as an efficient and convenient option for assessment of genetic diversity, population structure, association mapping and targeted allele mining for agronomically important traits and acts as a gateway to the germplasm. Using the mini core collection approach, scientists at ICRISAT and in national programs have identified diverse sources of resistance/tolerance for many biotic and abiotic stresses, and for agronomic and quality traits in chickpea, groundnut, pigeonpea, sorghum, pearl millet, foxtail millet and finger millet. This is expected to enhance the use of germplasm in crop improvement. Molecular characterization of the mini core will further enhance its use in plant breeding programs.

Key Words: Plant Genetic resources, Core collection, Mini core collection, Biotic and abiotic stresses, Nutritional quality traits

Introduction

Plant genetic resources (PGR) that harbor a large genetic variation are the most basic and essential raw material in crop improvement programs. Vavilov (1926, 1951) was the first to realize the significance of PGR in plant breeding. He recognized the centers of origin and diversity and organized massive germplasm collection missions. The crop germplasm which includes diverse landraces, exotics and wild relatives, holds a wealth of alleles, including rare alleles, which can help raise the yield ceiling and enhance stress resistance and nutritive quality level of elite cultivars. After the success of early plant breeding efforts and introduction of modern high yielding genetically uniform hybrid and inbred varieties much of the species diversity has been lost due to replacement of traditional varieties and landraces over wide areas all over the world. In addition, change in dietary habits, natural calamities, land conversion (deforestation, developmental activities such as hydroelectric projects, roads, and urbanization) and introduction of exotic and industrial (biofuels) crops have further aggravated the situation. Though they helped raise the world food output, the vulnerability of genetically uniform modern varieties to pests and diseases with occurrence of epidemics, changes in climate and market needs became evident since the 1980's. Thus the need for development of genetically broad based cultivars and concurrently stabilizing their yield potential through

incorporation of resistance to biotic and abiotic stresses was recognized. As this requires incorporation of alleles from highly diverse genetic resources, a network of international centers was initiated in 1960's and 1970's to accelerate the collection, characterization, evaluation, documentation, conservation and distribution of the crop genetic resources. Since then the germplasm collections of major crop plants continued to grow in number and size in the world (Brown, 1989a). The crop germplasm, exposed for millennia to edaphic and climatic variations found among and within different regions, socioeconomic differences among regions, as well as among farmers within these regions resulted in the evolution of specialized landraces (Paterniani, 1990). Diversity of cropping systems also contributed to variation and differentiation among landraces. At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India, a multi-disciplinary approach is followed for assessing the genetic worth of these genetic resources for biotic and abiotic stresses, agronomic traits and quality traits to identify donor lines as well as for updating and maintenance of databases.

Before modern plant breeding had its impact on agriculture, farmers were cultivating a large number of landraces of each crop. However, in the contemporary commercial and competitive agriculture, intensive monocropping with a few very successful cultivars that shared

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a narrow genetic base, eroded the ecosystem diversity and made crops vulnerable to many pests, diseases and climate change. The extinction of landraces and erosion of genetic diversity in the last century resulted in an estimated 75% loss of the crop diversity. A report by RAFI (Rural Advancement Foundation International, <http://www.rafiusa.org>) indicates that a large number of germplasm accessions in U.S. Department of Agriculture lists have been lost in the last 80 years. In The Philippines, only two rice varieties account for 98% of the area sown today against thousands of landraces farmers used to grow in earlier decades. Of 8000 traditional rice varieties that were grown in China in 1949, only 50 remained in 1970. Mexico has lost an estimated 80% of its maize landraces (<http://www.primalseeds.org/bioloss.htm>). Similarly in India also only a few modern varieties, with common pedigree are making a sustained presence in the seed chain of major crops.

The genetic resources management has two important aspects – germplasm conservation and its utilization in crop improvement. Germplasm can be conserved *in situ* by establishing ‘reserves’ or *ex situ* by assembling collections in genebanks through exchange or exploration. Maintenance is done by monitoring and protecting the reserves or storing the seed and periodically rejuvenating it, *ex situ*, in controlled conditions along with maintaining passport data. The evaluation involves assessing germplasm for agronomic traits which interact with the environment. Further the germplasm is enhanced by introgressing high value traits from exotic germplasm into adapted varieties (Bretting and Widrechner, 1995) through pre-breeding. To guard against the loss of valuable diversity, intensive collection of different crop species was undertaken by the global community. As a result, over 7.4 million *ex-situ* germplasm accessions are conserved in ~1750 genebanks globally, of which ~ 11% are in the genebanks of various CGIAR institutions. These genetic materials comprise of landraces or traditional varieties,

wild and weedy forms, related wild species, genetic stocks, inbred lines and even modern cultivars. ICRISAT has one of the largest collections in the CGIAR system, conserving 119,739 accessions of its mandate crops and six small millets from 144 countries (Table 1).

The Need and Use of Germplasm by Plant Breeders

After the initial wave of high yielding cultivars in most crops, further improvement in yield potential has slowed down and is progressing in small increments and current breeding efforts are mainly directed towards stabilizing the yield potential as the vulnerability of genetically uniform modern varieties to pests, diseases, changes in climatic conditions and consumer preferences is well recognized. The diverse landraces, exotics and wild relatives hold a wealth of alleles, which, if included in breeding programs can help raise the yield ceiling as well as enhance stress resistance level and nutritional quality of cultivars. Most breeders concentrate their efforts on yield enhancement using already genetically alike cultivars/superior breeding lines as parents. Usually breeders deploy a small working collection of germplasm they are familiar with, as reliable information on potential donors for important traits on large germplasm collection is not readily available.

A large number of germplasm lines are distributed by the international genebanks for use in crop improvement programs. ICRISAT genebank distributed ~ 1.4 million seed samples to scientists in 144 countries (Table 1). In several instances, the exotic germplasm lines have been found high yielding and adapted to local conditions. Seventy five of such germplasm accessions (33 sorghums in 17 countries, 13 pigeonpeas in 7 countries, 15 chickpeas in 15 countries, 10 groundnuts in 14 countries, 2 finger millets in 1 country, 1 pearl millet in 3 countries and 1 barnyard millet in 1 country) which have performed significantly better for yield and other traits of economic importance have been directly released as cultivars. In

Table 1. Status of germplasm collections conserved at ICRISAT, Patancheru, India

Crop	Number of accessions conserved	Samples distributed		
		India	Other countries	ICRISAT
Sorghum	37,949 (92)*	130,212	128,749 (106)	237,035
Pearl millet	22,211 (50)	61,424	33,624 (79)	54,729
Chickpea	20,267 (60)	72,477	58,078 (88)	188,535
Pigeonpea	13,632 (74)	49,257	21,481 (111)	84,224
Groundnut	15,445 (92)	47,173	51,797 (94)	96,299
Small millets (6)**	10,235 (50)	42,604	20,803 (58)	7,906
Total	119,739 (144)	403,147	314,532 (143)	668,728

* Figures in parenthesis indicates the number of countries

** Finger millet, Foxtail millet, Proso millet, Barnyard millet, Little millet and Kodo millet

addition, 787 cultivars in 78 countries were released by the NARS partners from breeding materials supplied by ICRISAT that were developed using germplasm lines.

Only a very small proportion (<1%) of the germplasm collections has been used in crop improvement programs. During the period 1986-2008, the ICRISAT groundnut breeding program, for example, developed a total of 10331 advanced breeding lines (ICGV #) from thousands of crosses involving 1270 unique parents – out of these only 171 were germplasm lines, including 10 wild, from an entire collection of 15445 accessions. The most frequently used lines being Robut 33-1 (3110 times), Chico (1180 times), JL 24 (845 times), NCAc 1107 (481 times) and NCAc 2214 (469 times); they being either popular cultivars or breeding/germplasm lines. Like wise in chickpea (1978-2008), out of 20,267 accessions conserved only 94 unique accessions (including 5 wild) were used in developing 3728 advanced breeding lines; L550 (903 times), K850 (854 times) and GW 5/7, Annigeri and H 208 (>500 times) being the most frequently used. The pedigree analysis of the grain legume cultivars released by India's national and regional breeding programs (229 cultivars, up to 2003), showed that Pb 7 in chickpea, L 9-12 in Lentil, T 1 and T 90 in pigeonpea, T 9 in blackgram and T 1 in mungbean were the most frequently used parents (Kumar *et al.*, 2004), which clearly indicates their narrow genetic base. Similar situation prevails in other crops as well. Low use of germplasm has also been reported in wheat (Dalrymple, 1986), spring barley (Vellve, 1992) and maize (Cantrell *et al.*, 1996).

The reasons for low use of germplasm by crop breeders are that they continue to make reasonable progress, with their working collections and the apprehension that broadening the adapted genetic base would result in diminished agronomic performance (Kannenberg and Falk, 1995). In fact, elite inbred lines are considered the best genetic resources simply because each line contains a select combination of genetic traits that satisfies the farmer and the marketplace (Troyer, 1990). Yet, new germplasm if used in crop improvement programs can (a) raise the ceiling of genetic yield potential, (b) improve resistance to biotic and abiotic stresses, and (c) add new developmental pathways and ecological adaptations (Kannenberg and Falk, 1995).

Although plant breeders recognize the potential value of the diverse genetic resources, they are often reluctant to use these resources due to lack of reliable knowledge about their genetic worth; the load of unwanted genetic

linkages; lack of time and resources for identifying new superior donor genotypes for yielding ability, stress tolerance or better nutritional quality from a reservoir of germplasm; possibility of introducing toxic, allergenic, or pharmaceutically active plant products into food products, a risk that is virtually absent in crossing elite, widely grown germplasm (Heslop-Harrison, 2002). Thus a wide gap between available genetic resources and their use in breeding programs (Marshall, 1989) continues to exist.

Strategies to Enhance the Use of Germplasm

Most economically important traits are quantitative, which are highly environment sensitive and display a great deal of genotype $\times$ environment interaction. Hence, donor lines with very specific and simply inherited traits such as resistance to biotic stresses and occasionally abiotic stresses which can be followed easily through generations are preferred. Moreover, selecting a few lines from the vast pools of germplasm is like searching for a needle in a haystack. Obviously, it is more appropriate to have a small sample of a few hundred accessions, representing the entire diversity exhibited by the crop species, coupled with a multi-environment evaluation data, which would greatly encourage the breeders to opt for induction of more germplasm lines in to their breeding programs. Frankel (1984) proposed 'core collection' approach to meet this objective, which would 'represent with a minimum of repetitiveness, the genetic diversity of a crop species and its relatives'.

The Core Collection

A representative sample that more or less reflects the diversity in the large entire collection would be cost effective and easy to maintain by individual breeders and facilitate the enhanced use of germplasm in breeding programs. The representative sample, named "core collection" (Frankel, 1984) is a subset, consisting of ~10% of total accessions, which between them capture most of the available diversity in the entire collection (Brown, 1989a). The size of the core collection should be limited to ~10%, using the sampling theory of selectively neutral alleles, with a ceiling of ~3000 per species. This level of sampling is effective in retaining a minimum of 70% of alleles of entire collection (Brown, 1989b). These can be thoroughly evaluated and the information so derived can be utilized for improving the efficiency of breeding programs. The guiding principles to constitute a core collection are that: a) the entire collection is a large taxonomic entity; b) the core collection has a greatly reduced size; c) the core

is a true representative of the entire collection and d) the core too is nearly as diverse as the entire collection.

It is not desirable to opt for absolute maximum possible diversity in the core collection, as it would lead to inclusion of large numbers of wild relatives. So a good core collection need not represent every part of the entire collection equally. Steps involved in constituting the core (Brown, 1989b; Upadhyaya *et al.*, 2009c) are:

1. Deciding the size of the core: The size of the core depends on the purpose for which it is being constituted. In general, the core should ultimately be of great use for all types of diverse breeding programs. If the core is assembled with a specific objective such as grain nutrient quality, only relevant accessions that are most diverse can be included, limiting the size of the core. The data on taxonomy, passport and characterization of the entire collection should be assembled and verified. About 10% of accessions from the total collection that retain most (at least 70%) of the alleles present in the entire collection are to be selected, to form the core.

2. Sorting accessions into groups: Using the available data, the accessions are grouped hierarchically into taxonomic groups (subspecies and races), geographic groups (country, state), climatic (agro-ecological) groups and by characterization data into specialized groups. Grouping the collection into smaller subgroups within groups is also done in such a way that the within group or subgroup variance is very low and between group variance is high. This type of stratification will increase the efficiency of sampling with the right choice of sample size for each group. When there is no basis for stratification, simple random sampling can be used (Brown, 1989a). The accessions that constitute a subgroup would be more or less uniform and therefore ~10% of accessions are retained from each subgroup generally.

3. Selecting accessions for core: After dividing the entire collection into groups, the number and choice of accessions from each group that enter into core is decided, based on considerations such as group size, within group genetic diversity, or the accessions with special merit and utility. The magnitude of diversity in the core is then compared statistically with that of entire collection to confirm that the core is representative and has captured most of the diversity in the entire collection.

4. Managing the core collection: The final stage is managing the core accessions themselves. They may be regenerated, held separately from the parent collection and further evaluated in multiple environments for agronomic,

quantitative traits or screened for specific purposes.

Following the above strategies, ICRISAT has developed core collections capturing over 80% of variability in the entire collections of sorghum (3575 accessions, Prasada Rao and Ramanatha Rao, 1995; 2247 accessions, Grenier *et al.*, 2001), pearl millet (1600 accessions, Bhattacharjee *et al.*, 2007; 2094 accessions, Upadhyaya *et al.*, 2009a), chickpea (1956 accessions, Upadhyaya *et al.*, 2001), groundnut (1704 accessions; Upadhyaya *et al.*, 2003), pigeonpea (1290 accessions; Reddy *et al.*, 2005), finger millet (622 accessions, Upadhyaya *et al.*, 2006a) foxtail millet (155 accessions, Upadhyaya *et al.*, 2008c), and Proso millet (Upadhyaya *et al.*, 2011b) using passport information and characterization data generated over a period of time (Table 2). The core collection could differ on scale and can be global, regional or even trait specific. However, against trait specific core, the arguments are: a) if the information is available for a trait on entire germplasm which is required, there is no need to develop core, as scientists can select the desirable genotypes from entire collection, and b) there would be multiple core collections (as many as traits) from a single entire collection, thus diluting the purpose of constituting the core collection. All the other germplasm that is not included in the core is retained and maintained as 'reserve collection'.

The Mini Core Collection

The germplasm collections held by genebanks at most International Agricultural Research Centers (IARCs) are very large in size. For example the IRRI genebank holds ~ 120,000 rice accessions; hence the size of core collection (~10%) will be about 12000 accessions, which again restricts its proper evaluation and use by breeders. To overcome this constraint of large sized core collections, Upadhyaya and Ortiz (2001) postulated the "mini core" collection concept, and developed a two stage strategy to constitute it. The first stage in constituting the mini

Table 2. Core and mini core collections developed at ICRISAT, India

Crop	Number of accessions			
	Entire Collection	Used for core development	Core collection	Mini core collection
Sorghum	37,949	22,474	2,247	242
Pearl millet	22,211	20,844	2,094	238
Chickpea	20,267	16,991	1,956	211
Pigeonpea	13,632	12,153	1,290	146
Groundnut	15,445	14,310	1,704	184
Finger millet	5,949	5,940	622	80
Foxtail millet	1,535	1,474	155	35
Proso millet	842	833	106	—

core involves development of a core collection from the entire collection and the second stage involves evaluation of the core for various morphological, agronomic, stress tolerance and quality traits or need specific characters and selecting a further subset of about 10% accessions from the core. At both stages, standard clustering procedures are used to create groups of similar accessions to select entries to represent the group in the core/mini core (Figure 1, Upadhyaya *et al.*, 2009c).

Following the strategy suggested by Upadhyaya and Ortiz (2001), scientists in different countries such as USA (groundnut, 112 accessions, Holbrook and Dong, 2005), Japan (rice, 50 accessions, Ebana *et al.*, 2008) and at ICRISAT have developed mini core collections (Table 2) of chickpea (211 accessions; Upadhyaya and Ortiz, 2001), groundnut (184 accessions, Upadhyaya *et al.*, 2002), pigeonpea (146 accessions; Upadhyaya *et al.*, 2006b), sorghum (242 accessions; Upadhyaya *et al.*, 2009b), pearl millet (238 accessions; Upadhyaya *et al.*, 2011d), finger millet (80 accessions; Upadhyaya *et al.*, 2010a) and foxtail millet (35 accessions; Upadhyaya *et al.*, 2011a). The reduced size of mini core collections has facilitated the efficient and economic multi-environment evaluation of germplasm lines by scientists resulting in identification of several new sources of variation for different traits for utilization in breeding programs.

Identification of Promising Donor Lines

Knauf and Gorbet (1989) observed that in general the use of germplasm in breeding programs has been limited to sources of - resistance to pests and diseases, male sterility, short stature or traits that have a simple inheritance. Efforts to identify germplasm lines for increasing yield potential are rare compared to stress resistance or nutritional quality traits (Halward and Wynne, 1991). Thus identification of promising sources for quantitative traits is a difficult task. Important accessions for tolerance to abiotic and biotic stresses and for agronomic and nutritional traits identified in ICRISAT mandate crops (chickpea, pigeonpea, groundnut, sorghum and pearl millet) and small millets using mini core collections are presented here.

Drought: Deep and extensive root system has been recognized as one of the most important traits for improving the productivity of the crop plants under limited soil moisture. From the chickpea mini core collection, Kashiwagi *et al.* (2005, 2007) identified 10 accessions each in desi and kabuli types of chickpea with high root length density (RLD), 10 accessions with long deep

roots and 6 accessions with slightly large shoot to root length density ratio (S/RLD) in comparison to a known drought tolerant accession, ICC 4958. A landrace from Turkey (ICC 8261), had a unique character of large RLD with long deep roots and large biomass allocation to the root system, which could be of high importance under severe drought conditions. Similarly in groundnut 18 lines with better drought avoidance traits were identified (Upadhyaya, 2005).

Genotypes with high water use efficiency (WUE) sustain their productivity even when water availability is limited. Upadhyaya (2005) evaluated groundnut mini core collection for traits such as SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA), which are surrogate traits and highly correlated with WUE and identified 18 (5 vulgaris and 13 hypogaea) highly diverse accessions with high SCMR and low SLA. About 10 accessions for transpiration efficiency, 10 accessions for root length density, and 10 accessions for total dry biomass were also identified from the groundnut mini core. Kashiwagi *et al.* (2006a) evaluated chickpea mini core collection and identified ICC 16374 for high SCMR (66.4). Similarly, lines for WUE and high SCMR (ICC 1422, 4958, 10945, 16374, 16903); for high carbon isotope discrimination ($\delta^{13}\text{C}$) (-26.0%) and high TE under stress (3.9 g kg^{-1}) and under well-watered (2.8 g kg^{-1}) conditions (ICC 5337) were identified (Kashiwagi *et al.*, 2006b). Further, ICC 14799 had largest canopy area with relatively cool canopy temperature (Kashiwagi *et al.*, 2008). In groundnut, 30 (11 from mini core) consistently drought tolerant lines were identified from the reference set. (Hamidou, *et al.*, 2011).

Water-logging: Krishnamurthy *et al.* (2011a) identified 24 highly tolerant and 39 tolerant germplasm lines for water-logging from the pigeonpea mini core consisting of 146 accessions.

Salinity: Thirty salinity tolerant accessions yielding more than the tolerant control CSG 8962 were identified (Krishnamurthy *et al.*, 2011b) from the chickpea mini core collection screened under saline condition (80mM NaCl; using pot culture screening method) and large variation for seed yield under salinity was observed. Likewise, in pigeonpea mini core, 16 salinity (1.9 L of 80mM NaCl per 7.5 kg vertisol) tolerant lines were identified (Srivastava *et al.*, 2006). Similarly, 10 accessions in sorghum, 13 in pearl millet, 14 in groundnut, 10 in finger millet and 10 accessions in foxtail millet were identified as tolerant to salinity (Upadhyaya *et al.*, 2009c, 2010b).

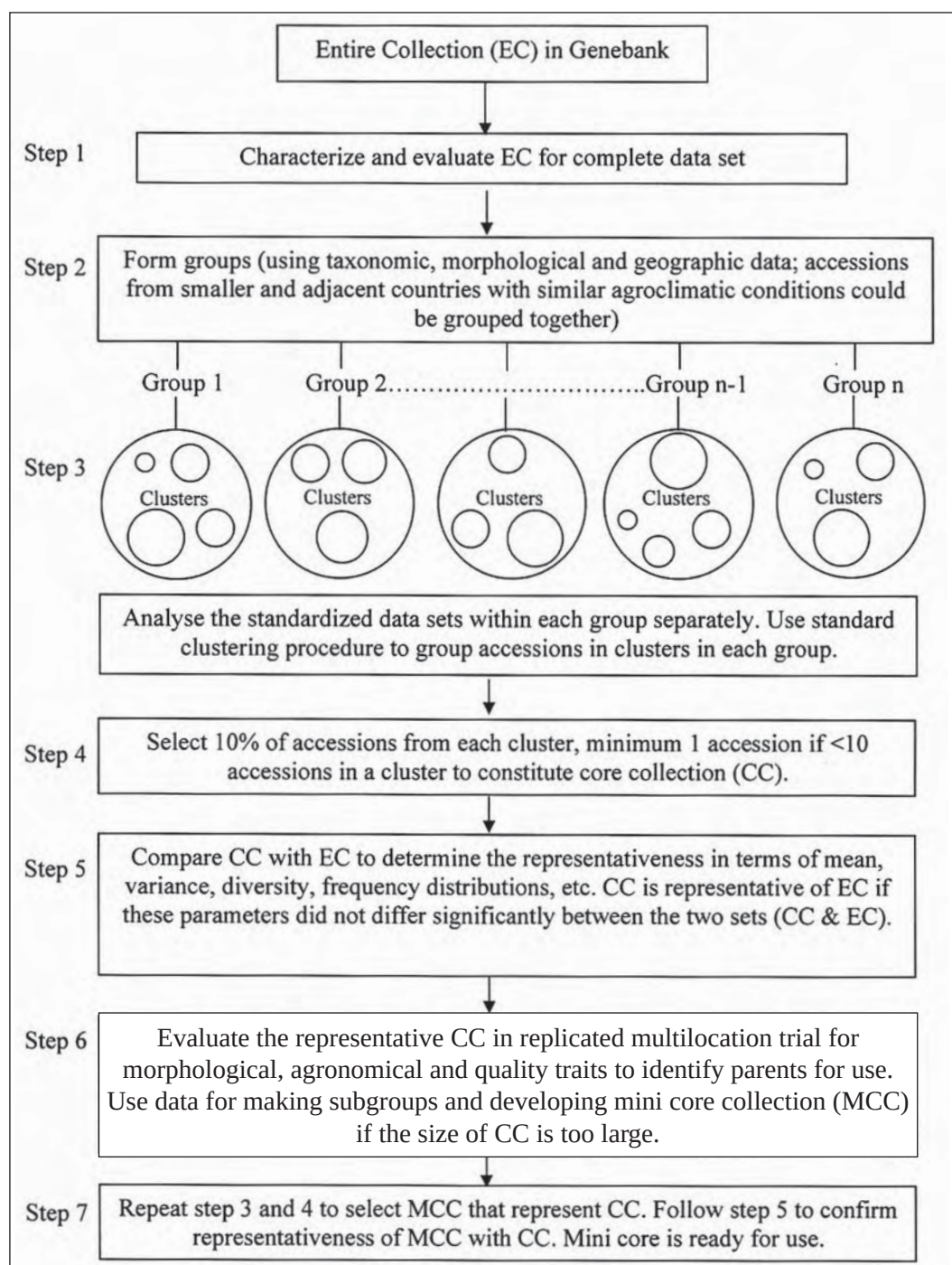


Fig. 1: Flow diagram to establish core and mini core collections in a crop species (adapted from Upadhyaya *et al.*, 2009c)

Low and high temperature: In groundnut, tolerance to low temperature at germination (12 °C) is an important trait. Several accessions of the groundnut mini core with capacity to germinate at lower temperature have been identified, many of them maturing and/or yielding similar to or better than the best control (Upadhyaya *et al.*, 2009d). Some of

the best performing low temperature tolerant accessions for pod yield include ICGs 12625, 13284, 2039, 13513, and 1824 in rainy season, ICGs 12553, 12625, 7898, 10595, 6148, 6022, 7013, 7884, 7905, and 4992 in post rainy season, and ICGs 12625, 7898, 11130, 6148, 7013, 6022, 7905, 7884, and 4992 for both the seasons.

In chickpea, ICC 14346 (BG 274, India) showed high tolerance to heat stress with least reduction in yield. A few accessions (ICC 14284, 6121, 7410, 13124, 14653, 11916, 5597, 14368, and 5829) that were on-par or high yielding than the control under heat stress and responsive to stress mitigation measures such as irrigation and nitrogen management were identified (Upadhyaya *et al.*, 2011c). Similarly from the chickpea reference collection, Krishnamurthy *et al.* (2011c) identified 18 (16 from mini core) stable heat tolerant lines.

Diseases: Pande *et al.* (2006) identified sources of moderate (with 3.1-5.0 score, on 1-9 scale) resistance to ascochyta blight (AB, 3 accessions), botrytis gray mold (BGM, 55 accessions) and dry root rot (DRR, 6 accessions). Twenty-one asymptomatic and 24 resistant sources for fusarium wilt (FW) and several multiple resistant lines such as ICC 11284 (for AB and BGM); ICC 11763 and 12328 (for BGM and DRR); ICC 1710, 2242, 2277 and 13441 (for DRR and FW); and ICC 2990, 4533, 6279, 7554, 7819, 9848, 12028, 12155, 13219, 13599 and 13816 (for BGM and FW) were also identified from the chickpea mini core collection (Pande *et al.*, 2006). Similarly in pigeonpea mini core, many accessions resistant to wilt (22), sterility mosaic (11) and both wilt and sterility mosaic (3) were identified.

In groundnut, 6 accessions were identified as having combined resistance to late leaf spot (LLS) and rust (R), 4 accessions for early leaf spot (ELS) and 3 for all the three diseases. Three accessions resistant to the bud necrosis disease, 5 to *A. flavus* colonisation and aflatoxin contamination were identified. In China, 14 accessions resistant to the bacterial wilt were identified. Similarly, Damicone *et al.* (2009) identified 5 accessions with high multiple resistance to *Sclerotinia* blight, pepper spot and web blotch.

Forty-nine grain mold resistant, 50 downy mildew resistant (≤ 3.0 score) accessions and one with multiple resistances have been identified from sorghum mini core collection by Sharma *et al.* (2010). In further evaluation 13 mini core accessions were found resistant (≤ 3.0 score) to anthracnose, 27 to leaf blight and 6 to both diseases (Sharma *et al.*, 2011). One accession, IS 473 showed resistance to all the four diseases (Anthracnose, Leaf blight, Rust and Grain mold) in the mini core collection. Scientists at the Texas A & M University, USA, have identified sorghum mini core accessions resistant to anthracnose (123), head smut (58) and downy mildew.

From the pearl millet mini core collection IPs 8418, 9934, 10263, 11405, 11428, 11930, 17775, and 20715 were identified as downy mildew free, for use in DM resistance breeding program.

In the finger millet core, 11 accessions highly resistant (< 1 score on 1-5 scale) to neck blast, 57 accessions highly resistant to finger blast and 3 accessions resistant to both neck and finger blast, compared to $> 80\%$ incidence in susceptible controls (VL 149 and VR 708) were identified (Kiran Babu *et al.*, 2011).

Blast disease of foxtail millet [*Setaria italica* (L.) P. Beauv.] caused by *Pyricularia grisea* (Cooke) Sacc. (teleomorph- *Magnaporthe grisea*) is a major problem both in India and Africa, causing substantial yield loss. Foxtail millet core collection was evaluated and neck blast resistant accessions ISe 375, 480, 748, 751, 769, 1037, 1067, 1204, 1320, 1335, 1387, 1419, 1547, 1593, 1685, 376 and 1541 were identified (Upadhyaya *et al.*, 2010b).

Insect-pests: Chickpea mini core was evaluated for helicoverpa pod borer resistance using detached leaf assay screening (Sharma *et al.*, 2005). ICC 5878, 6877, 11764, 16903, and 18983 (1.0-2.3) had very low leaf-feeding score as compared resistant control cultivar ICC 506-EB (3.1). ICC 12537, 9590, 7819, 2482, and 4533 (37-47%) had least larval survival rate. Larvae fed on ICC 16903, 6877, 3946, 11746, and 18983 (1.2-2.1 mg larva⁻¹) gained lowest larvae weight compared to ICC 506-EB (2.3 mg). Similarly, in pigeonpea, ICP 7, 655, 772, 1071, 3046, 4575, 6128, 8860, 12142, 14471, and 14701 exhibited promising levels of tolerance (damage rating 5.0 as compared to 9.0 in ICPL 87) to the helicoverpa pod borer. These lines also showed good yield potential (> 0.85 to 1.54 t ha⁻¹) under unprotected conditions, and had no wilt incidence as compared to 38.2% wilt in the control cultivar, ICP 8266. Twenty lines from groundnut reference set (including mini core) were promising for insect tolerance (defoliation $< 5\%$) and with resistance to bud necrosis disease (< 1) and high pod yield (2.25-4.25 t ha⁻¹) compared to control cultivars M 13, Gangapuri, ICGS 44 and ICGS 76 (0.78-1.11 t ha⁻¹) based on three years performance (Upadhyaya *et al.*, 2010b).

Early maturity: Appropriate time to maturity is a major component of crop adaptation, particularly in the environments where the growing season is restricted by terminal drought and high temperature and most breeding programs target early-maturing cultivars whose maturity

period matches with the available cropping duration. Twenty-eight early maturing chickpea accessions which were similar or earlier than the control cultivar Harigantars and ICCV2 and produced on an average of 22.8% higher seed yield than the control cultivars (Upadhyaya *et al.*, 2007c) were identified. Twenty-one early-maturing groundnut accessions which were similar in maturity to earliest maturing control cultivar Chico and produced 12.6% higher pod yield at 75 days and 8.4% more pod yield at 90 days compared to the average of control cultivars Chico, Gangapuri, and JL 24 were identified, (Upadhyaya *et al.*, 2006c). In pigeonpea, 20 accessions were early in maturity and produced more seed yield than the early maturing control cultivar ICPL 87. ICP 14471, 14903, 16309, 15068, 14832 and 9336 were the most promising accessions for extra early flowering (Upadhyaya *et al.*, 2010b). Khairwal *et al.* (2007) identified 25 pearl millet accessions for early flowering. IEs 501, 2093, 2957, 3543, and 4374 (40-50 days) in finger millet, ISe 1575 and ISe 1647 (<23 days) in foxtail millet were the most promising early flowering accessions. Similarly, six accessions (<50 days) were identified in sorghum for early flowering (Upadhyaya *et al.*, 2010b).

Large Seed Size: In chickpea consumers prefer the large seeded and white types for whole seed consumption, confectionary products, salads and savory meals. Thus seed size and color are important traits for trade in chickpea. Gowda *et al.* (2011) identified 65 large seeded (100-seed weight >40g) Kabuli chickpea lines for use in crop improvement using the core collection approach. ICC 14190, a highly fusarium wilt resistant, large-seeded ($37.4\text{ g } 100\text{ seeds}^{-1}$) Kabuli landrace from India which also ranked first with a mean yield of 1.43 t ha^{-1} and high productivity ($13.64\text{ kg ha}^{-1}\text{ day}^{-1}$) was identified. ICC 14194 and ICC 7344 were early flowering, extra-large seeded types ($>55\text{ g } 100\text{ seeds}^{-1}$) with grain yield on par with the best control, L 550. All these 3 genotypes exhibited high stability with a regression value of unity and deviation near zero. Another accession, ICC 17109, is an extra large seeded type ($63\text{ g } 100\text{ seed}^{-1}$) but with a lower grain yield and low stability (highly significant S^2_d) (Gowda *et al.*, 2011). These large seeded Kabuli types with high yield and stable performance can be used in breeding program to develop large-seeded high yielding Kabuli cultivars or used directly for cultivation. In groundnut, we identified, ICGs 2381, 5016, 5051, 5745, 5662, 6057, 6766, 8760, 11219, 11855, 11862 and 14482 (100-seed weight >60g) and in pigeonpea, ICP 14976, 13359 and 13139 (100-seed weight > 16g) for large seed size.

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Similarly, 15 accessions (>5.0g) in sorghum (Upadhyaya *et al.*, 2010b) showed high 100 seed weight. Khairwal *et al.* (2007) identified 16 large-seeded pearl millet accessions for utilization in crop improvement programs. Evaluation of chickpea mini core in India and groundnut in China, Vietnam, and Thailand resulted in identification of 13 large seeded chickpea accessions (Kaul *et al.*, 2005) in India and five large-seeded groundnut accessions each in China, Vietnam, and Thailand (Upadhyaya *et al.*, 2009c; Upadhyaya *et al.*, 2010b).

Yield and Components: Evaluation of chickpea core led to the identification of 39 highly diverse and superior accessions for a combination of agronomic traits such as early maturity, seed size and grain yield (Upadhyaya *et al.*, 2007a). Eighteen accessions had higher pod number (>50) and 2 accessions had higher seed number per pod (>1.5). Twenty three accessions were adapted to irrigated, 11 to non-irrigated, and 14 to both irrigated and non-irrigated environments. In multilocation testing, chickpea mini core accessions, ICCs 637, 1098, 3325, 3362, 4918, 7441, 8384, 8621, 9586, 12307, 14402, 14815 and 15868 produced greater seed yield than the control cultivars. Upadhyaya *et al.* (2005) identified 15 fastigiata, 20 vulgaris, and 25 hypogaea type groundnut accessions for pod yield and its components upon multilocation evaluation of ground core collection for Asia region. Similarly, upon multilocation evaluation of groundnut mini core (Upadhyaya *et al.*, 2002) ICGs 36, 1519, 3992, 5195, 5236, 8083, 9037, 9157, 9809, and 12988 for shelling percentage; ICGs 5745, 6646, 10036, 11088, 13099, and 15419 for pod yield were identified. From the pigeonpea mini core evaluation, several accessions with early maturity, greater harvest index and shelling percentage, and high grain yield were identified. Five accessions with higher grain yield ($>2.5\text{ t ha}^{-1}$) compared to the control cultivars ICPL 87 (extra early), UPAS 120 (early), Maruti (medium) and Gwalior 3 (late) were identified. Two accessions ICP 14900 and ICP 1156 flowered in less than 100 days and produced higher seed yield than the extra early control cultivar ICPL 87. The study also identified ICP 8860 for greater number of primary branches (29); ICP 5860, ICP 11230, ICP 4167, ICP 8602 for more pods per plant based on multilocation evaluation of pigeonpea mini core collection (ICRISAT Archival report 2009).

Accessions with high green fodder yield, more productive tillers per plant, high ear head spikelet density, higher grain yield and large seed size were identified in pearl millet (Upadhyaya *et al.*, 2007b). Khairwal *et al.*

(2007) identified 15 accessions for green fodder yield and 9 accessions for higher grain yield potential based on multilocation evaluation of pearl millet core collection. Similarly, pearl millet core collection was evaluated at ICRISAT, Patancheru and we identified 20 accessions for grain yield, 9 for fodder yield, 11 for large seed size, and one accession for synchronous panicle maturity. Several new sources for high grain and/or fodder yield, extra-early flowering, more basal tillers, panicles with variable exertion and head shape were identified in sorghum. Additionally, 12 accessions with higher level of soluble sugar content in stalk (14-20%) were identified in the sorghum mini core collection.

Trait-specific accessions identified from the finger millet core collection include those with early flowering, more basal tillers, long inflorescence, high grain and/or fodder yield, more number of fingers per ear (ICRISAT Archival Report, 2009). New sources identified from foxtail millet core collection include ISe 1575 and ISe 1647 for early flowering (<23 days); ISe 792, 1059, 1067, 1258, 1474, 1575, 1581, 1593 and 1647 for high yield (>1.7 t ha⁻¹); ISe 1789 and ISe 1851 for longer (>250 mm) and wider (>45 mm) inflorescence (Upadhyaya *et al.*, 2010b)

Quality traits: Core and mini core collections were evaluated for nutritional traits and 5 accessions for high seed protein (22.5-23.8%) in chickpea, 14 accessions each for zinc (38.9-41.4 mg kg⁻¹) and iron (43.3-45.0 mg kg⁻¹) in pigeonpea, 10 accessions each for high iron (58.2-87.0 mg kg⁻¹) and zinc (33.4-39.1 mg kg⁻¹) in sorghum, 10 accessions each for iron (104.2-123.6 mg kg⁻¹) and zinc (83.7-88.3 mg kg⁻¹) in pearl millet. Similarly, 15 accessions each for zinc (22.46-25.33 mg kg⁻¹), iron (37.66-65.23 mg kg⁻¹), protein (8.66-11.09%) and calcium (3860-4890 mg kg⁻¹) contents in finger millet (Upadhyaya *et al.*, 2011e) and 21 accessions each for zinc (54.5-74.2 mg kg⁻¹), iron (58.2-68.0 mg kg⁻¹), protein (15.6-18.5%) and calcium (171.2-288.7 mg kg⁻¹) contents in foxtail millet were identified (Upadhyaya *et al.*, 2011a). In a collaborative evaluation at ICRISAT, Patancheru and University of Agricultural Sciences, Dharwad, we identified 18 accessions each with high protein content (>29%), high oil content (>48%), high Oleic acid content (>58%) and high Oleic(O)/Linoleic(L) acid ratio (>2.5) and one accession with very high Oleic acid content (73.3%) and O/L ratio (6.91) (Upadhyaya *et al.*, 2012) and 2 accessions for low lectin content (Kusuma *et al.*, 2006) from the groundnut mini core collection. Similarly in China, 3 accessions with

high O/L ratio were identified. High oil accessions, 5 each in India, China, Thailand, and Vietnam were identified for use in the crop improvement programs (ICRISAT Archival Report 2009).

Trait specific lines for resistance/tolerance to late leaf spot, early leaf spot, rust, bacterial wilt, *A. flavus*, drought, low temperature at germination, and multiple resistance in groundnut; early maturing, large-seeded, high-yielding, high shelling lines with high seed protein, vegetable types, and lines tolerant to salinity, wilt, sterility mosaic, and *Phytophthora* blight in pigeonpea; early maturing, large-seeded, high yielding lines with, high zinc and iron content, and resistance to downy mildew in pearl millet; early maturing, large-seeded, high-yielding lines with high seed calcium and high stalk sugar content, and resistant to grain mold, downy mildew, leaf blight, rust, and multiple resistant in sorghum; early maturing, high-yielding lines with high calcium, iron, zinc and protein content, and resistance/ tolerance to drought, salinity, and blast disease in finger and foxtail millet have been identified.

Molecular Marker Characterization of Mini Core Collections

Characterization of germplasm with molecular markers provides an opportunity for structural dissection to assess allelic diversity, identification of rare alleles from cultivated and wild species accessions which could be used to select specific accessions for allele mining for crop improvement. ICRISAT in collaboration with generation challenge program (GCP) and partners such as ICARDA, Syria; CIRAD, France; EMBRAPA, Brazil; and CAAS, China has developed the composite collections of sorghum, pearl millet, chickpea, pigeonpea, groundnut, finger millet and foxtail millet. The composite collections include core and mini core collections and were genotyped using 20-50 SSR (Simple Sequence Repeats) markers to study genetic diversity, population structure and to establish reference sets of genetically diverse accessions (200-400 accessions). To cite an example, the genetic structure, diversity and allelic richness in a world composite collection of chickpea (3000 accessions), using 48 SSR markers, was assessed and a reference set of 300 accessions was established at ICRISAT (Upadhyaya *et al.*, 2008b). The 48 SSR markers detected 1683 alleles in 2915 accessions, of which, 935 were considered rare, 720 common and 28 most frequent. The composite collections were also characterized for morpho-agronomic traits at ICRISAT, India. Reference sets based on SSR markers, qualitative traits, quantitative

traits and their combinations were formed and compared for allelic richness and diversity. In chickpea, for example, 48 SSR based reference set captured 78.1% alleles of the composite collection (1683 alleles) compared to 73.5% of alleles in the reference set based on 7 qualitative traits. The reference sets based on SSR and qualitative traits captured 80.5% alleles (1354) of composite collection. Similarly, in groundnut the SSR-based reference set captured 95.1% alleles (466) of composite collection (490) compared to 93.3% of alleles (457) in the reference set based on 14 qualitative traits. The reference sets based on SSR and qualitative traits captured 95.9% (470) alleles of the composite collection (Upadhyaya, 2008). In pigeonpea, a reference set based on SSR data and consisting of 300 most diverse accessions, captured 187 (95%) of the 197 alleles of the composite collection. Another reference set based on qualitative traits captured 87% alleles of the composite set (Upadhyaya *et al.*, 2008a). This demonstrated that both SSR and qualitative traits were equally efficient in capturing the allelic richness in the reference sets. Further, the reference set selected using quantitative agronomic traits performed well for these traits than the reference set based on SSRs.

Mini Core Collection and Plant Breeders

Mini core collection, an International Public Good, is the gateway to access the genetic diversity by global community in the large germplasm collections of any species. Many national programs have shown interest in the mini core sets of different crops and ICRISAT, on request, has supplied 116 sets (Table 3) of mini core of chickpea, groundnut, pigeonpea, sorghum, pearl millet, finger millet and foxtail millet to NARS researchers in 18 countries. In many other countries the development of core and mini core sets is in progress in various crop species.

The feedback from NARS researchers revealed that mini core is most convenient for evaluation and identification of donors for various beneficial traits. Many scientists have reported useful variation for grain yield, quality and resistance/tolerance to various biotic and abiotic stresses. For example, 4 large seeded kabuli (ICCs 12033, 14203, 14187 and 14199) and 6 desi and kabuli types (ICCs 5879, 7255, 8350, 10393, 10885 and 13125) are being used in chickpea improvement in India (Kaul *et al.*, 2005, Johnson *et al.*, 2007). Likewise, 2

Table 3. Core, Mini-core, Reference and Composite sets of germplasm supplied to researchers in various countries by ICRISAT, Patancheru, India

Country	No. of consignments	Crop / collection
Algeria	1	Chickpea mini core
Argentina	1	Sorghum mini core
Australia	2	1 Sorghum reference, 1 Chickpea reference
Canada	3	3 Chickpea mini core
China	6	4 Groundnut, 1 Sorghum and 1 Foxtail millet mini core
Germany	2	1 Finger millet and 1 Foxtail millet Core
France	2	1 Sorghum and 1 Foxtail millet mini core
India	105	Sorghum (1 Core, 3 mini core, 2 reference); Pearl millet (2 core, 1 mini core); Chickpea (22 mini core, 1 reference); Pigeonpea (17 mini core); Groundnut (13 mini core, 1 reference); Finger millet (1 composite, 8 core, 12 mini core); Foxtail millet (13 core, 1 mini core); Proso millet (2 core) and Barnyard millet (4 core, 1 mini core)
Japan	6	3 Sorghum, 1 Chickpea, 1 Groundnut mini core, and 1 Foxtail millet mini core
Kenya	4	1 Finger millet core, 1 Finger millet mini core, 1 Pigeonpea core and 1 Sorghum reference
Mexico	1	Chickpea mini core
Mali	2	1 Sorghum and 1 Groundnut reference
Malawi	2	2 Groundnut mini core
Niger	4	1 Pigeonpea core, 2 Pigeonpea reference and 1 Groundnut reference
Nigeria	3	2 Groundnut mini core and 1 Groundnut reference
Senegal	1	Groundnut reference
Syria	1	Chickpea reference
Sweden	1	Chickpea mini core
Thailand	2	1 Groundnut and 1 Finger millet mini core
Tanzania	1	Finger millet mini core
United Arab Emirates	1	Pigeonpea mini core
Uganda	1	Finger millet mini core
USA	14	1 Chickpea mini core, 1 Finger millet mini core, 2 Groundnut mini core, 7 Sorghum mini core, 1 Foxtail millet core, 1 Pigeonpea mini core, and 1 Finger millet core
Viet Nam	2	2 Groundnut mini core
Total	168	

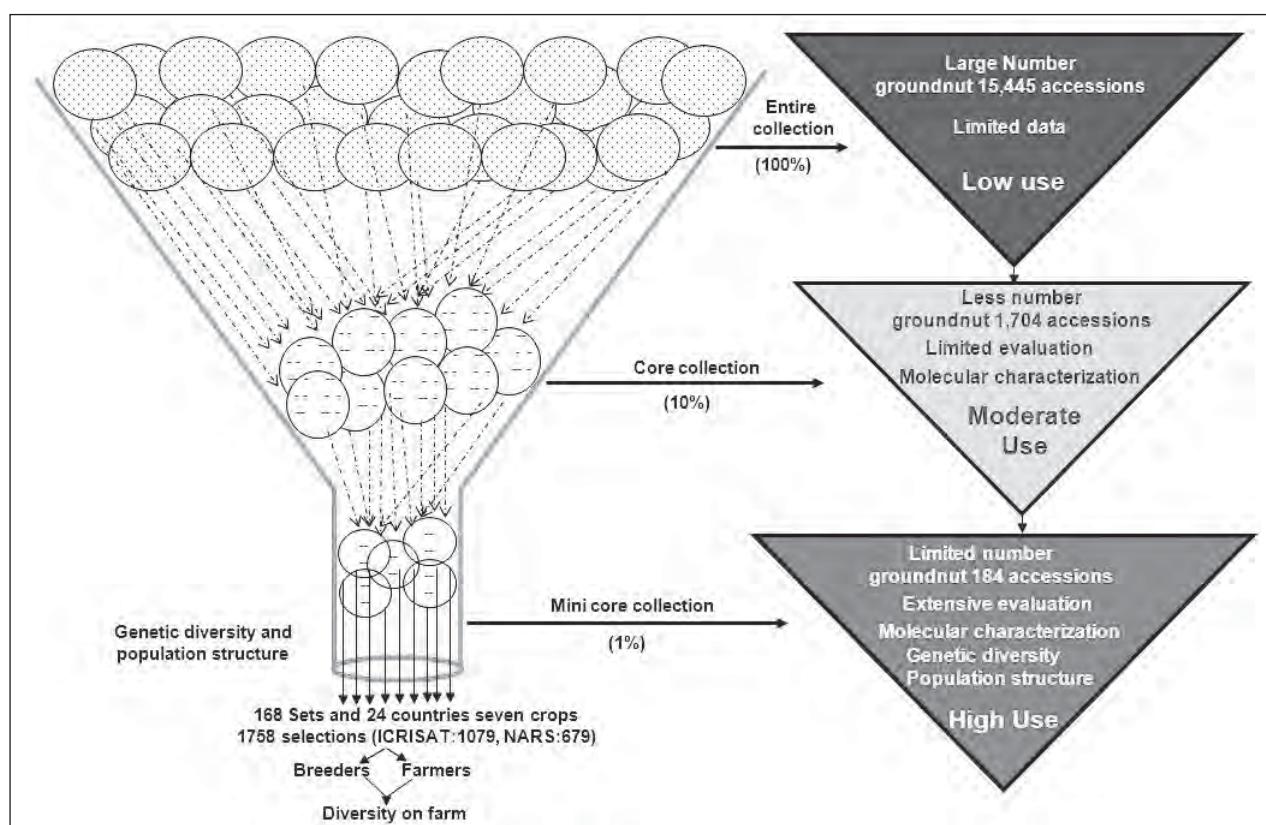


Fig. 2: Utility of the mini core collections for crop improvement

groundnut accessions ICG 8760 and ICG 3787, resistant to rust and late leaf spot in India (Kusuma *et al.*, 2007); 11 groundnut accessions with high quality oil and 14 accessions resistant to bacterial wilt in China; 5 large-seeded groundnut accessions each in China and Thailand; and 5 high shelling groundnut accessions each in China, Thailand and Vietnam provided useful variation for use in crop improvement in those countries (Upadhyaya *et al.*, 2010b). Several pigeonpea mini core accessions exhibited rich diversity for agronomic traits that researchers selected for use in pigeonpea breeding in India (Singh *et al.*, 2007). Preliminary evaluation of pigeonpea mini core further revealed that some of these accessions are adapted to nutrient-poor soil conditions (Rao and Shahid, 2007).

Overall, the mini core collections with their optimal and convenient size have helped in better evaluation, identification and increased use of germplasm by breeders (Fig. 2). This would definitely improve and enrich plant breeding by infusing new genetic diversity for developing broad based cultivars, paving way towards an ever green revolution.

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References

- Bhattacharjee R, PJ Bramel, IS Khairwal and KN Reddy (2007) Establishment of a pearl millet [*Pennisetum glaucum* (L.) R. Br.] core collection based on geographical distribution and quantitative traits. *Euphytica*. 155: 35-45.
- Bretting PK and MP Widrlechner (1995) Genetic markers and plant genetic resources management. In: Janick J(ed.) *Plant Breeding Reviews*, John Wiley and Sons Inc., New York. pp 11-87.
- Brown AHD (1989a) Core collections: a practical approach to genetic resources management. *Genome* 31: 818-824.
- Brown AHD (1989b) The case for core collections. In: Brown AHD, OH Frankel, DR Marshall and JT Williams (ed.) *The use of plant genetic resources*. Cambridge Univ. Press, Cambridge, pp.136-155.
- Cantrell RP, R Christopher, CR Dowsell and RL Paliwal (1996) *Maize in the third world*. Boulder, USA, Westview Press.
- Dalrymple DG (1986) *Development and spread of high-yielding wheat varieties in developing countries*, 7th edition. Washington DC, US Agency for International Development.
- Damicone JP, CC Holbrook, DL Smith, HA Melouk and KD Chamberlin (2009) Reaction of the core collection of peanut germplasm to *Sclerotinia* blight and pepper spot. *Pea. Sci.* 37: 1-11.

- Ebana K, Y Kojima, S Fukuoka, T Nagamine and M Kawase (2008) Development of mini core collection of Japanese rice landrace. *Breed. Sci.* **58**: 281-291.
- Frankel OH (1984) Genetic perspective of germplasm conservation. In: Arber W, K Limensee, WJ Peacock and P Stralinger (ed.) *Genetic manipulations: Impact on man and society*. Cambridge University Press, Cambridge, UK. pp161-170
- Gowda CLL, HD Upadhyaya, N Dronavalli and Sube Singh (2011) Identification of large seeded high yielding stable kabuli chickpea (*Cicer arietinum* L.) germplasm lines for use in crop improvement. *Crop Sci.* **51**: 198-209.
- Grenier C, PJ Bramel and P Hamon (2001) Core collection of the genetic resources of sorghum: 1. Stratification based on eco-geographical data. *Crop Sci.* **41**: 234-240.
- Halward TM and JC Wynne (1991) Generation mean analysis for productivity in two diverse peanut crosses. *Theor. Appl. Genet.* **82**: 784-792.
- Hamidou F, P Ratnakumar, O Halilou, O Mponda, T Kapewa, E Monyo, I Faye, BR Ntare, SN Nigam, HD Upadhyaya, V Vadez (2011) selection of intermittent drought tolerant lines across years and locations in the reference collection of groundnut (*Arachis hypogaea* L.). *Field Crops Research*, doi:10.1016/J.FCR.2011.10.009.
- Heslop-Harrison JS (2002) Exploiting novel germplasm. *Aust. J. Agric. Res.* **53**: 873-879.
- Holbrook CC and W Dong (2005) Development and evaluation of a mini core collection for the US peanut germplasm collection. *Crop Sci.* **45**: 1540-1544.
- ICRISAT Archival Report (2009)
http://intrnet/Admin%20pages2009/Documents/Archival_2009.pdf.
- Johnson PL, RN Sharma, SK Nair, RL Pandey and OP Kashyap (2007) Study of genetic diversity in chickpea under rainfed situation. In: *Abstracts: National Symposium on Legumes for Ecological Sustainability – Emerging Challenges and Opportunities*. IIPR, Kanpur, India. pp199.
- Kannenberg LW and DE Falk (1995) Models for activation of plant genetic resources for crop breeding programs. *Can. J Plant Sci.* **75**: 45-53.
- Kashiwagi J, L Krishnamurthy, HD Upadhyaya, H Krishna, S Chandra, V Vadez and R Serraj. (2005) Genetic variability of drought avoidance root traits in the mini-core germplasm collection of chickpea (*Cicer arietinum* L.). *Euphytica* **146**: 213-222.
- Kashiwagi J, L Krishnamurthy, S Singh, PM Gaur and HD Upadhyaya (2006a) Variation of SPAD chlorophyll meter readings (SCMR) in the mini-core germplasm collection of chickpea. *International Chickpea and Pigeonpea Newsletter* **13**: 16-18.
- Kashiwagi J, L Krishnamurthy, S Singh, PM Gaur, HD Upadhyaya, JDS Panwar, PS Basu, O Ito and S Tobita (2006b) Relationships between transpiration efficiency and carbon isotope discrimination in chickpea (*C. arietinum* L.). *International Chickpea and Pigeonpea Newsletter* **13**: 19-21.
- Kashiwagi J, L Krishnamurthy, HD Upadhyaya and PM Gaur (2008) Rapid screening techniques for canopy temperature status and its relevance to drought tolerance improvement in chickpea. *SAT e- Journal* **6**.
- Kashiwagi J, L Krishnamurthy, HD Upadhyaya and S Singh (2007) Identification for large seeded kabuli germplasm with drought tolerance root traits in chickpea. *SAT e-Journal* **6**.
- Kaul J, S Kumar and SN Gurha (2005) Evaluation of exotic germplasm of kabuli chickpea. *Indian J. Plant Genet. Resour.* **18**: 201-204.
- Khairwal IS, SK Yadav, KN Rai, HD Upadhyaya, D Kachhawa, B Nirwan, R Bhattacharjee, BS Rajpurohit, CJ Dangaria and Srikant (2007) Evaluation and identification of promising pearl millet germplasm for grain and fodder traits. *J. SAT. Agri. Res.* **3**(1).
- Kiran Babu T, RP Thakur, PN Reddy, HD Upadhyaya, AG Girish and NDRK Sharma (2011) Development of a field screening technique and identification of blast resistance in finger millet core collection. *Indian J. Plant Protection* (in Press)
- Knauff DA and DW Gorbet (1989) Genetic diversity among peanut cultivars. *Crop sci.* **29**: 1417-1422.
- Krishnamurthy L, HD Upadhyaya, KB Saxena and V Vadez. (2011a) Variation for temporary water logging response within the mini core pigeonpea germplasm. *J. Agri. Sci.* pp:1-8. doi: 10.1017/S0021859611000682.
- Krishnamurthy L, NC Turner, PM Gaur, HD Upadhyaya, RK Varshney, KH M.Siddique and V Vadez (2011b) Consistent variation across soil types in salinity resistance of a diverse range of chickpea (*Cicer arietinum* L.) genotypes. *J. Agronomy and Crop Sci.* **197**: 214-227.
- Krishnamurthy L, PM Gaur, PS Basu, SK Cahturvedi, S Tripathi, V Vadez, A Rathore, RK Varshney and CLL Gowda (2011c) Large genetic variation for heat tolerance in the reference collection of chickpea (*Cicer arietinum* L.) germplasm. *Plant Genetic Resources: Characterization and Utilization.* **9**: 59-69.
- Kumar S, S Gupta and BB Singh (2004) How wide is the genetic base of pulse crops? In: Ali M, BB Singh, S Kumar and V Dhar (ed.). *Pulses in new perspective. Proceedings of the National Symposium on Crop Diversification and Natural Resources Management*. ISPRD and IIPR, Kanpur, India. pp: 211-221.
- Kusuma VP, BC Vishwanath, BM Swamy and MVC Gowda (2006) Variation for lectin content in groundnut germplasm. International conference on biotechnological approaches for alleviating malnutrition and human health. 9-11 January 2006, University of Agricultural Sciences, Bangalore, India.
- Kusuma VP, G Yugandhar, BC Ajay, MVC Gowda and HD Upadhyaya (2007) Identification of sources of multiple disease resistance in groundnut (*Arachis hypogaea* L.) mini core. In: *ISOR National Seminar*, 29-31 January 2007, Directorate of Oilseeds Research, Rajendranagar, Hyderabad, India. pp 31-32.
- Marshall DR (1989) Limitations to the use of germplasm collections. In: Brown ADH, OH Frankel, DR Marshall, JT

- Williams (ed.) *The use of plant genetic resources*. Cambridge: University Press. Cambridge, UK. pp 105-120.
- Pande S, GK Kishore, HD Upadhyaya and JN Rao (2006) Identification of multiple diseases resistance in mini core collection of chickpea. *Plant Dis.* **90**: 1214-1218.
- Paterniani, E (1990) Maize breeding in the tropics. *CRC Critical Review in Plant Sci.* **9**: 125-154.
- Prasada Rao KE and V Ramanatha Rao (1995) The use of characterization data in developing a core collection of sorghum. In: Hodgkin T, AHD Brown, JL van Hintum Th and BAV Morales (ed.). *Core collection of plant genetic resources*. Wiley-Sayee, Chichester, UK: pp109-116.
- Rao NK and M Shahid (2007) Desert farming: continued quest for new crops. *Biosalinity News* **2**.
- Reddy LJ, HD Upadhyaya, CLL Gowda and S Singh (2005) Development of core collection in pigeonpea [*Cajanus cajan* (L.) Millsp.] using geographic and qualitative morphological descriptors. *Genet. Resour. Crop Evo.* **52**: 1049-1056.
- Sharma HC, G Pampapathy, MK Dhillon and JT Ridsdill-Smith (2005) Detached Leaf Assay to Screen for Host Plant Resistance to *Helicoverpa armigera*. *J. Econ. Entomol.* **98(2)**: 568-576.
- Sharma R, VP Rao, HD Upadhyaya, VG Reddy, and RP Thakur (2010) Resistance to grain mold and downy mildew in a mini core collection of sorghum germplasm. *Plant Dis.* **94**: 439-444.
- Sharma R, HD Upadhyaya, SV Manjunatha, VP Rao and RP Thakur (2011) Resistance to foliar diseases in a mini core collection of sorghum germplasm. *Plant Dis.* (in press).
- Singh F, ND Majumder, R Kant and G Kumar (2007) Germplasm resources in pigeonpea – A scope for their utilization. In *Abstracts: National Symposium on Legumes for Ecological Sustainability – Emerging Challenges and Opportunities*. Kanpur, India: IIPR. pp 197.
- Srivastava N, V Vadez, HD Upadhyaya and KB Saxena (2006) Screening for intra and inter specific variability for salinity tolerance in Pigeonpea (*Cajanus cajan*) and its related wild species. *SATe-Journal.2* (<http://icrtest:8080/Journal/cropimprovement/v2i1/v2i1screeningfor.pdf>).
- Troyer AF (1990) A retrospective view of corn genetic resources. *J of Hered.* **81**: 17-24.
- Upadhyaya HD and R Ortiz (2001) A mini core subset for capturing diversity and promoting utilization of chickpea genetic resources in crop improvement. *Theor. Appl. Genet.* **102**: 1292-98.
- Upadhyaya HD, PJ Bramel and S Singh (2001) Development of a chickpea core collection using geographic distribution and quantitative traits. *Crop Sci.* **41**: 206-210.
- Upadhyaya HD, PJ Bramel, R Ortiz and S Singh (2002) Developing a mini core of peanut for utilization of genetic resources. *Crop Sci.* **42**: 2150-2156.
- Upadhyaya HD, R Ortiz, PJ Bramel and S Singh (2003) Development of a groundnut core collection using taxonomical, geographical and morphological descriptors. *Genet. Resour. Crop Evol.* **50**: 139-148.
- Upadhyaya HD (2005) Variability for drought resistance related traits in the mini core collection of peanut. *Crop Sci.* **45**: 1432-1440.
- Upadhyaya HD, BP Mallikarjuna Swamy, PV Kenchana Goudar, BY Kullaiswamy and S Singh (2005) Identification of diverse accessions of groundnut through multi-environment evaluation of core collection for Asia. *Field Crops Res.* **93**: 293-299.
- Upadhyaya HD, CLL Gowda, RPS Pundir, VG Reddy and S Singh. (2006a) Development of core subset of finger millet germplasm using geographical origin and data on 14 quantitative traits. *Genetic Resour. Crop Evol.* **53**: 679-685.
- Upadhyaya HD, LJ Reddy, CLL Gowda, KN Reddy and S Singh (2006b) Development of a Mini Core subset for Enhanced and Diversified utilization of Pigeonpea Germplasm Resources. *Crop Sci.* **46**: 2127-2132.
- Upadhyaya HD, LJ Reddy, CLL Gowda and S Singh (2006c) Identification of diverse groundnut germplasm: Sources of early-maturity in a core collection. *Field Crops Res.* **97**: 261-267.
- Upadhyaya HD, SL Dwivedi, CLL Gowda, and S Singh (2007a) Identification of diverse germplasm lines for agronomic traits in a chickpea (*Cicer arietinum* L.) core collection for use in crop improvement. *Field Crops Res.* **100**: 320-326.
- Upadhyaya HD, KN Reddy and CLL Gowda (2007b) Pearl millet germplasm at ICRISAT genebank- status and impact. *J. Sat Agric. Res.* **3**: 1-5.
- Upadhyaya HD, PM Salimath, CLL Gowda and S Singh (2007c) New early maturing germplasm lines for utilization in chickpea improvement. *Euphytica.* **157**: 195-208.
- Upadhyaya HD (2008) Crop germplasm and wild relatives: a source of novel variation for crop improvement. *Korean J. of Crop Sci.* **53**: 12-15.
- Upadhyaya HD, R Bhattacharjee, RK Varshney, DA Hoisington, KN Reddy, and S Singh (2008a) Assessment of genetic diversity in pigeonpea using SSR markers. In: Abstracts (no 657-3), Annual Joint meeting of ASA/CSSA, 5-9 October, 2008, Houston, USA.
- Upadhyaya HD, SL Dwivedi, M Baum, RK Varshney, SM Udupa, CLL Gowda, D Hoisington and S Singh (2008b) Genetic structure, diversity and allelic richness in composite collection and reference set in chickpea (*Cicer arietinum* L.). *BMC Plant Biology* **8**: 106 <http://www.biomedcentral.com/1471-2229/8/106>.
- Upadhyaya HD, RPS Pundir, CLL Gowda, VG Reddy and S Singh (2008c) Establishing a core collection of foxtail millet to enhance utilization of germplasm of an underutilized crop. *Plant Genet. Resour. : characterization and utilization.* **7**: 177-184.
- Upadhyaya HD, CLL Gowda, KN Reddy and S Singh (2009a) Augmenting the pearl millet [*Pennisetum glaucum* (L.) R. Br.] core collection for enhancing germplasm utilization in crop improvement. *Crop Sci.* **49**: 573-580.
- Upadhyaya HD, RPS Pundir, SL Dwivedi, CLL Gowda, V Gopal Reddy and S Singh (2009b) Developing a mini core collection of sorghum [*Sorghum bicolor* (L.) Moench] for diversified utilization of germplasm. *Crop Sci.* **49**: 1769-1780.

- Upadhyaya HD, RPS Pundhir, SL Dwivedi and CLL Gowda (2009c) Mini core collections for efficient utilization of plant genetic resources in crop improvement programs. Information Bulletin no.78. Patancheru 502324 Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. pp 52. ISBN 978-92-9066-5199-9.
- Upadhyaya HD, LJ Reddy, CLL Gowda, and S Singh (2009d) Phenotypic diversity in cold tolerant peanut (*Arachis hypogaea* L.) germplasm. *Euphytica*. **165**: 279-291.
- Upadhyaya HD, NDRK Sarma, CR Ravishankar, T Albrecht, Y Narasimhudu, SK Singh, SK Varshney, VG Reddy, S Singh, SL Dwivedi, N Wanyera, COA Oduori, MA Mgonja, DB Kisandu, HK Parzies and CLL Gowda (2010a) Developing Mini Core Collection in Finger Millet Using Multilocation Data. *Crop Sci*. **50**: 1924-1931.
- Upadhyaya H.D., D Yadav, N Dronavalli, CLL Gowda and S Singh (2010b) Mini core germplasm collections for infusing genetic diversity in plant breeding programs. *Electronic J. of Plant Breeding*. **1(4)**: 1294-1309.
- Upadhyaya HD, CR Ravishankar, Y Narasimhudu, NDRK Sarma, SK Singh, SK Varshney, VG Reddy, S Singh, HK Parzies, SL Dwivedi, HL Nadaf, KL Sharawat and CLL Gowda. (2011a) Identification of trait-specific germplasm and developing a mini core collection for efficient use of foxtail millet genetic resources in crop improvement. *Field Crops Research* **124(3)**: 459-467.
- Upadhyaya HD, S Sharma, CLL Gowda, V Gopal Reddy and S Singh (2011b). Developing proso millet (*Panicum miliaceum* L.) core collection using geographic and morpho-agronomic data. *Crops and Pasture Science* **62(5)**: 383-389.
- Upadhyaya HD, N Dronavalli, CLL Gowda and S Singh (2011c) Identification and evaluation of chickpea germplasm for tolerance to heat stress. *Crop Sci*. **51**: 1-16.
- Upadhyaya HD, Devvart Yadav, KN Reddy, CLL Gowda and S Singh (2011d) Development of Pearl Millet mini core collection for enhanced utilization of germplasm. *Crop Sci*. **51**: 217-223.
- Upadhyaya HD, S Ramesh, Shivali Sharma, SK Singh, SK Varshney, NDRK Sarma, CR Ravishankar, Y Narasimhudu, VG Reddy, KL Sahrawat, TN Dhanalakshmi, MA Mgonja, HK Parzies, CLL Gowda and Sube Singh (2011e) Genetic diversity for grain nutrients contents in a core collection of finger millet (*Eleusine coracana* (L.) Gaertn.) germplasm. *Field Crops Research* **121(1)**: 42-52.
- Upadhyaya HD, G Mukri, HL Nadaf and S Singh (2012) Variability and stability analysis for nutritional traits in the mini core collection of peanut. *Crop Sci*. **52**: 168-178.
- Vavilov NI (1926) Studies on the origin of cultivated plants. *Inst. Appl. Bot. Plant Breed*. **16**:1-248.
- Vavilov NI (1951) The Origin, Variation, Immunity and Breeding of Cultivated Plants. (translated from Russian by K Starr Chester) *Chronica Botanica*. **13**: 1-366.
- Vellve R (1992) Saving the seeds: genetic diversity and European agriculture. Earthscan Books, London.

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