Wild Relatives of Horticultural Crops: PGR Management in Indian Context

K. Joseph John and K. Pradheep

Abstract Crop wild relatives (CWR) are wild taxa closely related to crop plants, including wild progenitors and/or wild forms of crops. CWR were successfully employed in incorporation of desired traits in a few horticultural crops. In fruit crops, wild relatives also serve as clonal rootstocks/pollinizers to increase productivity and impart resistance/tolerance to abiotic and biotic stresses. The distribution, variability, and conservation status of various CWRs in horticultural crops are described. The representation of CWRs in seed banks is inadequate and often collected sporadically (rather than systematically). The PGR management in these species (exploration, collection, characterization, and conservation) is also dealt in detail. Analysis revealed the existence of huge gaps in CWR collection in terms of number as well as representative collection, even in the crucial crop-groups such as vegetables and in protected areas and fragile ecosystems such as coastal and cold-arid ecosystem. The future needs of research in CWR related to horticultural crops are dealt with.

Keywords Crop Wild Relatives · Plant genetic resources · Agro-biodiversity hotspot · Crop improvement

1 Introduction

India, located at 6°4′–37°6′ N latitudes and 68°7′–97°25′ E longitudes, having a landmass of 3029 m ha ranging from below sea level to high reaches of the Himalayas, exhibits magnificent ecological diversity, micro habitats and ethnic diversity. It harbours four (out of 35) 'biodiversity hotspots' in the world – Western

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Ghats, Himalayas, Indo-Burma and Sundaland (Nicobar). India is the home to about 166 cultivated crops, over 326 species of high-priority wild relatives of crop plants, 1000 wild edible plants and 9500 species of ethno-botanic significance (of which, 7500 are of medicinal value). This Vavilovian Center, designated as Hindustani Center of Origin/Diversity, is recognized as the primary centre of origin of rice, sugarcane, green gram, black gram, jute, mango, citrus, banana, snake gourd, yam, taro, turmeric, ginger, cardamom, black pepper, jack fruit, etc. Also it forms the secondary centre of diversity for crops like maize, red pepper, potato, coconut, areca nut, several types of bean and grain amaranth. Besides, there are many wild species in domestication interphase, for instance, Malabar tamarind (*Garcinia gummi-gutta*), kokum (*Garcinia indica*), cowa mangosteen (*G. cowa*), spine gourd (*Momordica dioica*), teasel gourd (*Momordica subangulata* subsp. *renigera*) and sweet gourd (*M. cochinchinensis*).

Horticultural crops are important components of cultivated agro-biodiversity. For the past 50 years, this sector achieved about nine times increase in production (in contrast to 2–3 times increase in agricultural crops) in India. Though they occupy one tenth of gross cropped area in the country, their species diversity is very high, in contrast to agricultural crops. Out of 480 crops cultivated in this country, about 397 (fruits and nuts, 86; vegetables and edible tubers, 94; spices, condiments and flavourings, 50; medicinal and aromatic plants, 83; others, 84) belonged to this category (Nayar et al. 2003). India is bestowed with a wide variety of agroclimatic conditions, resulting in almost all kinds of horticultural crops being cultivated in one region or the other. India is the second largest producer of fruit and vegetables in the world and ranks first in the production of mango, banana, papaya, coconut, cashew, tea and spices. In some tribal parts of the country, horticultural crops like potato, sweet potato, banana, cassava, yams and taro form staple food. Thus, there exists a vast potential for the cultivation of horticultural crops, which helps in enhanced food and nutritional security.

Occurrence of progenitors/closely related species of cultivated plants, which evolved in time and space with varied landscape ecology and terrestrial heterogeneity, is an important indication of richness of agro-biodiversity. India has a considerable number of wild species coming under the crop genus boundary, as indicated below.

2 Importance of CWR in Horticultural Crops

Crop wild relatives (CWR) are wild taxa closely related to crop plants, including wild progenitors and/or wild forms of crops. There is a continuous and increasing requirement for novel traits for use in the development of new varieties. Crop wild relatives form an important source of useful traits such as agronomic, quality and biotic and abiotic stresses, which are identified as critical component for food security and environmental sustainability in the twenty-first century (Scholten et al. 2005). Hajjar and Hodgkin (2007) surveyed 20 crops, out of which 17 cultivars had

Table 1 Transfer of traits from CWR into crops: some examples

Crop	Wild species	Trait incorporated	Reference
Cucumber	*Cucumis hystrix*	Resistance to downy mildew	Zhou et al. (2008)
Muskmelon	*Cucumis melo* subsp. *agrestis*	Resistance to melon vine decline	Dias (2003)
Black pepper	*Piper attenuatum* *P. barberi*	*Pollu* beetle resistance	Krishnamoorthy and Parthasarathy (2011)
Strawberry	*Fragaria nilgerrensis*	Aroma	

genes introgressed from CWR. Later, Maxted and Kell (2009) reviewed the use of CWR in crop improvement and cited 291 articles reporting the identification and transfer of useful traits from 183 CWR taxa into 29 crop species. They concluded that the number of papers describing the use of CWR in breeding has increased gradually over time. The most widespread use of CWR has been and continues to remain in the development of disease and pest resistance, with 39% of use associated with improving disease resistance, 17% with pest resistance, 13% with abiotic stress, 10% with yield increase, 11% with quality improvement, 6% with husbandry improvement and 4% with cytoplasmic male sterility and fertility restoration (Maxted and Kell, 2009). CWR were extensively utilized in commercial crops – rice, wheat, sugarcane and potato. CWR were successfully employed in incorporation of desired traits in few horticultural crops also (Table 1). In fruit crops, wild relatives also serve as clonal rootstocks/pollinizers to increase productivity and impart resistance/tolerance to abiotic and biotic stresses.

No country is self-sufficient in the quantum of genetic wealth available with it. At the same time, it is equally important to recognize the importance of exploring and utilizing those related species available in the country, in the wake of recent global developments. Meanwhile, there are many wild species added over the years in the Red Data Book. Besides, CWRs are often associated with disturbed habitats, and neither these habitats are offered adequate protection by ecosystem conservation agencies (Maxted and Kell 2009) nor their diversity properly conserved ex situ. CWR diversity, like that for many species, is at a declining stage; this decline is associated with the loss of genetic diversity (Hopkins and Maxted 2010). This necessitates the need to establish CWR inventories (Scholten et al. 2005) which is also an indispensable tool for exploration, surveys and collection of CWR (Hammer 1991; Prendergast 1995). Therefore, the need for novel genes, the need for developing climate-resilient varieties, advantages offered by breakdown of barriers to introgression through biotechnological tools, increasing pressure on wild species population and habitat and the present meagre ex situ collections all accentuate the importance of collecting germplasm of wild relatives. Limitation of genetic diversity for desirable traits including resilience to climatic change in cultivated gene pool has forced the breeders to look for desirable traits in progenitors and close relatives of crops.

3 What Is a CWR?

Maxted et al. (2006) defined a CWR as 'a wild plant taxon that has an indirect use derived from its close genetic relationship to a crop'. Common approach of considering all the species of the same crop genus as CWR is not appreciable, especially for big genera (e.g. *Ficus*) and in well-worked crops (here usefulness of related genera is too often visualized). Possibility of successful incorporatation of desirable traits from wild species to crops would be more if they are closely related to cultivated species. Maxted et al. (2006) were of the opinion that more close wild relatives can be in GP_{1B} or taxon groups 1 and 2. From the crop improvement angle, cytogenetical relationship needs to be given priority. Existence of variants/natural hybrids and successful experimental hybridizations mean that the species are closely related. Different species of the genus exhibiting the same chromosome number and homology would be closely related. Relationship can further be established through other means such as biochemistry, palynology, molecular biology, geography, etc. Pradheep et al. (2014) highlighted informal ways to specify CWRs. In general, an integrated approach of various means may bring out a clear picture. Though in the light of contemporary biotechnological advances, most, if not all, species are potential gene donors to crops (Maxted et al. 2008), in practical sense of conservation and use, it is important to prioritize the most closely related taxa through some estimate of the degree of interrelationship (Hopkins and Maxted 2010) and other means.

Arora and Nayar (1984) reported the occurrence of 190 wild relatives of horticultural crops (fruits, 109; vegetables, 54; others, 27) in India. It is of paramount importance to monitor the changes over the period of time, with respect to species distribution, influx, changes in species concept, new light on species relationship, utility, threat status, discovery of new taxa, etc. In well-studied genera, more number of wild relatives have been reported, indicating that more the in-depth researches, greater the possibility of identifying more CWR. Species concepts are under constant change in response to revisionary works – affects outlook on target crop species. In many species, the extension in their distributional range, especially in the plains, was reported. It should be noted that synonymy, taxonomic changes and differences in expert opinion do directly affect the statistics and hence the interpretation of the results. Few taxonomic problems often noticed are lumping and splitting at inter/intraspecies level (e.g. *Abelmoschus*, *Cucumis*, *Trichosanthes*) and merger of smaller genera due to monophyly (e.g. *Cucumella*, *Dicaelospermum*, *Mukia*, etc. with *Cucumis*). In the Indian context, knowledge of related taxa is still fragmentary in most crops. It is partially due to the lack of an updated comprehensive flora of India. However, genera *Abelmoschus*, *Cucumis*, *Momordica* and *Trichosanthes* were studied fairly well for their diversity and field identification manuals prepared in the former two genera (Yadav et al. 2014). In this context, production of at least a tentative enumeration of crop wild relatives with the ultimate aim of enhancing the use of CWR diversity is needed, which will help in preparing CWR inventories, as well as aid in rationalizing what taxa to be prioritized for collection/conservation/utiliza-

tion. A pragmatic exercise to shortlist the CWRs of native horticultural crops (based on ICAR's mandate, closeness and usefulness in breeding) resulted in 552 taxa belonging to 490 species, including wild/weedy form(s) or populations of 110 crop taxa (modified from Pradheep et al. 2015b; see below).

For further prioritization, a scoring technique (Pradheep et al. 2015b) employing criteria (with a set of indicators) indicating economic importance of crops per se, level of closeness to crops, possessing traits of breeders' interest/need, extent of distribution/threat and seed storage behaviour (see table below) would be of use. Such a work identified top priority CWRs in vegetables as *Luffa acutangula* var. *amara*, *Abelmoschus tuberculatus*, *A. angulosus* var. *grandiflorus*, *A. tuberculatus* var. *deltoidefolius*, *Allium roylei*, *Cucumis melo* subsp. *agrestis* var. *agrestis*, *C. sativus* var. *hardwickii*, *Momordica sahyadrica* and *M. dioica* (>14 score out of 18).

4 CWR in Indian Bio-Geographic Zones

Generally, CWRs, especially of field crops, occur as components of disturbed bio-edaphic communities such as disturbed grasslands, scrub vegetation, open forest areas, in man-transformed ecosystems such as field borders and road sides (e.g. *Abelmoschus tetraphyllus*, *Cucumis melo* subsp. *agrestis*, *C. sativus* var. *hardwickii*). These habitats are likely to be subjected to increasing level of anthropogenic destruction as well as invasive alien weeds. Nevertheless, related species of perennial horticultural crops are also found in forest areas. Nayar (1996) identified 25 micro-centres of endemic plants in India, while Nagarajan et al. (2007) identified 18 agro-biodiversity hotspots in India. As CWRs occur in both man-transformed and undisturbed habitats, a brief account of the biogeographic zones and zone-wise distribution of important CWRs (Rodgers and Panwar 1990; Rao 1994) has been highlighted below.

4.1 Western Ghats

The Western Ghats occupies 5% of the country's land area (1,59,000 sq. km) (Negi 1993). The region lies as a 1500 km long chain of hills, plateaus, plains in the rainy and rain shadow areas, slopes, coastal plains and valleys from Kanyakumari district in Tamil Nadu to Tapti River in Gujarat. Altitude varies considerably from sea level in the west coast to above 2700 m in Idukki of Kerala and Nilgiris of Tamil Nadu and merges with rain shadow areas in eastern slopes and plains in Tamil Nadu and with the Deccan Plateau in Karnataka and Maharashtra. In the Konkan region, hills are lower and form a plateau. Further, extensive ramification of the mountain systems in the three southernmost states gives rise to very diverse ecological situations such as tropical wet evergreen, tropical semievergreen, tropical dry deciduous, shola and few pockets of semi temperate forests above 1500 m. Broadly, seven

important areas having forest covers and surrounding plantation and agricultural areas of human inhabitation have been identified: (1) Agasthyamalai of Thiruvananthapuram and Kollam and Tirunelveli hills; (2) Anamalai, Idukki, Palani hills and Sabarigiri areas; (3) Nilgiri Biosphere Reserve in Palakkad, Nilgiri, Mysuru and Wayanad districts; (4) Kodagu, Dakshina Kannada, and Chikmagalur areas; (5) Udupi, Shimoga and Chikmagalur districts; (6) Uttara Kannada, Karwar and Goa areas; and (7) Ratnagiri in Konkan region of Maharashtra. There are 2 biosphere reserves, 3 national parks and about 44 wildlife sanctuaries in the region serving in situ conservation of flora and fauna to a great extent. The zone is also considered as a continuation of Indo-Malayan region with some common or related floristic elements and is characterized by high degree of endemism.

This region holds about one fourth of the country's plant species (4000) including 1800 endemic species, 500 medicinal and aromatic plants, 160 crops and 406 crop wild relatives, 500 medicinal plants and scores of edible and other useful plant species. This region is the centre of origin/domestication of black pepper, jack fruit, and small cardamom. High genetic/species diversity in CWR genera like *Abelmoschus*, *Amorphophallus*, *Artocarpus*, *Curcuma*, *Dioscorea*, *Garcinia*, *Momordica*, *Piper*, *Myristica*, *Cinnamomum* and *Zingiber* was observed in this zone. Besides *Abelmoschus angulosus* vars. *purpureus* and *angulosus*, *Cucumis indicus*, *C. silentvalleyi*, *Artocarpus hirsutus* and newly described CWR taxa like *Momordica sahyadrica*, *Abelmoschus enbeepeegeearensis*, *Garcinia pushpangadaniana*, *G. gamblei* and *Cinnamomum mathewianum* are endemic to the Western Ghats.

4.2 Coasts

India has a vast stretch of coastal zone running to a length about 7517 km, which includes coastal waters, wetlands and adjacent shore lands influenced by marine waters or vice versa (Nayak et al. 1989). Besides loss of habitat due to severe anthropogenic pressures, the east coast faces threats from natural calamities such as frequent cyclones, heavy winds and floods, high rainfall events and seawater intrusion. Plant species in this region exhibit distinct ecological preferences – inhabiting strands (sand dune, sandy and rocky coast) or mangroves/mangrove associates/back mangals – therefore expected to have inbuilt salinity tolerance. The west coast harbours an extension of the Western Ghats flora.

Some CWR species of horticultural crops occurring in coastal areas includes:

- *Abelmoschus tetraphyllus* (Roxb. Ex Hornem.) Wall.
- *Alocasia macrorrhizos* (L.) G. Don.
- *Aloe abyssinica* Lam.
- *Amaranthus tricolor* L.
- *Canavalia cathartica* Thouars.
- *Canavalia rosea* (Sw.) DC. [syn. *C. maritima* (Aubl.) Thouars, *C. obtusifolia* (Lam.) DC.)]

- *Chlorophytum tuberosum* Baker.
- *Citrullus colocynthis* (L.) Schrad.
- *Clitoria ternatea* L.
- *Drimia indica* (Roxb.) Jessop [syn. *Urginea indica* (Roxb.) Kunth].
- *Gloriosa superba* L.
- *Ipomoea littoralis* (L.) Blume.
- *Manilkara hexandra* (Roxb.) Dubard.
- *Manilkara littoralis* (Kurz) Dubard.
- *Morinda citrifolia* L.
- *Mucuna gigantea* (Willd.) DC.
- *Mucuna monosperma* DC. Ex Wight.
- *Mucuna nigricans* (Lour.) Steud.
- *Mucuna pruriens* (L.) DC.
- *Ocimum gratissimum* L.
- *Phoenix paludosa* Roxb.
- *Phoenix pusilla* Gaertn. [syn. *P. farinifera* Roxb.].
- *Solanum arundo* Mattei.
- *Solanum nigrum* L.
- *Solanum torvum* Sw.
- *Solanum trilobatum* L.
- *Solanum violaceum* Ortega.
- *Solanum virginianum* L.
- *Tacca leontopetaloides* (L.) Kuntze.
- *Tinospora cordifolia* (Willd.) Hook. f. & Thomson.
- *Trichosanthes cucumerina* L.
- *Ziziphus mauritiana* Lam.
- *Ziziphus williamii* Bhandari and Bhansali.

About two-thirds of the above species also occur inland indicating their adaptation to a wider range of ecological and habitat conditions, which might yield diverse and trait-specific germplasm. Taxa restricted to coastal areas, namely, *Canavalia rosea*, *Aloe abyssinica*, *Lablab purpureus*, *Manilkara littoralis*, *Phoenix paludosa*, *P. pusilla*, *Solanum arundo* and *Ziziphus williamii*, are confined to few localities, necessitating adequate conservation attention, probably through a combination of more than one strategy. Tolerance to salinity is normally exhibited in species occurring in coastal environments (Nayak and Bahuguna 2001).

4.3 Trans-Himalaya

Cold arid tract in the western edge of trans-Himalaya encompasses 30°64′–37°20′ N latitude and 72°30′–80°15′ E longitude covering an area of 98,600 km^2 (Murti 2001). Politically, this region consists of the entire Ladakh region of Jammu and Kashmir state, the Lahaul and Spiti district and Pangi area of Chamba district of

Himachal Pradesh and beyond Mana and Niti and Nelang valley areas in Chamoli and Uttarkashi districts of Uttarakhand. This region is characterized by extremes of climatic conditions such as subzero temperature (up to −75 °C, Drass) with a great diurnal fluctuation (difference of up to 40 °C), meagre rainfall (80–300 mm), heavy snowfall (up to 300 cm), speedy afternoon winds (40–60 kmph), heavy influx of infrared and ultraviolet radiations and very low relative humidity (25–50%). Land is extremely barren with poor organic matter (1.17%), loose texture and low level of nutrients except potassium and high p^H (7–11) (Rana et al. 2007).

This zone was reported as essentially a region of open vegetation above the treeline on the mountain (Mani 1978). It is characterized by stunted shrubs, low-growing herbs and grassy meadows. It consists of a highly specialized group of plants with peculiar mechanisms suitable for survival in specialized harsh climatic conditions leading to endemism. Hence, this cold desert ecosystem is recognized as one of the important fragile ecosystems of India. *Allium*, *Artemisia*, *Bunium*, *Carum*, *Fragaria*, *Hippophae*, *Malus*, *Prunus*, *Ribes* and *Rubus* form important horticultural genera, besides few ornamentals like *Rosa*, *Primula*, *Gentiana* and *Rhododendron*. Though alpine zone is poor in CWR diversity, wild species would form valuable source for cold and drought tolerance.

4.4 Himalaya

The Himalayan Mountains rise abruptly, resulting in a diversity of ecosystems that range from alluvial grasslands and subtropical broadleaf forests to alpine meadows above the treeline. About 10,000 plant species including 3160 endemic species occur here. The largest family of flowering plants in the zone is the Orchidaceae, with 750 species. This zone is threatened by anthropogenic pressure, livestock grazing and destructive harvesting of medicinal plants.

The Himalayan region is also known for its rich diversity of plant genetic resources of crop plants and their wild relatives. In Western Himalaya, there exist about 135 cultivated species and 125 CWR (Rana et al. 2015). Major genera for which diversity occur represent *Pyrus*, *Prunus*, *Sorbus*, *Ribes*, *Rubus*, *Allium*, *Carum*, *Bunium* and *Cucumis*. In Eastern Himalaya, high rainfall and cold climate coupled with altitudinal variations add to the diversity of habitats and thus provide a variety of microclimates and ecological niches. Hence it is considered as a region of active speciation and designed as cradle of flowering plants. Major genera for which diversity occur represent *Musa*, *Mangifera*, *Citrus*, *Malus*, *Pyrus*, *Prunus*, *Fragaria*, *Vitis*, *Rubus*, *Allium*, *Actinidia*, *Phoenix* and *Garcinia*. The Eastern Himalaya is also a centre of diversity for several widely distributed plant taxa such as orchids, *Rhododendron*, *Primula* and *Pedicularis*.

4.5 North-East

The region is the 'gateway' for much of India's flora and fauna with a high level of endemism. Five major forest types, viz. tropical moist deciduous forests, tropical semievergreen forests, tropical wet evergreen forests, subtropical forests and temperate forests, are found here. Natural vegetation of the region is characterized by a composition of Eastern Himalayan and Burmese (Myanmar) floral elements. The endemic richness of plant genetic diversity in this region is confined mainly in West Kamrup, Lushai Hills, Tura, Balphakram, Khasi Hills, Jaintia Hills, Jampui Hills, Naga Hills and Cachar areas. The region is also the home of approximately half the number of total tribal groups in the country. The economy of this region is agriculture-based; however, little land is available for settled agriculture. Agriculture has been the main livelihood among the hills and the plain tribes. Along with the settled agriculture, '*jhum*' or shifting cultivation or slash-and-burn method of cultivation is often carried out by majority of tribal groups, which contributes 85 per cent of the total cultivation in hill region.

This region is a centre of origin/diversity for a number of agri-horticultural crops, wild relatives and minor economic plants, for instance, bamboos (78 taxa), banana (18 species), citrus (17 species), aroids (15 species), orchids (700 species), medicinal plants (>2000 species), wild relatives (132 species) and many other rare and endangered taxa. Some horticultural genera of plant genetic resources importance having rich species diversity from this region include *Abelmoschus*, *Amomum*, *Artocarpus*, *Camellia*, *Cinnamomum*, *Citrus*, *Curcuma*, *Cucumis*, *Dioscorea*, *Docynia*, *Elaeagnus*, *Ensete*, *Garcinia*, *Fragaria*, *Hedychium*, *Hodgsonia*, *Malus*, *Mangifera*, *Momordica*, *Mucuna*, *Musa*, *Prunus*, *Pyrus*, *Rubus*, *Solanum*, *Trichosanthes*, *Zingiber*, etc. besides a number or orchid genera. Unique, rare, endemic crop wild relatives include *Momordica subangulata* subsp. *subangulata*, *M. cochinchinensis*, *Cucumis hystrix*, *C. muriculatus*, *Abelmoschus tetraphyllus* var. *pungens*, *Solanum spirale*, *S. kurzii*, etc. Expansion of agricultural activities, over-exploitation of forest resources, urbanization, man-made forest fires, invasion of exotic plant species, ill-managed road construction and mining are some of the notable threats to the rich biodiversity occurring in the region. Declared in situ conserved area is around 6% of the total geographical area of the region, mainly in the form of biosphere reserves, national parks, wildlife sanctuaries, gene sanctuary, sacred groves and heritage sites. Dehang-Dibang, Manas, Kanchanjunga, Nokrek and Dibru-Saikhowa are the five declared biosphere reserves in the region. Besides these, 16 national parks and 55 wildlife sanctuaries afford in situ protection to the flora and fauna.

4.6 Desert

The arid region in India includes about 60% of Rajasthan (1,96,150 sq. km), 20% of Gujarat (62,180), 5% of Punjab (14,510) and 4% of Haryana (12,840). The boundary includes Aravalli ranges in the east, Champaner in south-west to near Delhi in

the north-east (Shetty and Singh, 1996). This desert is characterized by low and erratic rainfall, high solar radiation, extreme diurnal and seasonal variation in temperature and low relative humidity for larger part of the year. Vegetation cover is poor owing to sandy soil with poor water holding capacity, deep water table, salinity and desiccating winds and dusty storms. All these features make this region ideal for locating drought-tolerant germplasm, not only for the species endemic/restricted to this area but also other species having wider range of ecological and habitat adaptations.

Jodhpur-Bikaner belt is considered as an agro-biodiversity hotspot. Vegetation in this desert zone has been conveniently classified as below (Shetty and Singh 1996) with examples of some CWR.

1. Sand dunes and interdunal areas: *Citrullus colocynthis*, *Ziziphus nummularia*
2. Sandy and hummocky plains: *Ziziphus nummularia*, *Citrullus colocynthis*, *Cucumis prophetarum*, *Coccinia grandis*, *Momordica dioica*, *M. balsamina*, *M. charantia* var. *muricata*, *Trichosanthes cucumerina*
3. Gravelly/rocky plains: *Ziziphus nummularia*
4. Isolated hills and rock outcrops
5. Saline habitats: *Solanum virginianum*
6. River beds: *Cucumis melo* subsp. *agrestis*, *C. sativus* var. *hardwickii*, *Abelmoschus ficulneus*, *A. tuberculatus*
7. Marshy and aquatic habitats
8. Weeds of cultivated and fallow fields: *Trigonella corniculata*, *T. occulta*, *Withania somnifera*, *Cucumis callosus*, *C. prophetarum*, *Cyamopsis tetragonoloba* (*adak-guar*, the weedy form)

Ziziphus truncata is an endemic taxon from this zone.

4.7 Semiarid

This forms a transitional zone between the desert, Western Ghats and Deccan Peninsula. This ecosystem is distributed in Rajasthan, Punjab, Delhi, Haryana, Gujarat and adjoining parts of Madhya Pradesh, Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir. Vegetation cover is discontinuous; water deficit occurs throughout the year. Two types of vegetation – tropical dry deciduous forest and tropical thorn forest – are common. Climate is very dry (8–10 months) alternating with a very short rainy period, besides alternation in the day length hours during summer and winter. North African-Indian Desert (Saharo-Sindian) elements are prominent in these areas owing to dry and hot conditions.

The two micro-centres, Aravalli ranges and Kathiawar-Kutch, come under this zone and some genera of interest include *Capparis*, *Phoenix* and *Flacourtia*. Gulfs of Gujarat (Rann) and Kathiawar and North Gujarat/Mewar are two identified agro-biodiversity hotspots in this zone. The trait of drought tolerance can be expected in germplasm collections from this zone.

4.8 Deccan Peninsula

Largest of all phyto-geographic zones, this includes major areas of Maharashtra, Madhya Pradesh, Uttar Pradesh, Karnataka, Tamil Nadu, Telangana, Andhra Pradesh, Odisha and Jharkhand. Major portion of this zone is covered by tropical thorn forests and tropical dry and moist deciduous forests. Average annual rainfall is about 100 cm. Marathwada-Satpura ranges, Tirupati-Cuddappa-Nallamalai hills, Visakhapatnam-Ganjam-Jeypore hills, southern Deccan (Leeward side) and Chota Nagpur plateau form micro-centres, whereas Koraput region, Bastar and adjoining area, Cauvery system and Kolli Hills form important agro-biodiversity hotspot regions within this zone. Some important taxa of horticultural importance include *Michelia*, *Santalum*, *Ziziphus*, *Capparis*, *Lagerstroemia*, *Hiptage*, *Dioscorea* and *Phoenix*. This zone is characterized by the presence of black cotton soil. *Luffa tuberosa* with extra small fruits is endemic and confined to this region.

The eastern edge of the Deccan Plateau leads to the Eastern Ghats which discontinuously run almost parallel to the east coast of India. It spreads over the states of Odisha, Chhattisgarh, through Andhra Pradesh to Tamil Nadu and adjoining Karnataka, northern boundary being Simlipal massif, and towards the south, it meets with the Western Ghats in the Nilgiri hills. The variations in altitude and climatic conditions, especially in rainfall, have immensely contributed to the evolution of rich floristic diversity. Out of 2500 species of flowering plants of the Eastern Ghats, about 4% of the flora is endemic (Ahmedullah and Nayar 1987). Important CWR genera of horticultural importance are *Abelmoschus*, *Amaranthus*, *Amorphophallus*, *Cinnamomum*, *Cucumis*, *Curcuma*, *Dioscorea*, *Luffa*, *Momordica*, *Phyllanthus*, *Piper*, *Solanum*, *Trichosanthes*, *Vanilla* and *Zingiber*. *Cucumis setosus*, *Abelmoschus crinitus*, *A. tuberculatus*, *A. ficulneus*, *Luffa echinata*, *Momordica dioica*, etc. are found in this zone. Some of the CWRs from Eastern Ghats region have been assigned IUCN status, e.g. *Amorphophallus sylvaticus* (Vulnerable); *Phyllanthus indofischeri* (Vulnerable Globally); *Trichosanthes cucumerina* (Near Threatened); *Zingiber roseum* and *Plectranthus barbatus* (Endangered); and *Syzygium alternifolium* and *Pimpinella tirupatiensis* (Endangered Globally) (Pandravada et al. 2008).

4.9 Gangetic Plains

Primarily an agrarian zone, it supports dense human population stretching from eastern Rajasthan through Uttar Pradesh to Bihar and West Bengal. The Gangetic Plains also include the area adjacent to Terai-Bhabar tracts, located at Himalayan foothills, in Uttar Pradesh, Bihar and West Bengal. Climate is characterized by warm wet season during rainy period and then dry season for the rest of the year. Its climatic conditions support the growth of dry deciduous forests. Lower Ganges system, Gangetic Delta and Triveni-Allahabad belt forms agro-biodiversity hotspots.

Five types of forests recognized in this zone include *sal* forests (in northern belt), mixed forests, swamp forests, alluvial forests (along banks of river) and mangroves of Sunderbans. Some important genera of horticultural importance include *Phyllanthus*, *Lagerstroemia*, *Ziziphus* and *Syzygium*. *Rosa involucrata* is sometimes found in open grassy swamps.

4.10 Islands

Andaman and Nicobar group of islands in the Bay of Bengal has 573 islands, the former considered as the southern continuation of Arrakkan-Yoma tectonic unit and the latter the northern continuation of Sumatran unit. This resulted in the northern one having Myanmar (Burmese) elements, while the southern one with Sumatran elements. Nearly 10% of its vegetation is endemic (total 3000 taxa). High annual rainfall (3180 mm) contributed to the dense humid tropical forests, which occupies about 86% of the area. Vegetation includes littoral forests, evergreen and deciduous forests; the latter two occur as inland vegetation. Only 36 islands have been inhabited by humans. The union territory of Lakshadweep comprises 10 inhabited and 17 uninhabited islets with a total land area of 28.5 sq. km. Soil is calcareous and poor in nutrient content. Rich diversity in noni (*Morinda citrifolia*) was found, especially in Minicoy islands.

Some WRs identified for PGR management from this zone includes:

- *Abelmoschus moschatus*
- *Artocarpus chama*
- *Artocarpus gomezianus*
- *Bouea oppositifolia*
- *Canavalia cathartica*
- *Cinnamomum bejolghota*
- *Cucumis melo* subsp. *agrestis*
- *Curcuma mangga*
- *Dioscorea bulbifera*
- *Dioscorea glabra*
- *Dioscorea vexans*
- *Garcinia cowa*
- *Garcinia hombroniana*
- *Jasminum multiflorum* var. *nicobaricum*
- *Knema andamanica*
- *Mangifera nicobarica*
- *Mangifera andamanica*
- *Mangifera camptosperma*
- *Mangifera sylvatica*
- *Momordica charantia* (wild)
- *Mucuna gigantea*
- *Musa acuminata*

- *Musa balbisiana*
- *Musa indandamanensis*
- *Musa paramjitiana*
- *Myristica elliptica*
- *Nephelium uncinatum*
- *Piper betel*
- *Piper miniatum*
- *Piper pedicellosum*
- *Piper wallichii*
- *Rauvolfia sumatrana*
- *Saccharum spontaneum*
- *Solanum insanum*
- *Solanum torvum*
- *Tinospora sinensis*
- *Vanilla andamanica*
- *Vigna adenantha*
- *Vigna trilobata*
- *Ziziphus brunoniana*
- *Ziziphus horsfieldii*

5 CWR Genetic Resources in Horticultural Crops

As stated earlier, there are a number of crops of horticultural importance cultivated in India. This is especially true in case of ornamentals and medicinal and aromatic plants. They exhibit diversity in habit such as annuals, biennials, perennials, trees, tubers, bulbs, etc. Correspondingly, species related to cultivated plants are enormous in number, which makes their prioritization crucial for germplasm conservation. While vegetables and seed spices have small seed size and mostly share orthodox seed storage behaviour (like most of field crops), other horticultural crops are quite often recalcitrant and of large seed size demanding large storage space. The former group is easily bankable in seed gene bank, while the latter requires to be conserved in field gene bank or in vitro/cryo gene bank. Wild species are more difficult to regenerate than cultivated species. Therefore, strategies for conservation of perennial horticultural crops are different from that of field/agricultural crops.

The representation of CWRs in seed banks is inadequate and often collected sporadically (rather than systematic). The second *State of the World Report on Plant Genetic Resources for Food and Agriculture* (FAO 2010) reports about 10% share of wild species in the global germplasm holdings, in which CWRs constitute about 2–6% (Maxted and Kell 2009). The National Gene Bank (NGB) at ICAR-NBPGR, New Delhi, is the second largest ex situ seed repository having a total of 4,16,637 accessions belonging to 1762 species in various crop groups and wild/weedy relatives. CWRs occupy about 2.76% of the total collections in this gene bank.

In the past, Dr. Harbhajan Singh, nicknamed ‘Indian Vavilov’, undertook many international collaborative explorations during post-independence era for the col-

lection of horticultural crops like *Musa*, cucumber and melons, tea clones and ornamental orchids from diverse regions of the country. Extensive effort for the collection of wild germplasm was made during the implementation of National Agricultural Technology Project on Plant Biodiversity (1999–2006). As of today, the collected accessions accounts for about 12% of the total wild germplasm collected by the Bureau, CWRs accounting for about 30% of the total wild germplasm collected. Significant collections were made in some CWR under the genera *Citrus*, *Abelmoschus*, *Cucumis*, *Momordica* and *Solanum*. Table 2 lists out the breeders' needs for desirable traits in horticultural crops in the Indian context based on inputs from horticultural crop-based institutes. Table 3 lists the high-priority CWR identified, along with their distribution and potentialities.

Table 2 Crop-group-wise native CWR occurring in India

S. No.	Crop group (crops**)	No. of CWR species*	Taxa
1.	Fruits and nuts (36)	135 (12)	156
2.	Vegetables (25)	78 (11)	89
3.	Spices and condiments (12)	54 (7)	60
4.	Ornamentals (13)	141 (61)	152
5.	Medicinal and aromatic plants (20)	70 (19)	81
6.	Plantation crops (3)	12	14
	Crops: 109	490 (110)	552

*Figures in parenthesis are crop species with wild/weedy form(s) or populations occurring in India, which are also included for counting as CWR; **one crop may involve more than one species

Table 3 Criteria indicating economic importance of crops

#	Criterion	Indicator(s)	Score
1.	Economic importance of crops (corresponding to intended relative) at national context	Commercial/principal crops	5
		Well-known/established crops	3
		Minor/economically less important crops	1
2.	Relative closeness of CWR and its usefulness	[Wild form/progenitor of principal/well-known crops] [those from whom desired trait(s) incorporated/under incorporation] [those having multiple breeding traits]	5
		[Wild populations of minor crops] [successful crossing with crops established] [having well-known economic use]	3
		Morphological closeness	1
3.	Extent of distribution/threat of CWR	[Threatened] [confined to 1–2 localities]	5
		Restricted to 1 or 2 phytogeographical areas	3
		Of common occurrence	1
4.	Conservation status/ requirement of CWR	[Poor representation at the National Gene Bank] [having orthodox seed storage behaviour]	3
		[Having recalcitrant/intermediate seed storage behaviour] [required to be maintained in field Gene Bank]	1

5.1 Fruits and Nuts

Fruit crops like mango, citrus and banana have originated in India. India is also the centre of origin and diversity for fruits like jackfruit, walnut, apricot, pomegranate, ber, jamun, aonla, etc. as their putative wild forms and progenitor/closely related wild species are found here. Progenitors of peach (i.e. *Prunus mira*) and citrus fruits (i.e. *Citrus indica*, *C. hystrix* and *C. medica*) occur in India. A perusal of Tables 2 and 3 reveal that some traits of breeders' interest in apple (e.g. resistance to powdery mildew, scab) are found in related species (*Malus baccata* and *M. sikkimensis*). Wild species of *Mangifera* restricted to Andaman and Nicobar Islands, namely, *Mangifera griffithii* and *M. andamanica*, are reported to be rich in vitamin C and total sugars, hence useful in mango breeding. Many wild relatives have shown potential as rootstocks, for instance, Himalayan *Pyrus pashia* is a common rootstock for European and Asiatic pears. In Kerala, nursery men commonly use *Artocarpus hirsutus* as rootstock for breadfruit, *Manilkara hexandra* for sapota and *Solanum torvum* for brinjal.

Few species (e.g. *Prunus undulata*, *P. jacquemontii*, *Citrus indica*, *Mangifera nicobarica*, *M. andamanica*) are niche-specific, while some species are threatened (e.g. *Corylus jacquemontii*) due to ruthless collection of economic produce, hampering their natural regeneration (Rana et al. 2007). Besides, some CWR species are used as minor fruits or plants of medicinal/firewood/timber/ornamental value. Those species with narrow/restricted geographical distribution, as well as difficult to propagate under experimental setup, needs conservation in their natural habitat. In this regard, the *Citrus* gene sanctuary was established to conserve *Citrus* species at Nokrek Biosphere Reserve in Garo Hills of Meghalaya.

Out of 135 species identified as CWR of 36 crops, only 53 (belonging to 26 fruit crops; 1071 acc.) have been collected so far. Highest number of CWR collected include *Ziziphus nummularia* (176), *Z. oenopolia* (42), *Citrus medica* (93), *C. indica* (42), *C. macroptera* (36), *Carissa spinarum* (34), *Manilkara hexandra* (103), *Fragaria nubicola* (syn. *F. vesca* auct.; 70), *Pyrus pashia* (49) and *Olea europaea* subsp. *cuspidata* (32). As of June 2015, 94 acc. of CWR are conserved in seed gene bank. ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR), New Delhi, has undertaken several systematic explorations under collaborative mode in diversity-rich regions across the country for collection of *Citrus* and minor fruits gene pool. Localities with significant number of CWR collections in field gene bank include ICAR-Central Institute of Subtropical Horticulture, Lucknow (for subtropical fruits); ICAR-Indian Institute of Horticultural Research, Bengaluru (tropical fruits); ICAR-Central Institute for Temperate Horticulture, Srinagar (temperate fruits); and ICAR-NBPGR, RS Thrissur for *Garcinia*, besides other designated NAGS for fruit crops. Case study of *on farm* conservation of four wild and semiwild species of Citrus in Northeast India (Malik et al. 2013) indicated the role of socio-economic and cultural values resulting in planting *Citrus indica* and *C. macroptera* in backyard gardens, while those having no direct use like *C. megaloxycarpa* and *C. ichangensis* were neglected, resulting in threatened status of these species in Northeast India.

5.2 Vegetables

Vegetables form an important crop group having the advantage of (mostly) annual habit and seeds easily conserved in gene bank (possible exception is tuber crops). Out of 78 CWR prioritized (for 25 crops), 11 are wild/ weedy forms of crops (Table 4). Wild forms of some crops occur almost all over the country, for instance, ivy gourd (up to 1200 m), sponge gourd (up to 1000 m), spine gourd (up to 1200 m), potato yam and taro. Other crops whose wild forms restricted to few regions include hyacinth bean (plains of peninsular India), *bhat karela* (Eastern Himalaya and hills of North Eastern India, pointed gourd (plains of North to North Eastern India) and drumstick (Western Himalaya and northern Uttar Pradesh up to 700 m). Some progenitor species of crop plants occurring in India include *Trichosanthes cucumerina* (snake gourd), *Raphanus raphanistrum* (radish), *Solanum insanum* (brinjal), *Lactuca serriola* (lettuce), *Abelmoschus tuberculatus* (okra), *Citrullus colocynthis* (watermelon), *Cucumis sativus* var. *hardwickii* (cucumber) and *Dioscorea hamiltonii* (greater yam). More number of shortlisted species occurs in genera like *Solanum*, *Cucumis*, *Abelmoschus*, *Momordica*, *Amaranthus* and *Colocasia*.

Deccan Peninsula has emerged as an important region in terms of relatives of this crop group. The taxa confined to India and occurring in a narrow stretch are *Abelmoschus tuberculatus* var. *deltoidefolius*, *Cucumis indicus*, *C. silentvalleyi*, *Momordica sahyadrica* and *Solanum wightii*. Few CWRs are mainly found in specific habitats, namely, temperate areas (*Vicia*), mixed broad-leaved/conifer/*Khair*

Table 4 Species richness in major genera of CWR

S.N.	Genus	No. of species		
		World	India	Wild in India
1.	*Abelmoschus*	12	11	9
2.	*Allium*	780	38	35
3.	*Amaranthus*	70	15	12
4.	*Citrus*	25	10	7
5.	*Cucumis*	53	12	10
6.	*Curcuma*	93	41	41
7.	*Malus*	55	3	2
8.	*Mangifera*	69	7	7
9.	*Momordica*	45	7	7
10.	*Musa*	79	26	25
11.	*Piper*	1000	69	69
12.	*Prunus*	435	36	28
13.	*Pyrus*	28	4	1
14.	*Rosa*	150	30	15
15.	*Solanum*	1500	50	44
16.	*Vitis*	65	4	3
17.	*Zingiber*	145	24	23

forests (wild forms of *Moringa oleifera*), tropical moist forests (*Momordica sahyadrica*, *Abelmoschus angulosus*, *Cucumis silentvalleyi*, *C. indicus*), black cotton and red soils (*Luffa tuberosa*) and coasts (*Canavalia rosea*).

In crops like cucumber, musk melon and brinjal, traits of breeding value such as pest and diseases resistance, quality and agronomic traits and cytoplasmic male sterility were transferred (or under progress) from wild species. Some traits of breeders' demand already exist in native CWRs such as in okra, resistance to fruit borer and tolerance to *Bhendi yellow vein mosaic virus* (*Abelmoschus angulosus*, *A. enbeepeegeearensis*) and *Okra enation leaf curl virus* (*A. ficulneus*); in onion, male sterility (*Allium roylei*); in cucumber, resistance to powdery mildew and downy mildew (*Cucumis sativus* var. *hardwickii* and *C. hystrix*); in muskmelon, resistance to Fusarium wilt and drought tolerance (*Cucumis callosus*); in bitter gourd, fruit fly tolerance (*Momordica charantia* var. *muricata*) and cucurbit yellow mosaic (*M. balsamina*); in brinjal, resistance to fruit borer (*Solanum incanum*, *S. lasiocarpum*, *S. virginianum*); and bacterial wilt (*Solanum torvum*).

Wild relatives of this crop group have received significant attention for exploration at ICAR-NBPGR, as witnessed by the massive collection of 4221 acc. of 47 CWRs belonging to 16 crops. CWR genera with the highest number of collections at ICAR-NBPGR include *Abelmoschus* (10 spp./982 acc.), *Cucumis* (8/898), *Momordica* (6/758), and *Solanum* (8/743), while species-wise highest number of accessions conserved are *Cucumis melo* subsp. *agrestis-callosus* complex (577), *Momordica charantia* var. *muricata* (526), *Cucumis sativus* var. *hardwickii* (267), *Solanum incanum-insanum* complex (265), *Solanum violaceum* (*S. indicum* auct.; 238) and *Trichosanthes cucumerina* (232). Also systematic studies at Bureau in the crop genera – *Momordica* (John and Antony 2007, 2010; John et al. 2007), *Abelmoschus* (John et al. 2013b), *Cucumis* (John et al. 2013a, 2014, 2017), *Trichosanthes* (Pradheep et al. 2015) and *Allium* (Pandey et al. 2017) – advanced the knowledge on CWR and their relationship with cultivated species, apart from describing new species, extended distribution records and botanical combinations. In the NGB of ICAR-NBPGR (as of June 2015), 3914 acc. of 96 species (including introduced species) were conserved.

Solanaceous Vegetables There are about 43 species of *Solanum* occurring in India; about half the taxa are naturalized in this country, while 8 occur almost throughout India. *Solanum melongena* (brinjal) is represented by a wild, weedy and highly spiny form which has been designated to *S. insanum* and was collected from diverse areas for potential as trait-specific germplasm for breeding programmes. There exists considerable confusion in taxonomic nomenclature of *S. violaceum*, *S. ferox*, *S. incanum* and *S. insanum*. Samuels (2011) opined that better understanding of taxonomic relationship of brinjal with wild relatives would allow more accurate prediction of the likelihood of cross transfer of genes in the context of *Bt* brinjal. *Solanum melongena* complex is among the materials studied for natural outcrossing potential of the crop with the wild relatives under a collaborative project between India and USA.

Leguminous Vegetables Peninsular India is reported to be one of the early domestication place for African origin *Lablab purpureus* (Fuller et al. 2004), which is also evident from the presence of semiwild forms in the region. In *Canavalia*, though many potential traits were identified in CWRs, they need to be introgressed into cultivated ones. In cowpea, while subsp. *sesquipedalis* is purely a vegetable type, subsp. *unguiculata* also finds cultivation as vegetable in India. Its wild relatives occurring in India are confined to coastal areas.

Cucurbitaceous Vegetables Many genera under this group have more than one species cultivated as vegetable (e.g. *Trichosanthes*, *Luffa*, *Momordica*, *Cucumis*). Genus *Luffa* has most of its species occurring in India, which prompted workers to suggest Indian subcontinent as a centre of its species diversity. Though the genus *Trichosanthes* has many species existing in India, many are far distant from that of *T. cucumerina* or *T. dioica*, and their cytological relationships are yet to be established. In case of *Cucumis melo*, main cultivar groups cultivated in India include Reticulatus (muskmelon), Cantalupensis (cantaloupe), Inodorus (zarda melon), Flexuosus (snake melon, *kakri*), *Momordica* (Indian snapmelon, *phoot*, *vellarikkai*) and Conomon (oriental pickling melon). The former four cultivar groups belong to subsp. *melo*, while the latter two to subsp. *agrestis* (Nesom 2011). It is to be noted that subsp. *agrestis* had both wild forms and cultivated types in India.

In case of *Luffa tuberosa*, difference of opinion still exists in its grouping under *Luffa* or *Momordica* (as *M. cymbalaria* or *M. tuberosa*) (Bharathi et al. 2011), implying its role as bridge between these two genera. Molecular studies revealed the closeness of ash gourd and round melon, which resulted in the merger of two unispecific genera *Praecitrullus* Pangalo and *Benincasa* into one (*Benincasa*) (Schaefer and Renner 2011). Similar studies resulted in the conclusion that genus *Cucumis* is paraphyletic with *Cucumella* Chiov., *Dicoelospermum* C. B. Clarke, *Mukia* Arn., *Myrmecosicyos* C. Jeffrey and *Oreosyce* Hook. F., and hence, they have been merged under *Cucumis* (Ghebretinsae et al. 2007a, b). *Coccinia grandis* was crossed with *Diplocyclos palmatus* (Roy and Roy 1971), while *Momordica charantia* with *Trichosanthes anguina* (now *T. cucumerina* subsp. *cucumerina* 'Anguina') (Patrudu and Murti 1934). These findings indicate that potential for wide hybridisation and useful gene transfer exists beyond genus boundary.

Other Vegetables For okra, all the wild species occur in India including its two close relatives, namely, *Abelmoschus tuberculatus* and *A. ficulneus*, indicating the significance of India being the centre of origin and diversity. Wild form of *Moringa oleifera* was observed with fairly rich variability in economic traits like cluster bearing, bitter content in fruits, prolific yield, etc. (Pradheep et al. 2011). Occurrence of wild (in Western Himalaya) as well as diverse domesticated forms (in peninsular India) and its closest relative *M. concanensis* in dry plain areas of India justify the Indian origin of this crop.

5.3 Spices and Condiments

Spices can be conveniently classified as rhizomatous spices (cardamom, ginger, turmeric), tree spices (cinnamon, nutmeg, clove, tamarind, *Garcinia*), climber spices (black pepper, *Vanilla*) and seed spices (coriander, fenugreek, *ajwain*, black cumin, caraway, fennel, dill). In India, north-eastern region together with Andaman and Nicobar Islands and Western Ghats are the two independent centres of diversity in *Piper*. Cardamom occurs naturally in moist tropical evergreen forests of southern Western Ghats; wild populations declined due to forest destruction for raising plantation crops. Despite its cross-pollination (by honey bee), this species exhibited limited variability in the absence of ecosystem diversity. Its related genus, *Etlingera* (*E. fenzlii*, *E. loroglossa*, *E. linguiformis*), occurs in north-eastern region and Andaman and Nicobar Islands. Out of 54 CWRs prioritized (for 12 crops), 7 belong to wild/weedy forms of crops, viz. greater cardamom, caraway, cinnamon, turmeric, cardamom, pepper and kasurimethi (Table 4). More number of close relatives occurs in crops like black pepper, cinnamon, large cardamom, ginger and turmeric. In ginger, much sought-after trait of soft rot resistance is available in wild species, *Zingiber zerumbet*. There exists a number of region-specific spices in this country – curry leaf (leaf spice mainly in peninsular India); *Zanthoxylum rhetsa* (in southern Western Ghats and Northeast India) and *Z. acanthopodium* (Northeast India) used extensively as a spice (dried capsule) and tender leaf vegetable; and *Nigella sativa* (seed spice in sporadic pockets of North India and Assam).

In total, 412 acc. of CWR under this group have been augmented in 22 taxa. Significant CWR germplasm collections were made in *Curcuma*, viz. *Curcuma zedoaria* (71), *C. aromatica* (58), *C. amada* (39) and *Piper* (see Table 5). Collection in collaboration with ICAR-IISR, Kozhikode, and systematic study of wild species of turmeric and black pepper by the ICAR-NBPGR Regional Station, Thrissur, resulted in the discovery of some new species under these genera. Though most of the seed species are of exotic origin and have no obvious CWR in India, there exists wild form/populations of *Carum carvi* and *Bunium persicum* (from high altitudes of Western Himalaya) and a wild species *Trachyspermum roxburghianum* (a relative of *ajwain*). Seed gene bank of ICAR-NBPGR has only 96 acc. (belonging to 8 spp.)

Table 5 Piper CWR collections in India

Species	Accns.	Species	Accns.
Piper longum	230	*P. trichostachyon*	64
P. betle	214	*P. mullesua*	44
P. attenuatum	169	*P. bababudani*	20
P. sugandhi	139	*P. brachystachyum*	19
P. argyrophyllum	133	*P. hapnium*	14
P. galeatum	111	Others (including unidentified)	413
P. hymenophyllum	83		

under this group. Successful cryopreservation has been achieved in *Piper nigrum*, *P. mulleusua*, *P. attenuatum*, *P. argyrophyllum*, *P. trichostachyon* and *P. galeatum* and small cardamom.

5.4 Medicinal and Aromatic Plants

India is a treasure house of over 9500 valuable medicinal and aromatic plant (M&AP) species distributed under varied climatic conditions. M&APs form the essential raw material for the production of medicines in Ayurveda, Siddha, Unani, Tibetan, Tribal and Homoeopathy medicine systems. By and large, these species are still gathered from the wild, and relatively a few have attained cultivation status. Their unscrupulous exploitation from the wild (through destructive harvesting, harvesting whole plant before reproductive maturity) coupled with increasing urbanization has resulted in steady loss of biodiversity and genetic erosion from the natural habitat. The gene pool of M&AP includes both cultivated and wild germplasm (wild form/types of cultivated species and related wild species), which form an important source of useful traits in crop improvement.

Considering the large number of native M&AP species, priority has been given to those of major economic importance and/or a focus of ICAR/CSIR research institutes, for instance, *Andrographis paniculata*, *Mucuna pruriens*, *Ocimum basilicum*, *O. tenuiflorum*, *Tinospora cordifolia* and *Withania somnifera*. Resultantly, over 10,000 acc. of about 600 species have been collected. A large number of accessions are collected from different parts of the country – *Abrus precatorius* (171), *Acorus calamus* (108), *Aloe barbadensis* (207), *Alpinia galanga* (55), *Andrographis paniculata* (144), *Aristolochia indica* (46), *Asparagus adscendens* (48), *A. racemosus* (177), *Bacopa monnieri* (86), *Centella asiatica* (63), *Chlorophytum arundinaceum* (82), *Coleus forskohlii* (74), *Commiphora wightii* (113), *Costus speciosus* (96), *Curculigo orchioides* (45), *Gloriosa superba* (53), *Gymnema sylvestre* (173), *Hedychium spicatum* (41), *Mentha piperita* (79), *Mucuna pruriens* (79), *Ocimum* (243), *Plumbago zeylanica* (57), *Rauvolfia serpentina* (69), *Tecomella undulata* (44), *Tinospora cordifolia* (130), *Urginea indica* (75), *Valeriana jatamansi* (36), *Vitex negundo* (54) and *Withania somnifera* (193). The regions covered for germplasm collection included Kumaon and Garhwal hills of Uttarakhand, high altitude regions of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, Western and Eastern Ghats, Bastar in Chhattisgarh, Jharkhand, NEH region, Rajasthan and Gujarat. Based on collection gaps identified through GIS tools, systematic germplasm collection of selected native M&AP from diversity-rich pockets, viz. tropical forests, of Western Ghats, Eastern Ghats, the Vindhyas, Chotta Nagpur plateau, Aravalis and the Eastern Himalayas has been planned.

About 70 wild species (related to 20 important cultivated medicinal and aromatic plants), including wild forms of 19 cultivated species, have been prioritized. Some prioritized species are *Andrographis ceylanica*, *Chlorophytum arundinaceum*, *C.*

tuberosum, *Ocimum americanum*, *O.* × *africanum* (*Ocimum basilicum* × *O. americanum*), *O. minimum*, *Tinospora sinensis*, *T. crispa* and *Withania obtusifolia*. About 222 germplasm accessions in 18 CWRs have been assembled so far. It is reported that *Ocimum basilicum* on hybridization with *O. americanum* yields allopolyploids having higher herbage and essential oil content (Dhar, 1999). *Swertia chirayita* reported common in Himalayas a hundred years ago is now almost extinct in wild in Indian part of Himalayas, demanding the need for proper conservation measures, including banning illegal over-exploitation in the wild.

5.5 Ornamentals

Ornamentals need proper attention to collect crop gene pool, owing to the fact that many crop species are native and having commercial value, e.g. *Begonia*, *Crossandra*, *Cymbidium*, *Cypripedium*, *Dendrobium*, *Jasminum*, *Paphiopedilum*, *Phalaenopsis*, *Rosa* and *Vanda*. Wild ornamentals are a potential plant resource for exploitation by horticulture industry. Native species of Andaman and Nicobar Islands like *Caryota mitis*, *Cycas zeylanica* and *Sterculia parviflora*, and many species of orchids, palms and ferns are worth domesticating. Native rose species germplasm collections include *Rosa macrophylla* (26), *R. brunonii* (17) and *R. webbiana* (14). About 190 acc. belonging to 97 species have been conserved in seed gene bank of ICAR-NBPGR, New Delhi (till June, 2015). There are 141 CWR (including 61 native as well as cultivated species) shortlisted for exploration and germplasm collection.

6 PGR Management of Crop Wild Relatives: Some Considerations

6.1 Germplasm Collection

The very purpose of germplasm collection is to have maximum genetic representation of population without damage to the original population; this involves collecting from diverse habitats across altitudinal and distributional ranges. Depending on the objective of the collection mission, seed/vegetative propagule/in vitro material/pollen can be collected. In case of recalcitrant species, generally fruits are collected; seeds of the same are extracted after reaching laboratory and immediately put for cryopreservation. For genetic diversity augmentation, collection in the form of seeds (from population) is preferred, while for elite or unique types, vegetative materials are to be collected to ensure true-to-type. For instance, *Moringa oleifera* (drumstick) is propagated by seeds as well as cuttings. For genetic diversity

augmentation of truly wild populations from Shivaliks of Western Himalaya, one can collect seeds, while cultivated types of peninsular India may be collected as cuttings.

Collection of vegetative propagules is also made in circumstances where species rarely or hardly produce seeds, seeds mature at different times, high shattering (preventing sufficient sampling during brief visit) or for fruit trees with extended juvenile phase or when material is urgently required (Hanson and van de Wouw 2011). Collecting CWR of tuber crops necessitate repeat visits (one for marking/and another for digging up underground vegetative parts at senescence), as plants become inconspicuous after senescence. Some problems associated with collecting vegetative material include small sample size, slow sampling speed, short life, prone to infection, strict quarantine and preparation of material for gene bank (e.g. scion/budwood require grafting on rootstock before shifting to FGB) (Hamilton and Chorlton 1995). Therefore the major challenge in the collection of vegetative material lies in improving storage conditions during transport, in reducing the bulkiness of cuttings and in retaining survival rates (till reaching the regeneration site /FGB) (Hanson and van de Wouw 2011).

The purpose of the collecting programme (study/conservation/immediate use), number of target taxa and resources available influence the collecting process to a large extent. CWR conservation in seed gene bank is primarily determined by the quantum of seed samples and the seed viability percentage at the time of deposit, as specified in FAO guidelines, while for field gene bank (FGB), propagablity of collected live plants and scion material (at the time of reaching the regeneration site) as well as success rate of graft/bud union is the main criterion. Unlike crop germplasm, a reasonably good number of CWR accessions could not be conserved owing to not qualifying the gene bank standards; Table 6 indicates important bottlenecks identified for collection of some CWR of horticultural crops.

Rarity poses threat even for locating the populations of *Allium farctum* (in western Himalaya), *A. phariense* (Eastern Himalaya) and *Withania coagulans* (a dioecious species from north-western India) in the Indian region. The populations of *Bunium persicum* and *Luffa tuberosa* are on decline, mainly due to habitat destruction and/or over-exploitation. In some species, though commonly available, adequate seed sample size could not be achieved due to various reasons, for instance, wild *Moringa oleifera* (winged seeds disperse), *Momordica charantia* var. *muricata* (produce few seeds/fruit, high pest infestation in field, harvesting of immature fruits by local people), *Canavalia* spp. (extensive climbing nature and few-seeded individual pods needs to be assembled meticulously). Also taxonomic confusion on field identification of CWR while collecting pose hurdles for procuring sufficient sample size.

Analysis revealed the existence of huge gaps in CWR collection in terms of number as well as representative collection, even in the crucial crop groups such as vegetables and in protected areas and fragile ecosystems such as coastal and cold arid ecosystem. Trait-specific germplasm collection (biotic, abiotic stress, nutri-

Table 6 Important bottlenecks identified for collection of some CWR of horticultural crops

Reasons	Constraints	Examples
A. Environmental factors		
Niche specificity	Difficult to access and require more time to locate	Trans-Himalayan species (*Allium*, *Bunium*); and *Cucumis setosus* (grasslands in hill slopes >1000 m in Maharashtra)
Scattered distribution sparse population	Difficult to establish/multiply in FGB (needs simulated conditions akin to natural environment)	
Pest infestation/ infection at field	Low output of seeds for gene bank storage	*Momordica*
Wild harvesting for edible/economic use		
B. Plant-specific		
Staggered maturation	Require repeated visits and more time to locate and collect	Leguminous vegetables
Produce few fruit/ seeds	Often necessitates 2–3 years collection from same locality and bulking	
Seed shattering		
Presence of spines/ thorns and other protective structures	Difficult to gather	*Mucuna pruriens*
Tall climbing perennials	Difficult to gather	*Canavalia*, *Trichosanthes*
Long gestation period	Maintenance required till seed multiplication	
Fleshy or bulky fruit/seed	Difficult to handle/process in field	Cucurbits
	Occupy large storage space and in gene bank too	
Low seed viability	Necessitates large collection and quick processing for gene bank	Wild *Moringa oleifera* (lose viability within 3 months)
Rapid loss of viability		

Source: (modified from Pradheep et al. 2015a)

tional and other quality traits) using habitat/ecological parameters and information on pest infection/infestation-prone areas (hotspots) are the real focuses right now. Minimizing duplicates in collection is another important concern, particularly in perennial species, as they demand huge resources – land, labour and maintenance cost in field gene bank – without any perceptible use. Forecasting ideal habitats in locating germplasm for biotic and abiotic stress tolerances needs to be given due emphasis in searching for trait-specific germplasm. Germplasm collections from protected areas require strong linkages at inter-ministerial level (DAC with

MOEF&CC) and the involvement of NBA/state biodiversity boards and state forest departments.

Some Pockets Which Need Systematic Exploration for CWR

- Coastal tract, particularly East Coast and Gujarat coast
- Cold arid Himalaya
- Eastern Himalaya and NEH Region
- A&N, especially unexplored islands – Mount Thullier in Great Nicobar Biosphere Reserve
- Western Ghats – Agastyamala Biospere Reserve, Nilgiri Biosphere Reserve, Silent Valley National Park
- Eastern Ghats, especially that of Odisha, Karnataka and Tamil Nadu
- Vindhya-Satpura ranges in central India
- Chhottanagpur belt of Jharkhand
- Desert areas, esp. Thar Desert
- Semiarid environment – like northern and central Karnataka, adjoining Deccan Plateau, semiarid Tamil Nadu, Bundelkhand
- Duars and *terai* belt (of Uttarakahand, Uttar Pradesh, Bihar, Sikkim, West Bengal).
- Bastar-Vizag-Malkangiri-Koraput ranges

6.2 Germplasm Conservation

As stated earlier, orthodox seed-bearing CWR of field crops (including vegetables, seed spices) can be bankable in seed gene banks. However, the development of cryobank facility has led to the conservation of recalcitrant species like citrus, minor or underutilized fruits as well, which would otherwise be maintained through field gene bank. CWR germplasm collected through collection missions is often insufficient or does not qualify the gene bank germination standards, which demands seed multiplication in analogous climatic conditions. If the environmental conditions are not exacting, then the seed may die or only few will germinate, producing changes in gene frequencies and loss of rare genes/alleles. Advances in pollen preservation may help to resolve the temporal and spatial isolation of CWRs, which are otherwise compatible.

Certain constraints in seed conservation are that the storage conditions optimized for cultivated crops may not always be suitable for CWR, demanding their standardization after understanding storage behaviour. For example, cold storage often leads to loss of viability in dioecious *Momordica* species, indicating the need for proper understanding of storage physiology of their seeds. Seeds of groups such as legumes often pose variable seed dormancy or hard seededness with seed coat impermeability, which increase with reducing seed moisture content posing problems for their ger-

mination. Recalcitrant seeds need special attention, as seed storage behaviour can vary among and even within species and different provenances.

CWR of narrow endemic nature shows poor adaptability to ex situ, which is true for many high-value medicinal plants and of temperate fruits of alpine region and endemics of high altitudes in Western Ghats. Protected area network – wildlife sanctuaries, national parks and biosphere reserves – serves better for in situ conservation in this regard, but its coverage do not address majority of crop wild relatives. Very few CWRs receive the attention at national level either in IUCN Red List of Threatened Species (IUCN 2011) or publications from Botanical Survey of India. Though UNEP-WCMC Threatened Species Database (UNEP-WCMC 2011) mentions about few species like *Canavalia cathartica*, *C. rosea* and *Luffa umbellata*, it lacked essential information. Based on the knowledge obtained during the exploration for collecting wild relatives, Pandey et al. (2008) set a high level of conservation priority for *Abelmoschus tuberculatus* and medium level for *Abelmoschus manihot* subsp. *tetraphyllus* var. *pungens*, *Cucumis sativus* var. *hardwickii*, *Luffa acutangula* var. *amara*, *L. hermaphrodita* and *Solanum incanum*. Regardless, it is high time to undertake proper study on population trend, biology of the species, breeding behaviour, crossability, hybrid fertility, habitat preferences, major threats, conservation measures, etc. for the wild forms of crops and the prioritized species.

6.3 Germplasm Characterization, Evaluation and Utilization

These activities pave the way for understanding the worthiness of germplasm collection to enable their use in crop improvement programmes. As majority of CWR of fruit trees are perennial in nature, characterization/evaluation activity takes many years. Since genotype x environment interaction is high in perennial species, there are difficulties in authentic characterization and evaluation. However vegetative propagation possible in many species would help to reduce probability for genetic instability. Some constraints faced by the curators for perennial/tree species are as follows.

1. Since conservation is of utmost priority for the curators, emphasis was given to augment/ maintain germplasm over different years, which has resulted in trees of different age groups. This often restricts the relative comparison among the accessions for quantitative characters. An alternative is to establish clonal repository from the existing parental stock of seedling origin trees.
2. Often, the number of plants per accession maintained in FGB is 2–3 (seldom reaches 5). Hence, very basic statistical principles, viz. randomization, replication and local control, could not be achieved. Therefore, validity of the data is often questioned. Observations over different years on the same plant may yield to autocorrelation. Hence, field gene bank may not completely comply above-said statistical requirement.

3. Some accessions of the temperate fruit species need pollinizer because of self-incompatible or partial compatible nature. Hence, they depend on not only the pollinizer but also pollinators. Synchronous flowering and sufficient pollinator activity may not always be achieved for all the diverse germplasm maintained. The same is the case with dioecious taxa under *Momordica* and *Myristica*.
4. It is highly impossible to find a single suitable location for evaluation of genetically diverse germplasm having origin from different environmental conditions. Only some accessions will express their potential at a particular site. For one or other reason, some of the accessions could not set fruits even though they may show luxurious vegetative growth. This demands multilocation evaluation, which is not always feasible.
5. There are different species of rootstocks available especially for fruit tree germplasm. Occasionally different species of rootstocks, either seedling or clonal ones, are used due to easy availability, etc. Literature had proved their differential influence on scion for morphological, economical and quality attributes. Rootstock compatibility studies would help in realization of CWR potential.
6. Descriptors needed to be devised carefully to cater to the purpose of characterization and evaluation. Often descriptors can only render their service to one species/crop, hence, remain unsuitable for the related species. Field identification keys (used for differentiating species) are needed not only to identify the species taxonomically but also to avoid grouping plants of dissimilar species in the same block.

Field evaluation of wild species in (disease/pest) hotspots area will help in tagging resistant germplasm for biotic stresses, which would be further confirmed through laboratory techniques. Characterization could aid in the identification of characters/markers linked to abiotic/biotic tolerance, hence useful in locating (probable) tolerant germplasm at field conditions as well. In wide hybridization/prebreeding process, appropriate location, breaking down of dormancy, ensuring synchronous flowering, use of growth regulator in fruit setting/ retention, etc. would play a key role in the success. Any approach to shorten the long gestation period, like vegetative propagation (grafting/budding), would be appreciable.

6.4 Conclusion

With the identification of diversity-rich spots (biodiversity hotspots/warm spots/agro-biodiversity hotspots), availability of location details of intended taxa and diverse agroclimatic conditions (helpful for locating abiotic stress-tolerant germplasm), India strides forward in the systematic collection of CWR from diverse habitats for conservation and sustainable use. Cursory review of collected wild species indicates that only one third of shortlisted taxa have been assembled by ICAR-NBPGR, among them more than half the taxa with <10 accession holding. Analysis of gaps in collection in a scientific manner (keeping in view the conserved material,

actual variability/diversity present in habitats, best utilization of GIS tools) through a mission-mode approach is on the way. Also detailed studies on habitat ecology, floral biology and breeding system, crossability (with crop counter partner), seed dormancy and storage behaviour of species will enable their meaningful conservation and sustainable utilization. Crossability studies aid in realization of gene pool concept in crops, helpful in knowing the closer relatives (even from different genera) and distant relatives (even within the genera). In some works pertaining to the transfer of traits from wild species to cultivated ones, researchers do not explicitly differentiate the wild forms or progenitors as the taxa distinct from the crop; this hampers the actual assessment on utilization of wild germplasm. Ensuring correct taxonomic identity, safe conservation and supply of germplasm to crop-based institutes strengthen the prebreeding/base-broadening/gene-pyramiding activities through designing long-term multi-parental breeding programmes. It is imperative to undertake studies on assessing the gene flow between wild (progenitors and naturally crossable relatives) and cultivated taxa in the wake of concerns of biosafety.

Also, it is essential to undertake a more objective approach on systematic threat assessment using IUCN or national criteria or both. Though most CWRs have some economic use (e.g. minor fruits, leafy vegetable), people seldom pay attention for their conservation. This demands grass root-level awareness on the role of CWR in crop improvement under changing climatic conditions and also encouraging their mass planting along roadside, waste and degraded lands, vacant community lands, field boundaries and even inside the forests affording protection. Also sensitizing forest officials on the importance of CWR in nation building activities would pave the way for facilitating their germplasm collection from protected areas. In terms of habitats of occurrence, herbaceous wild relatives generally occupy the areas that have been habituated and disturbed by humans. This preference of wild relatives has a negative impact as well, due to the ongoing widespread prevalence of roadside/ forest edge cleaning, use of brush cutter in fields/ borders, besides the necessity to compete with invasive alien weeds.

All the above studies will facilitate national-level mapping of CWR distribution after incorporating additional information from ecogeographic studies, which will help in the identification of CWR hotspots, which can be matched with existing protected network in the country, thereby areas demanding conservation can be identified (Maxted et al. 2011). Strong networking among all the institutes working on characterization, evaluation and conservation in the field gene banks is the need of the hour, as it is difficult for a single institute to collect, conserve and evaluate all the target species due to paucity of land, resources and expertise.

References

Ahmedullah, M., & Nayar, M. P. (1987). *Endemic plants of Indian region*. Calcutta: Botanical Survey of India.

Arora, R. K., & Nayar, E. R. (1984). *Wild relatives of crop plants in India*. NBPGR Science monograph 7 (90 p). New Delhi: National Bureau of Plant Genetic Resources.

Bharathi, L. K., Munshi, A. D., Vinod, Chandrashekaran, S., Behera, T. K., Das, A. B., John, K. J., & Vishalnath. (2011). Cytotaxonomical analysis of *Momordica* L. (Cucurbitaceae) species of Indian occurrence. *Journal of Genetics, 90*, 21–30.

Dhar, A. K. (1999). Breeding culinary herbs. In P. Kachroo (Ed.), *Progress in cytogenetics* (Prof. AK Koul commemoration volume) (pp. 163–178). Dehradun: Bishen Singh Mahendra Pal Singh.

Dias, R. C. S. (2003). *Mejora de la Resistencia al Colapso del Melón: Control Genético y Desarrollo de Líneas Resistentes.* Ph.D. thesis, Universidad Politécnica de Valencia, Valencia, Spain, pp. 88–115.

FAO. (2010). The second report on the state of the World's plant genetic resources for food and Agriculture. FAO, Rome, Italy. http://www.fao.org/docrep/013/i1500e/i1500e.pdf.

Fuller, D., Korisettar, R., Venkatasubbaiah, P. C., & Jones, M. K. (2004). Early plant domestications in southern India: Some preliminary archaeobotanical results. *Vegetation History and Archaeobotany, 13*, 115–129.

Ghebretinsae, A. G., Thulin, M., & Barber, J. C. (2007a). Nomenclatural changes in *Cucumis* (Cucurbitaceae). *Novon, 17*(2), 176–178.

Ghebretinsae, A. G., Thulin, M., & Barber, J. C. (2007b). Relationships of cucumbers and melons unraveled: Molecular phylogenetics of *Cucumis* and related genera (Benincaseae, Cucurbitaceae). *American Journal of Botany, 94*(7), 1256–1266.

Hajjar, R., & Hodgkin, T. (2007). The use of wild relatives in crop improvement: A survey of developments over the last 20 years. *Euphytica, 156*, 1–13.

Hamilton, N. R. S., & Chorlton, K. H. (1995). Collecting vegetative material of forage grasses and legumes. In L. Guarino, V. Ramanatha Rao, & R. Reid (Eds.), *Collecting plant genetic diversity: Technical guidelines* (pp. 467–484). London: CABI International.

Hammer, K. (1991). Checklists and germplasm collecting. *FAO/IBPGR Plant Genetic Resources Newsletter, 85*, 15–17.

Hanson, J., & van de Wouw, M. (2011). Collecting vegetative material of forage grasses and legumes. In L. Guarino, V. Ramanatha Rao, & E. Goldberg (Eds.), *Collecting plant genetic diversity: Technical guidelines – 2011 update*. Rome: Bioversity International.

Hopkins, J. J., & Maxted, N. (2010). *Crop wild relatives*: *Plant conservation for food security*. Natural England research reports, number 037. Sheffield: Natural England.

IUCN. (2011). *IUCN Red list of threatened species*. Version 2011.1. www.iucnredlist.org. Downloaded on 10 September 2011.

John, K. J., & Antony, V. T. (2007). *Momordica sahyadrica* sp. nov. (Curcurbitaceae) an endemic species of Western Ghats of India. *Nordic Journal of Botany, 24*(5), 539–542.

John, K. J., & Antony, V. T. (2010). A taxonomic revision of the genus *Momordica* L. (Cucurbitaceae) in India. *Indian Journal of Plant Genetics Resources, 23*(2), 172–184.

John, K. J., Antony, V. T., & Roy, Y. C. (2007). On the occurrence, distribution and taxonomy of *Momordica subangulata* Blume subsp. *renigera* (G. Don) de Wilde in India. *Genetic Resources and Crop Evolution, 54*, 1327–1332.

John, K. J., Scariah, S., Muhammed Nissar, V. A., Latha, M., Gopalakrishnan, S., Yadav, S. R., & Bhat, K. V. (2013a). On the occurrence, distribution, taxonomy and genepool relationship of *Cucumis callosus* (Rottler) Cogn. & Harms, the wild progenitor of *Cucumis melo* from India. *Genetic Resources and Crop Evolution, 60*(3), 1037–1046.

John, K. J., Scariah, S., Nissar, V. A., Bhat, K. V., & Yadav, S. R. (2013b). *Abelmoschus enbeepeegearense* sp. nov. (Malvaceae), an endemic species of okra from Western Ghats, India. *Nordic Journal of Botany, 31*(2), 170–175.

John, K. J., Khedasana, R., Muhammed Nissar, V. A., Scariah, S., Sutar, S., Rao, S. R., Abdul Nizar, M., Latha, M., Yadav, S. R., & Bhat, K. V. (2014). On the occurrence, distribution and taxonomy of *Cucumis setosus* Cogn., an endemic wild edible vegetable from India. *Genetic Resources and Crop Evolution, 61*(2), 345–355.

John, K. J., Roy, Y. C., Krishnaraj, M. V., Nissar, V. A. M., Latha, M., & Bhat, K. V. (2017). Ecological and morphological characterisation of two rare and endemic wild edible *Cucumis*

species (Cucurbitaceae) of Western Ghats of India. *Genetic Resources and Crop Evolution, 64*(1), 149–158.

Krishnamoorthy, B., & Parthasarathy, V. A. (2011). Improvement of black pepper. In D. Hemming (Ed.), *Plant sciences reviews 2010* (pp. 37–48). London: CAB International.

Malik, S. K., Kumar, S., Singh, I. P., Dhariwal, O. P., & Chaudhury, R. (2013). Socio-economic importance, domestication trends and *in situ* conservation of wild *Citrus* species of Northeast India. *Genetic Resources and Crop Evolution, 60*(5), 1655–1671. https://doi.org/10.1007/s10722-012-9948-x.

Mani, M. S. (1978). *Ecology and phytogeography of high altitude plants of the northwest Himalaya*. London/New York/New Delhi: Chapman & Hall/John Wiley/Oxford & IBH.

Maxted, N., & Kell, S. (2009) *Establishment of a Global Network for the in situ conservation of crop wild relatives: Status and needs*. http://www.fao.org/docrep/013/i1500e/i1500e18a.pdf

Maxted, N., Ford-Lloyd, B. V., Jury, S., Kell, S., & Scholten, M. (2006). Towards a definition of a crop wild relative. *Biodiversity and Conservation, 15*(8), 2673–2685.

Maxted, N., Kell, S. P., & Ford-Lloyd, B. V. (2008). Crop wild relative conservation and use: Establishing the context. In N. Maxted, B. V. Ford-Lloyd, S. P. Kell, J. M. Iriondo, M. E. Dulloo, & J. Turok (Eds.), *Crop wild relatives: Conservation and use* (pp. 3–30). London: CABI Publishing House.

Maxted, N., Kell, S., Toledo, A., Dulloo, E., Heywood, V., Hodgkin, T., Hunter, D., Guarino, L., Jarvis, A., & Ford-Lloyd, B. (2011). A global approach to crop wild relative conservation: Securing the gene pool for food and agriculture. *Kew Bulletin, 65*, 1–16.

Murti, S. K. (2001). *Flora of cold deserts of Western Himalaya*. Volume 1: Monocotyledons (452 p). Kolkata: Botanical Survey of India.

Nagarajan, S., Kannaiyan, S., Yadav, S. P., Singh, A. K., Trivedi, R. K., & Pal, S. (2007). Agro biodiversity hot-spots. In S. Kannaiyan & K. Venkataraman (Eds.), National consultation workshop on "*Agrobiodiversity hotspots and access and benefit sharing*", held during 19–20th July 2007, organized by National Biodiversity Authority, Neelankarai, Chennai, Protection of plant varieties and farmers' right authority, New Delhi and Faculty of Agriculture, Annamalai University, Annamalai Nagar. pp. 11–19.

Nayak, S., & Bahuguna, A. (2001). Application of remote sensing data to monitor mangroves and other coastal vegetation of India. *Indian Journal of Marine Science, 30*(4), 195–213.

Nayak, S., Pandeya, A., Gupta, M. C., Trivedi, C. R., Prasad, K. N., & Kadri, S. A. (1989). Application of satellite data for monitoring degradation of tidal wetlands of the Gulf of Kachchh, Western India. *Acta Astronautica, 20*, 171–178.

Nayar, M. P. (1996). *Hotspots of endemic plants of India, Nepal and Bhutan*. Thiruvanthapuram: Tropical Botanical Garden and Research Institute.

Nayar, E. R., Pandey, A., Kamala Venkateswaran, Rita Gupta, & Dhillon, B. S. (2003). *Crop plants India: A check-list of scientific names.* Agro-biodiversity (PGR)-26. National Agricultural Technology Project on Sustainable Management of Plant Biodiversity, National Bureau of Plant Genetic Resources, New Delhi, 48 p.

Negi, B. (1993). *Biodiversity and its conservation in India (a primer)* (Vol. 18). Dehra Dun: Wild life Institute of India.

Nesom, G. L. (2011). Toward consistency of taxonomic rank in wild/domesticated Cucurbitaceae. *Phytoneuron, 13*, 1–33.

Pandey, A., Tomar, A. K., Bhandari, D. C., & Pareek, S. K. (2008). Towards collection of wild relatives of crop plants in India. *Genetic Resources and Crop Evolution, 55*, 187–202.

Pandey, A., Pradheep, K., & Negi, K. S. (2017). Onion and related taxa: Ecogeographic distribution and genetic resources in Indian subcontinent. In A. A. Ansari, S. S. Gill, Z. K. Abbas, & M. Naeem (Eds.), *Plant biodiversity: Monitoring, assessment and conservation* (pp. 429–441). Wallingford: CABI.

Pandravada, S. R., Sivaraj, N., Kamala, V., Sunil, N., & Varaprasad, K. S. (2008). *Genetic resources of wild relatives of crop plants in Andhra Pradesh – Diversity, distribution and conservation*. In Proceedings of Andhra Pradesh Akademi of Sciences. Special Issue on Plant Wealth of Andhra Pradesh, pp 101–119.

Patrudu, S. S., & Murti, P. K. (1934). Intergeneric cross in Cucurbitaceae. *Current Science, 2*, 431–432.

Pradheep, K., Singh, P. K., Pandey, A., & Bhandari, D. C. (2011). Collecting genetic resources of wild *Moringa oleifera* lam. From Western Himalayas. *Indian Journal of Plant Genetic Resources, 24*(3), 292–298.

Pradheep, K., Bhandari, D. C., & Bansal, K. C. (2014). *Wild relatives of cultivated plants in India* (728 p). New Delhi: Indian Council of Agricultural Research.

Pradheep, K., Pani, D. R., & Bhatt, K. C. (2015). Taxonomic notes on the *Trichosanthes cucumerina* group (Cucurbitaceae) from India. *Novon, 24*(1), 39–45.

Pradheep, K., Bhatt, K. C., & Nayar, E. R. (2015a). Problems in collection and conservation of some crop wild relatives in India: An analysis. *International Journal of Biological Sciences and Engineering, 6*, 73–77.

Pradheep, K., Bhatt, K. C., & Pandey, A. (2015b, August 19–28). Prioritization, planning and execution of crop wild relatives collecting. In K. Pradheep, A. Pandey, K. C. Bhatt, S. P. Ahlawat, D. P. Semwal, & K. C. Bansal (Compiled & Edited), *Crop wild relatives: Identification, collecting and utilization* (pp. 93–107). New Delhi: ICAR-NBPGR.

Prendergast, H. D. V. (1995). Published sources of information on wild plant species. In L. Guarino, V. R. Rao, & R. Reid (Eds.), *Collecting plant genetic diversity: Technical guidelines* (pp. 153–179). Wallingford: CAB International.

Rana, J. C., Pradheep, K., & Verma, V. D. (2007). Naturally occurring wild relatives of temperate fruits in Western Himalayan region of India: An analysis. *Biodiversity and Conservation, 16*(14), 3963–3991.

Rana, J. C., Sharma, P., & Singh, M. (2015, August 19–28). Crop wild relatives collecting in North Western Himalayan region- assessment and population studies. In K. Pradheep, A. Pandey, K. C. Bhatt, S. P. Ahlawat, D. P. Semwal, & K. C. Bansal (Compiled & Edited), *Crop wild relatives: Identification, collecting and utilization* (pp 179–193). New Delhi: ICAR-NBPGR.

Rao, R. R. (1994). *Biodiversity in India: Floristic aspects*. Dehra Dun: Bishan Singh Mahendra Pal Singh.

Rodgers, W. A., & Panwar, H. S. (1990). A biogeographical classification for conservation planning. In *Wildlife Institute of India*. Dehradun.

Roy, R. P., & Roy, P. M. (1971). An intergeneric cross in the Cucurbitaceae (*Coccinia indica* W. & A. × *Bryonopsis laciniosa* Arn). *Current Science, 40*(2), 46–48.

Samuels, J. (2011). Bt brinjal, wild relatives and biodiversity. *Current Science, 100*(5), 603–604.

Schaefer, H. & Renner, S. S. (2011). Cucurbitaceae. *The families and genera of vascular plants.* Vol. X: Flowering Plants: Eudicots: Sapindales, Cucurbitales and Myrtaceae. (ed: Kubitzki, K., pp. 112–174). Heidelberg: Springer.

Scholten, M., Maxted, N., Codd, R., Kell, S. P., Brehm, J. M., & Ford-Lloyd, B. V. (2005, September 14–17). *Construction and application of a national inventory of crop wild relatives: A methodological case study for the United Kingdom*. In First International conference on crop wild relative conservation and use. Book of abstracts. Agrigento, Italy, p. 15.

Shetty, B. V., & Singh, V. (1996). Arid zone. In *Flora of India* (Part I). Calcutta: Botanical Survey of India.

UNEP-WCMC. (2011). *UNEP-WCMC threatened species database*. Cambridge, United Kingdom.

Yadav, S. R., Bhat, K. V., Latha, M., Joseph John, K., Aitwade, M., Rao, S. R., Scariah, S., Nissar, M., Umdale, S., Patil, P., Krishnan, G., & Khedsana, R. (2014). *An Illustrated guide for the identification of* Vigna *Savi,* Cucumis *L. and* Abelmoschus *Medik. species in India* (145 p). New Delhi/Kolhapur/NEHU: NBPGR/Sivaji University/Shillong.

Zhou, X. H., Wan, H. J., Qian, C. T., & Chen, J. F. (2008, May 21–24). Development and characterization of *Cucumis sativus-hystrix* introgression lines exhibiting resistance to downy mildew. In: M. Pitrat (Ed.), *Proceedings of IX EUCARPIA Meeting on Genetics and Breeding of Cucurbitaceae* (pp. 353–358). Avignon: INRA.