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Plant genetic resources management under emerging climate change

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Abstract

Plant genetic resources (PGR) are the basic raw materials required to cater current and future needs of crop improvement. Climate change is expected to result in increased frequency of abiotic stresses like drought, heat stress, submergence, increased soil salinity etc. The negative impacts of climate change are visible in the form of declining crop productivity, shifting in crop suitability areas, species migration and extinction, emergence of new pests and weeds and altered phenology. Already, the existing genetic base of our crops and varieties has shrunken, and in future we may find it difficult to cope with new climatic challenges with the existing information on genetic resources. Consequently, food and sustainable livelihood security of larger section of populations is jeopardized. Substantial knowledge and insight is, therefore, needed to gauge what types of diversity now exist in the gene banks, and what will be needed in the future. There is a need to assemble and screen germplasm strategically and discover new sources of variations which will enable us to address the very pertinent issue of climate change. Strategies like genetic enhancement/ pre-breeding using crops wild relatives, developing core sets, focused identification of germplasm, mapping and cloning gene and gene constructs, allele mining, bioprospecting for novel biomolecules, and promoting on farm conservation in order to allow genes to evolve and respond to new environments would be of great help to mitigate the climate change impacts. There is also need to mobilize national and international opinion to make food security and poverty alleviation central in climate negotiations

Key words: Plant genetic resources, climate change, species migration, extinction, phenology

Introduction

Humanity by and large, has now acknowledged climate change as fact and reality. It is expected to become the first or second greatest driver of global biodiversity loss [1, 2] and thus poses many new challenges in the management of PGR. The average global surface temperature has increased by 0.2ºC per decade in the past 40 years, and global average precipitation increased 2% in the last 100 years [3, 4] and further expected to increase in the range of 1.6^{o}C to as much as 6^{o}C by 2050 [5]. Climate changes are spatially heterogeneous; some locations such as the arctic regions may experience much larger changes while others are exposed to secondary effects like sea level rise [6]. It might hasten species extinctions [7, 8] and risks will be more significant to wild biodiversity including crop wild relatives, varieties with narrow genetic base and species endemic to specialized regions. PGR management, therefore, in the context of climate change *vis-a-vis* food security is a world-wide concern and needs to be looked holistically and sustainably to appropriately address the challenges posed by climate change. FAO High-Level Conference on World Food Security in June 3-5, 2008 called for urgent measure to increase the resilience of the world's food systems to climate change and PGR occurring in diverse ecological regions across the world have greater role to play.

India's diverse climatic conditions houses immense richness of agricultural biodiversity including diversity in crop plants, wild plants, livestock, aquatic species, below ground biota, and microbes [9-11] and has potential to mitigate the negative impacts of climate change. Indian gene centre is one of the 12 mega diversity centres of the world and it has Eastern Himalaya and Western Ghats as two "biodiversity hot spots" among the 34 identified the world over [12] housing about 49500 species of flowering and non-flowering plants out of the 260000 described the world over [13, 14]. Flowering plants constitute 17500 species of which 5725 are endemic and distributed in the Himalaya and adjoining regions (3471), peninsular India (2015) and in the Andaman and Nicobar Islands (239) [10, 15]. Indian gene centre is also rich in domesticated crops diversity; nearly 45 species were indentified for

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Indian region by de Candole [16]; increased to 117 species by Vavailov [17, 18] and to 168 species by Zeven and de Wet [19] out of 2489 species distributed in 12 regions of diversity of cultivated plants. The crops cultivated in this centre have further updated to 479 species including exotics for agricultural crops and 336 species of wild relatives [20-22]. It also harbor 9,500 economic plant species, 1,256 grass species and over 2,000 species having ornamental value and 45 species of mangroves [23, 24]. The present paper discusses the status of PGR management in India, impact of climate change on the PGR *vis-a-vis* crop productivity and research strategies needed to address the challenges of climate change.

Status of Plant Genetic Resources

The NBPGR established in 1976 under the aegis of ICAR is primarily responsible for the management of PGR related to food and agriculture. Brief status of PGR management is given below:

(i) Collection and Evaluation

The NBPGR in collaboration with other crop based institutes has collected over 2.50 lakh accessions including about 28000 accessions of crops wild relatives through 2,350 explorations. The native genetic resource has been greatly enriched by introducing about 21 lakh samples of seed and planting material and many new crops viz. kiwi fruit, jojoba, guayule, oil palm, tree tomato, *Atriplex* sp., *Cuphea*, mangosteen, rambuttan, pawpaw, durian, non-astringent persimmon, *Feijoa*, Chinese ber, Adzuki bean, *Chenopodium quinoa*, hops from 113 countries and 8 IARCs. Germplasm comprising about 1.90 lakh accessions have been characterized and evaluated for various agronomic and biochemical traits and data have been compiled in 87 catalogues on 45 crops. As a result large numbers of varieties have been developed and promising genetic stocks have been indentified to enhance utilization of PGR. So far, NBPGR has registered 603 genetic stocks of 115 crops and supplied about 3.75 lakh samples to researchers across the country for their further use in research programme. The DNA fingerprinting of varieties to assess the level of genetic variability using ISSR, AFLP, STMA, and SNP techniques have been done for 2215 varieties in 33 different crops.

(ii) Conservation

PGR are being conserved in the form of seed, *in vitro* and *cryo* preserved for long term storage in the National Gene Bank as base collections while active collections are conserved in the medium-term storage and perennial crops in the field gene banks at National Active Germplasm Sites. Presently, 377008 accessions of 1549 species in seed gene bank, 2000 accessions of 158 vegetative propagated crops under *in vitro* and 8981 accession of 726 species have been *cryo* preserved (www.nbpgr.ernet.in). New protocols have been developed for micro-propagation and *in-vitro* conservation of vegetatively propagated species and for cryopreservation of non-orthodox seed species like tea, black pepper, almond, neem including pollen grains of 279 accessions of *Mangifera indica* and *Garcinia* spp., and dormant buds of 197 accessions of *Morus* spp. The NBPGR has also conserved 110288 accessions as active collections in medium-term storage facilities, 51473 in the field gene banks at 10 regional stations/ base centres while about 225000 accessions are being conserved at 58 NAGS located in different agro-climatic regions of the country. The activities have also been initiated to promote on-farm conservation of PGR particularly the landraces and crops of local importance in the Western Himalayan region [25-27]. The entire spectrum of plant biodiversity distributed over 10 bio-geographical zones, is being conserved *in-situ* in 92 National Parks, 504 Sanctuaries and 15 Biosphere Reserves spread over 16 million hectares [23]. Gene sanctuaries in Tura range in Garo Hills of Meghalaya for conservation of rich native diversity of wild *Citrus* and *Musa* species, and for *Rhododendron* and orchids in Sikkim are also a part of *in situ* conservation of economically important species [24].

Impact of climate change on plant genetic resources

The South Asian region is projected to be one of the most vulnerable to climate change and it will have significant direct impacts on PGR for Food and Agriculture. Changes to land use and agricultural management can affect biodiversity, both positively and negatively. Further, the intensification of agriculture has generated lot of pressure on plant genetic resources particularly on the traditional varieties, landraces and large number of crops wild relatives affecting therefore, crops productivity and biodiversity negatively.

(i) Crop Productivity

Agriculture is a core part of the Indian economy and provides food and livelihood activities to large section of its population. While the magnitude of impact of climate change varies greatly by region, the policy implications are wide-reaching, as changes in agriculture could affect food security, trade policy, livelihood activities and water conservation issues, impacting large portions of the population [28-32].

Agriculture production is likely to alter due to temperature expected to be much higher in winter than in rainy season while precipitation is expected to increase in all time slices in all months, excepting during December-February, when it is likely to decrease [33]. Further, the warming will be more pronounced over land areas with the maximum increase over northern India including Himalayan region. The regional differences in the response of wheat, maize and rice yields to projected climate change could likely be significant [34, 35]. Production of rice, maize, wheat and tea in the past few decades has declined in many parts of Asia due to increasing water stress arising partly from increasing temperature, increasing frequency of cyclones and reduction in the number of rainy days [36-40]. The yield of rice was observed to decrease by 10% for every 1°C increase in growing-season minimum temperature [41-43] while 0.5°C rise in winter temperature would reduce wheat yield by 0.45 tones/ha in India [44-46]. Some studies suggest 2 to 5% decrease in yield potential of wheat and maize for a temperature rise of 0.5 to 1.5°C in India [30] and decrease by 5 to 12% for rice in China [47]. The declining trend in snowfall and rising winter temperature has reduced productivity of apple from 7.06 t/ha in 1980-81 to 4.65 t/ha in 2004-05 [48]. The climate change is projected to increase coconut yield by 10% during 2020, up to 16% in 2050 and up to 36% in 2080 over current yield in west coast but at the same times it is projected to decline by 2% in 2020, 8% in 2050 and 31% in 2080 in east coast of India [49]. Similar trends were also suggested for other crops like sugarcane, ground nut, black pepper, potato, mango, and banana and other vegetables and spices in India [50-52] and in sub-Saharan Africa [39, 53].

(ii) Shift in crops suitability areas

Climate change will cause shifts in areas suitable for cultivation of a wide range of crops and also geographic distribution of species [54] whilst some regions considered marginal will gain suitability and others will lose [55]. It is also predicted that with rising temperatures and change in the rainfall regime the global suitability for crops does not *per se* decrease, but does shift geographically. For a given site, there is high likelihood that crops that are currently adapted to the conditions become mal-adapted, resulting in the need for new within-crop diversity to adapt to future conditions and under extreme conditions, new crops will be required [56]. The increase in temperature from 0.7-1.0^{0}C may shift the area suitable presently for the quality production of Dasehari and Alphonos varieties of mango [57]. Further, the red colour development on peel of guava requires cool nights at fruit maturity and rise in temperature by 0.2^{o}C may result into dramatic reduction areas suitable for development of red colour on guava [57]. Trend analysis of last few decades showed that fruit trees, vegetables and agricultural crops were most affected at the lower altitudes in mountain regions, whilst farmers have shifted from apple to vegetable crops like cauliflower, cabbage, peas, carrot, and other fruit crops like pomegranate, kiwi and pear cultivation at mid elevations. At the highest altitudes, only slight reduction is noticed in the productivity of some crops like potato and pulses at some locations and farmers are benefited the most due to increased temperature and consequently lengthened growing period. Here, the farmers have shifted traditional agricultural crops such as buckwheat, barley, finger millet, grain amaranth and chenopod to apple, potato, hops, garden pea and other off-season vegetables and medicinal plants, which fetch them high prices [58]. However, there is a apprehension that these crops will perform well till the irrigation water received through glaciers melt is available. But, if the glaciers receding continue the water course may change and some areas may become water scare in the cold arid regions and may hammer crops suitability to larger extent. Increasing glacier melt in Himalayas will also affect availability of irrigation especially in the Indo-Gangetic plains [59] and in Punjab and Sind province of Pakistan, which, in turn, has large consequences on our food production [60].

(iii) Species migration and extinction

The climatic factors such as temperature and precipitation when change beyond the tolerance of a species phenotypic plasticity, the inward and outward movement of species causing change in species composition is inevitable [61-63]. Though evidence of climate related biodiversity loss remains limited, a large number of plant and animal species are reported to be moving to higher latitudes and altitudes [64, 65]. While undertaking climate change studies in Shimla district of Himachal Pradesh on the upward shift of species, we found that many temperate species e.g. *Aconitum heterophyllum, Lilium polyphyllum, Sorbus lanata, Swertia chirayita, Androsace* spp. as frequented by Collet in 1902 [66] in and around Shimla hills are not being observed now in the localities mentioned; instead found at 200-600m above higher elevation [27]. The uppermost altitudinal limits have also changed *viz*. *Pinus longifolia* (100yrs back upper altitude in record is 1800 vs. current 2200m), *Woodfordia fructicosa* (1500 vs. 2000m), *Boehmeria platyphylla* (1500 vs. 2200m).

Upward migration of vascular plants and progressive replacement of cold temperate ecosystem by Mediterranean ecosystem was observed at high mountain sites in the Alps [67].

Upward movement and subsequent colonization as regular member especially of families such as Caryophyllaceae, Compositae and Chenopodiaceae at higher elevation was observed in North-western Himalayan region [68]. Dubey *et al*., [69] observed higher rate (19m/decade on south and 14m/decade on north slope) of upward shift of *Pinus wallichiana* at Saram, Parbati valley in HP in comparison to other species records in Alps and elsewhere, where the maximum upward migration has been recorded to be around 4m/decade [70-72]. Long term distributional changes in plants due to climatic change were reported by many workers [73-77]. According to Coope [78], most of the species appeared to shift their distribution through tracking the changing climate rather than staying stationary and evolving new form. Many species ranges have moved poleward and upward in elevation in the last century [79, 62, 80] and will almost certainly continue to do so. Local communities are disaggregating and shifting toward more warm adapted species [81]. It is predicted that climate change will remain one of the major drivers of biodiversity patterns in the future [1, 82, 83] and middle zones would be of great importance for identifying possible future boundary shifts and predicting the fate of species in the higher altitudes [84]. In fact, scientists have found mountain regions as excellent laboratories to study the impact of climate change because no other single region in the world provides a better picture of structural variation of vegetation under the influence of altitude [85-88].

On the contrary, the species inhabiting alpine tops in the cold arid region are narrowly distributed and have limited scope to march upwards with the temperature rise and therefore, facing highest risk of extinction. Species depending on snow cover for protection would be exposed to frost (*being observed in the attitudes >2000 m amsl (personal observation*), and others which require winter chilling for bud-break may not get sufficiently low temperature over sufficiently long period [89]. For instance, plants of alpine region such as sea buckthorn (*Hippophae* sp.), Bhojpatra (*Betula utilis*), *Cotoneaster* sp. *Juniper* sp., *Cicer microphyllum*, *Linum perenne, Arnebia benthamii, Nordostychus jatamansi* etc. are narrowly distributed thus are highly vulnerable. It is further argued that these species lack suitable corridors to move in the response of changing weather conditions and, therefore, it will likely be critical to protect migration corridors and elevation gradients or even conservationists might think to transplant some rare species to new locations – either in the wild or in botanic gardens with matching climate conditions. The rhododendrons and other woody species of lower ranges have begun to invade alpine meadows, thus composition of plants in meadows is certainly going to change [90-92]. A decrease in alpine flora in Hokkaido and other high mountains and the expansion of the distribution of southern broad-leaved evergreen trees have also been reported [93-96].

Crop wild relatives, a key component of interdependence, provide researchers with genes useful for developing biotic and abiotic resistance [55, 97] and have contributed in crops such as rice, strawberry, cucumber, sugarcane, tomatoes, tobacco etc. [98] are especially vulnerable to climate change. Unlike their cultivated allies, wild species do not receive management interventions which help them adapt to changing conditions and, thus adaptation is limited to their biological capacity to deal with change [99, 100]. Thomas *et al*., [2] predicted 15-37% of wild species to be in danger of extinction based on a cross section of about 1100 plant species, while looking at only wild relatives, Jarvis *et al*., [101] predicted that 16-22% of species with direct value to agriculture may be in danger of extinction and the process will go on, if no corrective measures are undertaken to minimize the adverse effect of climate change [102].

In the tropical ecosystems, species such as mangroves and coral reefs are threatened by changes in temperature, rising sea levels and increased concentrations of carbon dioxide in the atmosphere. Already, nearly 30 per cent of the coral reefs in the Gulf of Kutch are 'bleached' as they loose the colourful algae that live on them - an occurrence associated with seawater warming [103]. In future, the entire belt of coral reefs along the south Gujarat coast is in danger of getting bleached.

A central question in the application of species distribution models to understanding the impacts of climate change relates to the migration capacities of species [104]. Hence, species capable of migrating at unlimited rates are more likely to survive; and indeed in some cases may gain geographic range thanks to greater land mass in higher latitudes, and species-energy relationships [105, 106]. Species extinction rates estimated for 1103 species in diverse parts of the world under these two migration scenarios, providing extinction rates of 21-23% for species with unlimited dispersal, and 38-52% for species with limited or no dispersal [2].

(iv) New insect, diseases and invasive species outbreaks

The classic disease triangle i.e. interaction of a susceptible host, a virulent pathogen and a favorable environment establishes the conditions for disease development and result into morphological and physiological changes [107, 108]. Theophrastus (370-286 B.C.) observed that cereals cultivated in higher altitude regions exposed to the wind had lower disease incidence than cereals cultivated in lower altitude areas. The new diseases may arise in certain regions, and other diseases may cease to be economically important, especially if the host plant migrates into new areas [109] for instance, the host plant agro-climatic zoning for coffee will be altered [110]. According to Chakraborty [111, 112] more aggressive strains of pathogen with broad host range, such as *Rhizoctonia, Sclerotinia, Sclerotium* and other necrotrophic pathogens can migrate from agro-ecosystems to natural vegetation, and less aggressive pathogens from natural plant communities can start causing damage in monocultures of nearby regions. Some indigenous pests that were earlier not causing much damage are emerging as serious pests such as foliar blight in wheat, necrosis in sunflower, bract mosaic in banana, sheath blight in maize and paddy, and *Pyrilla* in sugarcane [24]. The range of many pathogens is limited by climate requirements for overwintering or oversummering of the pathogen or vector. For example, higher winter temperatures of -6^0C versus -10^0C increase survival of overwintering rust fungi (*Puccinia graminis*) and increase subsequent disease on *Festuca* and *Lolium* [113]. In case of *Phytophthora infestans*, the introduction of multiple mating types allowing sexual reproduction increases the ability of the pathogen to overwinter. The spore germination of rust fungus increases with increasing temperature over a range of temperatures [114] while root rot pathogen reproduces more quickly at higher temperatures [115]. Some studies [116, 117] agree that higher winter temperatures and longer growing seasons could result in increased pest populations in temperate regions as it would reduce winter kill. The changing pest and disease patterns, due to climate change will cause modifications in the current phytosanitary scenario and likely to affect food production systems in the future [118, 119].

Biological invasion of native flora in agriculture and forest land use, waste and community lands, road sides, railway tracks and wetlands is becoming of increasing concern worldwide and may have gene pool to ecosystem wide impacts [120-122]. The convention on Biological Diversity (CBD) 1992 has recognized biological invasion as second worst threat to biodiversity after habitat destruction [123]; it may soon surpass the damage done by habitat destruction and fragmentation [124]. In fact most invasive and noxious weeds respond more positively to increasing CO_2, temperature and even do better under water deficit/ excess than do most of the economically important plants including cultivated crops. Some invasive species *viz*., *Lantana camara*, *Parthenium hysterophorus, Ageratum conyzoides*, *Eupatorium adenophorum*, *Eupatorium odoratum*, *Mikania micrantha*, *Ageratum conyzoides*, *Galinsoga parviflora*, *Eichornia crassipes*, *Salvinia molesta*, *Ipoemia carnea* have invaded and altered community structure and population dynamics of native flora both in terrestrial and aquatic eco-systems across the country. Scores of others like *Ageratina adenophora*, *Bidens pilosa*, *Polygonum polystachyum, Solanum chacoense* and *Cyclanthera brachystachya* are at an early stage of invasion even at higher elevations, attributed mainly to rising temperature. A case study conducted by us showed that *Lantana, Parthenium* and *Ageratum* have not only outnumbered the native vegetation, but have shifted upwards. In Shiwalik hills, *Lantana camara* constituted 28.32% of the total shrub species while *Ageratum conyzoides* (21.42%) and *Parthenium hysterophorus* (20.51%) together accounted for 41.93% of the total herb species and these have significantly reduced the individuals of beneficial species *viz*., *Carissa spinarium*, *Adhatoda vasica, Dodonea viscosa, Cassia tora*, many grasses, medicinal herbs and wild flowers.

(iv) Change in phenological responses

Plants are finely tuned to the seasonality of their environment particularly temperature and photoperiod, and shifts in the timing of plant activity (i.e. phenology) provide some of the most compelling evidence that species and ecosystems are being influenced by climate change. For plant reproduction, timing is everything. An individual plant that flowers too early, before it has had time to accumulate sufficient material resources, will have a limited capacity for seed production. One that delays flowering might gain higher capacity, but might also run out of time to use it before the end of the season [63, 62]. These changes raise concerns about the effectiveness of existing biodiversity protection strategies [125-128] and events like advancing the onset of leaf burst, flowering and fruiting, delaying leaf drop and insect pollinated plants flowering earlier than wind pollinated plants have been studies in detail [129-132]. We noticed that in case of species like *Erigeron mutlicaulis*, *Thymus serphyllum* and *Dicliptera bupleuroides* flowering period as mentioned by Collet [66] is seemingly altered. The data recorded on different varieties of peach, apple and kiwi showed that flowering was considerably delayed in the year 2008 when winter temperature was very low while it was early in 2006 and 2009 when winters were comparatively warmer (Table 1). The Rhododendrons flowered in early February in 2009 than early to mid March in previous years in the Western Himalayan region.

The overall average advancement of flowering of 2.5 days was statistically related to a local increase in night time temperature of 0.2-1.2^{0}C in 89 species [133]. The temperature above 30^{0}C delay curd imitation in cauliflower and induce maximum flower and fruit drop in tomato [48]. The higher air temperature after cessation of growth in winter advanced the flowering in mango trees which increase the risk of exposing mango trees to night low temperature, thus affect fruit quality [57]. The prolonged low temperature has delayed spathe emergence in date palm which further extended the maturity and yield reduction was noticed to the tune of 10% whilst prolonged frost affect the new growth including soft twigs in lasoora (*Cardia mayxa*) [134]. High temperature than critical level during bulb initiation lead to poor bulb development whilst <10^{0}C during bulb development led to bolting of onion and clove sprouting in garlic [135]. Overall spring flowering events have advanced by 8 days over the past 60 years in Canada [136]. In Boreal region, a 12 days longer greening period was reported in a 20 year study from 1981-1999 [137-139] while in Japan cherries are currently flowering earlier than they have at any time during the previous 1200 years, probably the longest annual record of phenology from anyplace in the world [140].

(v) Effects on regeneration of species

The temperate species in general require chilling/ stratification (remained under snow for 2-3 months) of seeds to germinate. If such conditions are not met, the rejuvenation of species hammered largely. The data collected on the number of saplings and adult plants of *Quercus leucotrichophora*, *Rhododendron arboreum* and *Cedrus deodara* in the Shimla forests showed considerable reduction in the number of saplings compared to adult trees (Table 2). In the alpine region, big trees are noticed in their original distribution but not the saplings and the juvenile stages in case of *Prunus cornuta, Corylus jacquemontii* and *Pinus gerardiana* [27].

The poor winter precipitation also hammers seed germination of many species, for instance, the number of individuals of *Cyclanthera brachystachya* reduced significantly in the year 2009 as compared to 2007 and 2008 because of poor precipitation in winter. Similarly, the fruit set in temperate fruits was reduced by 40-80% as compared to normal years (*Personal observations*). These climatic variations have also been reported to cause new genetic and morphological characters which could result in the evolution of new phenotypes within a particular population [141]. We noticed various morphological forms of *Malus baccata, Vigna vexillata, Cotoneaster microphylla, Pyrus pashia* in Western Himalaya.

Table 1. Minimum and maximum temperature and corresponding date of flowering in peach, apple and kiwi from 2005-2009

Month	Min. & Max. temperature (^oC)				
	2005	2006	2007	2008	2009
December	6.8-16.3	2.4-16.8	3.5-15.9	8.5-17.5	10.6-19.2
January	0.4-11.7	4.1-12.5	0.8-20.5	-1.7-17.3	5.5-20.6
February	3.1-11.8	3.2-17.0	-0.2-18.1	-0.4-21.8	5.0-24.8
March	7.3-17.9	7.5-21.3	0.2-25.8	8.2-23.1	10.0-27.4
Flordasun (peach)	4.2.2006	1.2.2006	14.2.2007	16.2.2008	28.1.2009
Oragun spur (apple)	22.2.2005	18.3.2006	10.4.2007	15.4.2008	2.3.2009
Allison (kiwi)	5.4.2005	1.4.2006	10.4.2007	12.4.2008	14.3.2009

There are significant new demands for crop improvement programs to combat climate change, focused on the development of varieties with greater resistance levels to biotic and abiotic extremes. Breeding programs, therefore, must develop crop-specific and region-specific strategies so that the products are relevant to problems and conditions

Table 2. Effect of rising winter temperature on the regeneration of some tree species at different elevations

Altitudinal range	Plant species	No. of saplings	No. of adult tree
1500-2000 m	*Quercus*	28	154
	Rhododendron	2	14
	Cedrus deodara	18	40
2000-2500 m	*Quercus*	17	45
	Rhododendron	6	20
	Cedrus deodara	32	116

PGR management strategies in the context of climate change

10-15 years down the line [5]. The genetic diversity contained in traditional crops and varieties, crop wild relatives, landraces and modern cultivars provide a basis for food production, and also act as buffer for adaptation and resilience in face of climate change. The countries in the world are interdependent on PGR and there is a continuous need to conserve, exchange and transfer healthy germplasm for sustainable agriculture and maintenance of a dynamic agro-ecosystem [56]. Genetically diverse plant populations and species-rich ecosystems have greater potential to adapt to climate change and for increasing local adaptation and building ecosystem resilience. Climate change will threaten wild relatives of cultivated crops and potentially landraces themselves, but will also increase the need for diverse germplasm in order to bolster resistance to increasing abiotic and biotic stresses. These factors represent both a challenge for genebanks to ensure that important genepools are adequately conserved and an opportunity for stimulating greater use of germplasm holdings. As climate change brings about novel demands on germplasm for adaptation, an emerging challenge in genebanks will be to adequately characterize their germplasm for traits and characteristics useful for crop improvement to respond to new challenges.

Collecting genetic resources

As mentioned above, large number of genetic resources important for food and agriculture has been collected. Nevertheless, many collections are incomplete and have significant gaps. Climate change creates even more demands for germplasm, thus priority species and regions need to be identified to capture all those rare alleles evolved and continue to do so in the changing climatic scenario be it warming or cooling. As wild species are the most exposed to climate change, consolidation of global germplasm collections of wild species, wild crop relatives, biological control species, and underutilized and wild harvested species become a high priority. Collections should cover all taxonomic species of relevance to crop improvement. Collection also needs to cover the full geographic distribution of the species, and especially populations on the extremes of the distribution where novel abiotic traits may be found.

Valuation of genetic resources

Climate change is expected to result in increased frequency of drought, heat stress, submergence, and increased soil salinity. There is, therefore, a need to find new sources of variation in germplasm. There is need to develop and refine screening techniques to identify and dissect the physiological basis of tolerance to abiotic stresses. We now have a better perception of the critical phases in plant development most affected by these stresses. Germplasm management, therefore, currently recognizes the value of moving from the characterization of whole collections to representative samples commonly referred to as 'core' and more recently as 'subsets' of collections.

(i) Genetic enhancement and utilization

In the present context, genetic base of many species and varieties has shrunken, thus more extensive and strategic use of the genetic diversity may be warranted. Genetic enhancement is used to bring new desirable traits from unadapted, or wild germplasm to adapted germplasm or cultivars [142]. This pre-packaging of desirable genes from wild relatives brings genetic enchantment of the cultivated gene pool to a level at which breeders can use it directly for breeding purposes to keep pace with environmental changes. However, genetic enhancement is often considered to be an activity at the interface between germplasm conservation and utilization and also a pre-competitive activity which concerned breeder cannot afford in short term hence, proactive role of breeders and germplasm curator is warranted. Some targeted pre-breeding work has been conducted to develop phyllody MYMV resistance in sesame and in others like *Prunus* and *Pyrus* sp. of temperate fruits.

(ii) Core collections

The genebanks are now entering an era of increased activity and responsibility with regard to sources of genes for various purposes and this require huge resources if entire range of collection is to be evaluated. The core collection is an effective approach to improve the access to a diverse genepool particularly to that comprises large genebank collections [143]. A core collection is a subsample of a larger germplasm collection that contains, with a minimum of repetitiveness, the maximum possible genetic diversity of a species [143, 144]. NBPGR has developed core collection in sesame, okra, mungbean while they are being validated in brinjal and french bean.

(iii) Focused identification of germplasm strategy (FIGS)

(i) FIGS represents a new and pragmatic approach to the identification of useful adaptive traits within landrace and wild germplasm collections that have adequate passport data associated with them [145]. In some cases, FIGS has proved exceedingly successful in identifying useful traits, allelic variation, new genes and seemingly completely new sources of resistance from relatively small subsets (smaller than core sets) of collections represented not more than 3% of the total collection [146-145]. Further refinement of FIGS will entail utilization of more comprehensive global databases, more sophisticated environmental modeling, inclusion of non geo-referenced accessions and the use of different classes of information such as characterization/evaluation data, expert opinion, traditional knowledge and molecular data. Research is currently underway to compare the utility of the FIGS approach to the much cited core collection method [148]. It is hypothesized here that while the core collection approach is a useful method to capture and measure diversity within a small amount of germplasm [144]. FIGS may well be a straighter forward and efficient method of capturing specific adaptive traits from large, and better still, combined collections [149, 145]. Further, FIGS is entirely focused on the specific needs of the users and is size flexible depending on their resources available for evaluation. Utilizing expanding global plant genetic resource databases, FIGS, coupled with the potential of eco-TILLING [150], offers an exciting new development that will greatly facilitate the efficiency and effectiveness of mining genes from germplasm being conserved in the genebanks.

(iv) Bioprospecting for novel biomolecules and genes

Classic signal molecules such as auxin, cytokinin, gibberellins, abscisic acid and more recently brassinosteroids have been extensively studied for their role in morphogenetic processes in plants [151, 152]. These molecules are involved in diverse processes, including seed germination, pathogenesis, modulation of plant architecture and response to abiotic factors ([153-157]. Coat protein gene from tobacco mosaic virus (TMV) classified as a positive strand RNA virus has been transferred to tobacco, making it nearly resistant against TMV [158, 159]. Using gene for nucelocapsid protein resistance has been introduced in crops like tomato, tobacco, lettuce, groundnut, pepper against tomato spotted wilt virus [160-163]. A number of genes responsible for providing resistance against stresses such as to water stress heat, cold, salt, heavy metals and phytohormones have been identified. Resistance against chilling was introduced into tobacco plants by introducing gene for glycerol-1-phosphate acyl-transferase enzyme from Arabidopsis. Many plants respond to drought stress by synthesizing a group of sugar derivatives called polyols (Mannitol, Sorbitol and Sion) as plants that have more polyols are more resistant to stress. Using a bacterial gene capable of synthesizing mannitols, it is possible to raise the level of mannitol very high making plants resistant to drought (www.fbae.org.2009/biotech_horticulture.html).The insecticidal beta endotoxin gene (bt gene) has been isolated from Bacillus thuringiensis and transferred to number of plants like cotton, tobacco, tomato, soybean, potato, etc to make them resistant to attack by insects. A chitinase gene obtained from *Serratia marcescens* (soil bacterium) is introduced in tobacco making it resistant to *Alternaria longipes* which causes brown spot diseases [164]. Therefore, there is a need to capitalize on the biological wealth of India for novel genes and metabolites of agricultural and industrial importance.

(v) Allele Mining

Physiological dissection of tolerant germplasm led to the identification of several traits associated with tolerance to abiotic stresses [5]. Early flowering provides an escape mechanism to drought; and is a characteristic invariably used in breeding programs. Substantial variation in root traits, water use efficiency, amount of water transpired, transpiration efficiency, osmotic adjustment, stem water soluble carbohydrates, stay-green, and leaf abscisic acid have been reported in many cereal and legume crops [165-168]. This area of functional genomics, or gene discovery, allows us to decide which parts of the genome determine agronomic traits of interest, for instance, grain quality, nutritional value, disease and pest resistance and abiotic stress tolerance and so on. For identified genes of known function and basic DNA sequence, collections are screened for allelic variation by e.g. the 'TILLING strategy' using DNA chip technology [169]. With this method new point mutations, in relatively large DNA fragments, can be detected. This approach can be optimized by focusing on target sets of polymorphisms, for example by using SNP detection methods. The comparative genomics is expected to provide variant alleles of useful genes with enhanced biological functions.

(vi) Bioinformatics

Bioinformatics is used here as a shorthand for information technology systems support for the management of biological and ecological data to facilitate biological discoveries. It includes the application of modern computers, telecommunications, networks, and databases, as well as more specialized tools such as GIS, image analysis, and statistical and modeling software [170, 171]. The ability to capture, manage, process, analyze and interpret biological data became more important than ever [172]. Based on the available data, future biodiversity of a particular area can be predicted, and model can be formulated by computational methods, and thereby appropriate measures can be taken for its conservation and sustainable utilization. The electronic information may serve as the raw material for augmenting future developments in other areas of biology, including phylogenetic relationship among species/individuals, and biodiversity extinction rate. Establishment of a repository for gene constructs and large insert DNA fragments hastens utilization of diverse genomic resources. We need to develop high resolution models, comprehensive and accurate set of data, accurate assessment of different ecological and weather parameters, their frequency of re-occurrence and stability as well and construction of different weather scenario over time, diagnostic studies on vulnerability and adaptation to climate change in the context of sustainable development, and identification of species specific climate sensitive ecological niches.

(vii) Phenomics and genomic resource centre

Keeping in view the enhanced use and value of genomic resources instead of seed material as such and also to screen the germplasm under the expected climate change scenarios, the ICAR has established genomic resources centre in NBPGR and phonemics facility are in offing. This venture is expected to enhance the utilization of genomic resources and its availability to researchers across the country. There is need to have integrated conservation of genomic resources in genome research centre to collect, validate and facilitate the use of useful genes and gene constructs. The indigenous genetic resources possessing gene and combination of genes for desirable traits provide a buffer output in times of drought, heat tolerance, floods and physiological responses like photo-insensitivity, high photosynthetic rates, low respirations, flood and many other biotic stresses. Current economic decisions are largely based on direct use values, although the other uses may be of equal or greater importance and in the context of genetic resources are indeed likely to be positive. Genomic resources will comprise of genomic DNA including DNA of rare and endangered species, genomic & cDNA libraries, BAC libraries, gene constructs and promoters etc. and will be conserved for long-term. It will also help to protect our indigenous genetic resources because gene and gene constructs are patentable.

On farm conservation

Deployment of greater genetic diversity in the traditional production systems is expected to take care of both the sustainable use and conservation of PGR. On-farm conservation is a dynamic form of plant genetic resources management that builds on natural and farmer selection and that is prevalent in complex, diverse, risk-prone environments where local subsistence farming is risk-laden. Landraces themselves contain solution to many problems of climate change, with a wide range of abiotic and biotic adaptation traits. Further studies and strategic analysis should focus on better understanding of the local-regional-global impacts of climate change on landrace diversity. Traditionally, *in situ* conservation has been used to conserve forest trees, wild species, and valued ecosystems; while *ex situ* conservation was a predominant approach for conservation of plant genetic resources for food and agriculture. This is, however, changing as scientists recognize that each approach has particular advantages and disadvantages and there is a growing interest in promoting on-farm conservation particularly in areas where agricultural modernization has taken place. Effective conservation systems that incorporate elements of both are now referred to as 'integrated approach to genetic resources conservation'. By including decentralized breeding as part of an on farm programme, farmers and scientists can become partners in local improvement efforts. This 'grassroot breeding' can build upon existing knowledge and skills of farmers and link farmers from different regions through the exchange of information and genetic resources. Further, a blend of modern science and indigenous knowledge will be required to face the challenges of increasing agricultural production in decades ahead.

Epilogue

In the next millennium, agricultural development in the country would be guided not only by the compulsion of food and nutritional security, but also by the concern for environmental protection, sustainability and profitability. Such a target is not an easy one considering the diminishing availability of factors favorable for growth, fast decline in efficiency of input-use in the major cropping systems and rapidly shrinking resources base. Thus, it would be possible to obtain appropriate solutions to the problem only through a systematic research on plant species that are still unexplored. Global climatic changes and increasing climatic variability are likely to exert pressure on agricultural systems and may jeopardize future food production targets *vis-a-vis* food security. Available adaptation strategies can help to reduce negative impacts in short term but to a limited extent. We therefore, require focus on adaptation research, capacity building, development activities and changes in policies. A win-win solution is to start with such adaptation strategies that are anyway needed for sustainable development. Efforts on the PGR conservation and characterization and development of better adapted and resistant crops to the fluctuating environment will add to food security strategy and help copping with climate change. Biotechnology and modern tools of information technology, space technology and communication have great role to play in this. Domesticated plant biodiversity need to be promoted and maintained on farm so that genes can continue to evolve, adopt and respond to the expected climatic changes. Establishment of early warning system for emerging climatic risks such as drought, floods, heat and cold waves, and for pests and diseases outbreaks are desired. Also, incentivize farmers for resource conservation and efficient use. Strategies for adaptation to climate change will need to embrace different sectors, support development and will be interdependent, requiring collaboration amongst stakeholders, ranging from resource managers to policy makers. Mobilize national and international opinion to make food security and poverty alleviation central in climate change negotiations while GHG emissions are reduced. There is a need to be more proactive than reactive and to focus on measures that achieve multiple targets. Planning for biodiversity-inclusive impact assessment will ensure mitigation of biodiversity loss and secure economic development and human well-being.

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