Chapter 26

Underutilized Species and Climate Change: Current Status and Outlook

Stefano Padulosi, Vernon Heywood, Danny Hunter, and Andy Jarvis

Introduction

By "underutilized species" we refer to those species whose potential to improve people's livelihoods, as well as food security and sovereignty, is not being fully realized because of their limited competitiveness with commodity crops in mainstream agriculture. While their potential may not be fully realized at national level, they are of significant importance locally, being highly adapted to marginal, complex, and difficult environments and contributing significantly to diversification and resilience of agroecosystems. This means they are of considerable interest for future adaptation of agriculture to climate change. Underutilized species include not just food plants but also many other species—wild or cultivated—used as sources of oil, fuel, fiber, fodder, beverages, stimulants, narcotics, ornamental, aromatic compounds, and medicine.[1] The definition of what constitutes an underutilized species is not surprisingly challenging from both a technical and cultural point of view. A different approach, which would instead spell out the features that make underutilized species different from any other (commodity crop) is thus preferred over the use of a simple definition (Padulosi and Hoeschle-Zeledon 2004).

It is important also to clarify that when referring to underutilized species we do not include neglected cultivars of major crops, as we are concerned only with species which—unlike major crops—have so far not received proper research attention. Furthermore, the answer to whether a species should be included or not in this portfolio of "marginalized" genetic resources should also be guided by principles of social equity (Padulosi et al. 2008).

While there are many reasons today for promoting a greater use of underutilized species in agricultural activities (see later in the chapter), the overarching justification for the development and safeguarding of these species is certainly their close link that binds these resources and food security and climate change. The words of I. Grainger-Jones (2009)[2] well capture the need for the change in paradigm we should be pursuing:

> specializing in crops and systems that are efficient in certain temperature or precipitation ranges may not be effective in the long term run[. . .]and therefore we ought to investigate seriously (and urgently) in alternative forms of agricultural management, in which local but neglected species and varieties can play a key for the future of our planet.[2]

Crop Adaptation to Climate Change, First Edition. Edited by Shyam S. Yadav, Robert J. Redden, Jerry L. Hatfield, Hermann Lotze-Campen and Anthony E. Hall.

P1: SFK/UKS P2: SFK Color: 1C
BLBS082-26 BLBS082-Yadav June 29, 2011 17:56 Trim: 246mm X 189mm

As already mentioned, underutilized species can be wild or cultivated and because of their different status are characterized by having different needs for their use and development (Hoeschle-Zeledon and Jaenicke 2007). There is, in fact, an almost complete spectrum between completely wild and completely domesticated species (Heywood 1999a) and many of what we understand by underutilized species are often in a wild or semidomesticated status. One particular group of underutilized wild species that is of special value in our response to climate change is the wild relatives of crops (Heywood et al. 2007; Dwivedi et al. 2008; Maxted and Kell 2009; Hunter and Heywood 2011).

Importance of underutilized species: a brief overview

The importance of underutilized species in contributing to food and nutrition security has received substantial coverage by scientists in recent years (Smith 1982; Achinewhu et al. 1995; Longvah and Deosthale 1998; Hernández Bermejo and León 1992; Eyzaguirre et al. 1999; Heywood 1999a, 2008; Ali et al. 2000; Bahorun et al. 2004; Mulokozi et al. 2004; Frison et al. 2006; Smith et al. 2006; Weinberger and Swai 2006; Bhardwaj et al. 2007; Chadha et al. 2007; Hawtin 2007; Yang et al. 2007; Erlund et al. 2008; Smith and Longvah 2009). Likewise, their role in income generation in both domestic and international markets has been also highlighted in several studies and projects (Asaha et al. 2000; Mwangi and Kimathi 2006; Chadha and Oluoch 2007; Joordan et al. 2007; Hughes 2009; Mahyao et al. 2009; Padulosi et al. 2009; Rojas et al. 2009). Only a diversified agricultural portfolio represents a robust agricultural production system with the capacity to withstand future changes such as climate change (Cleveland et al. 1994; Reidsma and Ewert 2008; Cavatassi et al. 2006; Lovejoy 2006; Hassan and Nhemachena 2008; Henry 2009) and the role of underutilized species to that end need to be better recognized (Genetic Resources Policy Committee 1999; Dawson et al. 2007). Such a role can be realized in two ways; first, by providing genetic traits for adaptation and second by strengthening the resilience of agroecosystems through crop diversification. With regard to the first point, historically, in a climate stable world, crop wild relatives (CWR) as gene donors for plant breeding have been a major contributor to economic development and food security. For instance, Prescott-Allen and Prescott-Allen (1996) calculated that the yield and quality contribution by CWR to US grown or imported crops was over US$350 million a year, while Phillips and Meilleur (1998) estimated that potential losses associated with endangered threats to food CWR was worth about US$10 billion annually in wholesale farm values. With the accelerated rate of change predicted for future climate and recognition of the need to find quick solutions to expected increases in abiotic and biotic stresses, it is expected that the demand for such genetic traits will also rise significantly. Useful analyses of this point are those of Hajjar and Hodgkin (2007), Maxted and Kell (2009), and Maxted et al. (2010), whereas other chapters of this book deal also specifically with the use of climate-change related traits in CWR.

The other way in which underutilized species help agriculture to adapt to climate change is through their contribution in enhancing the diversification and resilience of agroecosystems in order to withstand the impacts of climate change scenarios (e.g., drought and increased frequency and intensity of extreme weather events such as cyclones and hurricanes). A good example is that of bambara groundnut (*Vigna subterranea*), a nutritious legume originating from west Africa and cultivated throughout sub-Saharan Africa (Heller et al. 1997). This legume, known for its drought tolerance (Collinson et al. 1996; Andika et al. 2008), is found growing in harsh climates and marginal soils (Padulosi 1988; Heller et al. 1997); but in spite of these traits the crop still suffers from a status of neglect because of its unpredictability in yields, long cooking time, and negative social image (Mayes et al. 2009). Other underutilized crops known for their drought tolerance are the minor millets, a category of several "coarse" cereals used particularly in South Asia whose drought-resistant traits coupled with an excellent nutritious profile offer major opportunities for the development of areas increasingly affected by water shortages such as those in the marginal hills of Tamil Nadu or Karnataka States of India (Bala Ravi 2004; Padulosi et al. 2009).

With regard to resistance to cold weather conditions, an interesting case is that of cañihua (*Chenopodium pallidicaule*), an underutilized Andean grain which has remarkable frost tolerance when compared with quinoa (*C. quinoa*) and used for such reasons by local farmers around the Titicaca Lake in Bolivia and Peru in their coping strategies to face climate change (Rojas et al. 2009). Among perennial species, a good example is that of the sea buckthorn (*Hippophae rhamnoides*), a species naturally distributed from Europe to Central Asia and China, which has been found to be more tolerant to abiotic stresses than apple and pear—tolerance which seems associated with its high levels in ascorbic acid and *myo*-inositol (Kamayama et al. 2009). Another excellent hardy crop is the tree moringa (*Moringa oleifera*), the "wonder tree," which as well as its drought-resistance trait also has leaves of high nutritional content.[3] Several species from India including custard apple (*Annona squamosa*), Indian gooseberry (*Emblica officinalis*), ber (*Zizyphus mauritania*), tamarind (*Tamarindus indica*), and neem (*Azadirachta indica*) are also well recognized for their drought tolerance and ability to thrive in poor soils and marginal lands (Hegde 2009). A globally renowned hardy and multipurpose tree species known for its drought resistance is prosopis (*Prosopis* spp.), a reliable crop for both human consumption and animal feed in difficult areas (Pasiecznik et al. 2001). According to a recent study (Smith and Beaulieu 2009), woody species that are characterized by slow growth (and hence slow adaptation) are expected to be more vulnerable to climate change than annual species. These findings which seem to shed a different light on our understanding of adaptation mechanisms should be also taken in due consideration in assessing genetic erosion risks of agrobiodiversity under climate change and guiding development of appropriate conservation strategies. Apart from being used directly in adaptation and coping strategies, underutilized species are also being used by farmers and community members to predict changes and anticipate possible shocks. This is the case for instance of so-called local drought indicators, found in many cultures around the world (see the case of the tree *Dobera glabra* in Ethiopia (Tsegaye et al. 2007)).

Traditional societies deploy strategies that use genetic diversity to reduce risks and mitigate impacts of long-term environmental changes (Jarvis et al. 2007). This is the case, for instance, of Indian farmers who plant many crops and varieties that allow them to adjust planting dates and crop mixtures (e.g., "*Akdi*" and "*Barhanaja*" systems) to better cope with erratic rainfall patterns.

Despite a growing awareness of the potential of underutilized species for future climate change adaptation and human wellbeing they continue to be seriously threatened primarily from habitat loss, fragmentation, and degradation. Further, underutilized species are seriously under-conserved. Although there has been significant attention given to in situ conservation of underutilized species in recent years, especially CWR, the effectiveness and impact of this appears to be far more uncertain than for ex situ conservation. This is due to a range of factors including political and institutional as well as technical and biological ones (Heywood and Dulloo 2005; Hunter and Heywood 2011). While Maxted et al. (2010) highlighted some examples of underutilized species, largely CWR, conserved in protected areas the likelihood of such areas continuing to afford adequate protection under future climates is largely unknown (Lira et al. 2009). The poor status of underutilized species conservation is a severe barrier to their successful improvement, utilization, and promotion. Much more needs to be done to improve ex situ and in situ conservation of these species as well as the linkages to end-users such as plant breeders and agronomists (FAO 1996, UNEP 2009).

Climate change and underutilized species: current studies and gaps in knowledge

The potential impact of climate change on the diverse range of underutilized species has not so far been assessed. With regard to underutilized species that are wild, the impact will affect taxa differently depending on where they occur and the detail of the climatic changes that are anticipated, their adaptive and resilience capacities, their ability to migrate, their dispersal capacity, the nature and ecology of their new bioclimatic envelopes and their ability to survive in them and spread, the availability of pollinators and dispersal agents, the environment and the management practices that might be associated with the species (e.g., timing or intensity of the wild harvests made by local populations). Extensive studies have been published on the impact of climate change on plants species (see Thomas et al. 2004 and references therein) that provide some indication of areas which will be most affected by the reductions in crop suitability (Intergovernmental Panel on Climate Change 2007; Lobell et al. 2007, 2008; Hawkins et al. 2008; Heywood 2011; Jarvis et al. 2009). The broad pattern of change in the location of vegetation belts is widely agreed, with movements expected toward the poles and altitudinal shifts but the details at local level is far from clear and will not be resolved until more sophisticated modeling can be undertaken. Along the same line is the low predictability of soil moisture variation in connection with expected climate change. Furthermore, warnings on the spreading of pests and diseases due to climate change have been also voiced (Diffenbaugh et al. 2008) along with preoccupations over the impact that extreme variations in temperature may have on the delicate stage of pollination (Lora Cabrera 2008). Models to predict these changes are still not accurate enough to allow the development of specific coping strategies by interested countries which would make optimal use of biodiversity and underutilized species in particular (Tanton and Haq 2008), although some studies represent a good basis for moving toward that direction (see the work by van Zonneveld et al. 2009).

Enough evidence exists, however, to indicate that many alpine/montane plants are likely to be at risk from climate change and those that are confined to specialized ecological niches may have difficulty in migrating to suitable niches in the new climatic envelopes (Heywood 2011a). Given that many locally used wild species grow in mountain regions, including aromatic and medicinal plants, wild greens, and CWR, some at least will be at risk from the effects of climate change. For instance, the numerous records gathered worldwide of shifting of species phenologies and distributions of plants due to change in temperature and rainfall could result in negative impacts for the survival of these species by exposing plants to late cold spells or facilitating the migration of invasive plants which would be competing for resources with underutilized native species (Cavaliere 2009).

Many coastal habitats will be at risk from predicted rises in sea level and this could affect species that occur in such habitats, notably mangrove species. Countries with least capacity to cope with such events would bear additional adverse impact of these changes. The impact could be dramatic in those countries characterized by poor coastal protection such as Bangladesh where the anticipated 0.6 m raise in sea level by 2080 is estimated to lead to the loss of 17% of its land (Tanton and Haq 2008).

Climate envelope modeling, which is the commonest approach used today to helping predict the likely response of species to climate change, is rapidly developing technique and is being applied to a wide range of plant (and animal) species but not specifically to underutilized species. Bioclimatic modeling has so far been applied to only a limited number of CWR but results so far suggest that many of them will be at risk through failure to migrate to new climatic

P1: SFK/UKS P2: SFK Color: 1C
BLBS082-26 BLBS082-Yadav June 29, 2011 17:56 Trim: 246mm X 189mm

envelopes. One of the few studies so far published (Lane and Jarvis 2007; Jarvis et al. 2008) used current and projected future climate data for ∼2055, and a climate envelope species' distribution model to predict the impact of climate change on the wild relatives of the world's major food crops, peanut (*Arachis*), potato (*Solanum*), and cowpea (*Vigna*). They considered three migrational scenarios for modeling the range shifts (unlimited, limited, and no migration) and found that climate change strongly affected all taxa, with an estimated 16–22% of these species predicted to go extinct and most species losing over 50% of their range size. Impacts were found to be differential between gene pools, with wild peanuts suffering far greater extinction risk when compared to wild *Vigna*.

Lira et al. (2009) used bioclimatic modeling and two possible scenarios of climatic change in Mexico to analyze the distribution patterns of eight wild Cucurbitaceae species closely related to cultivated plants, *Cucurbita argyrosperma* subsp. *sororia*, *Cucurbita lundelliana*, *Cucurbita pepo* subsp. *fraterna*, *Cucurbita okeechobeensis* subsp. *martinezii*, *Sechium chinantlense*, *Sechium compositum*, *Sechium edule* subsp. *sylvestre*, and *Sechium hintonii*. Most of these taxa have restricted distributions and many show proven resistance to various diseases, which could be crucial for the improvement of their related cultivars. The possible future role that the Mexican system of protected areas might have in the conservation of these taxa was also assessed. The results showed a marked contraction of the distributions of all eight taxa under both scenarios and also found that, under a drastic climatic change scenario, the eight taxa would be maintained in just 29 out of the 69 natural protected areas where they are currently found. Accordingly, it seems that most of the eight wild taxa will not have many opportunities to survive under such climate change.

Studies carried out on wild cowpea (*Vigna* spp.) estimate that almost half of the natural distribution area of these species will be lost by the middle of this century due to climate change (Anonymous 2007). Underutilized species, such as the forage species *Vigna marina* growing along the sea shores of Africa, would be certainly among those particularly affected by the rise of seawater levels.

Estimates of the number of underutilized wild species that will be lost as a result of climate change are currently not available as they are such a numerous and diverse array of species. Some ideas might be obtained indirectly from national Red Books or Lists, when they exist, which indicate those species that are currently at risk. It should be noted, however, that many species which are not currently threatened may become so as a result of accelerated climate change and the widely used International Union for Conservation of Nature (IUCN) criteria for assessing threats do not take climate change into account although this is under review. It should also be stressed that the effects of climate do not operate in isolation but interact with other components of global change, notably habitat loss, fragmentation or degradation, changes in disturbance regimes, and demographic factors such as human population growth and migrations (Heywood 2011b; Hunter and Heywood 2011). As for other groups of wild species, many underutilized species will be threatened by climate change but those that are not affected may well become extinct as a result of other global change processes.

Future opportunities and priorities for underutilized species under climate change

Maxted et al. (2010) highlight a number of important priority goals for CWR conservation and utilization over the next 10 years that would apply also to other underutilized (wild and cultivated) species. Some of these goals are to refine the estimate of global highest priority CWR for food and agriculture (such a list would greatly facilitate the targeting of in situ and ex situ conservation actions); take advantage of novel technological advances in trait recognition and interspecific breeding to extend the breadth of CWR use to a broader range of crops and systematically review the potentially useful diversity in CWR gene pools; undertake systematic threat assessment for as wide a range of CWR taxa as possible, using IUCN or national criteria, or both; extensive gap analysis of both ex situ and in situ conservation and based on this a more strategic approach taken to targeting ex situ CWR conservation and continued efforts to strengthen CWR conservation inside and outside protected areas. Complementary to these points that focus particularly on conservation, are those emerging from the 2007 Southampton conference on underutilized species (Smartt and Haq 2008) which lists some of the major issues that the research community need to address in order to enhance the sustainable use of underutilized species in the coming decades, namely, more studies on negative aspects (e.g., bitterness, lodging, and hard seed coat) that limit the diffusion of underutilized species; greater emphasis on consumer needs and studies on how these can be met through the plentiful diversity available in underutilized species (focus particularly on traits such as shelf life, processing aptitude, length of growing seasons); and enhancement of both local and global markets for target species (focus on demand creation, price stability, food safety, standards for commercialization).

The prioritization and research challenge

While the Green Revolution may have produced advances in agricultural development in some places with suitable physical and socioeconomic environments, its continued promotion in some regions such as Africa through the Alliance for a Green Revolution in Africa (AGRA) is being called into question. An alternative, or at the very least a complementary strategy, is surely to harness the huge potential of indigenous and underutilized species grown and conserved by local communities for generations in diverse and complex agroecosystems across variable climates. Such an alternative has received support in recent reports (e.g., WRI 2005; Perfecto et al. 2009; FAO 2010b; Pretty et al. 2010; Frison et al. 2011) that stress the need to give greater emphasis in agricultural development to the needs of local farmers and for investments that can "increase the sustainable productivity of major subsistence foods including orphan and underutilized crops, which are often grown or consumed by poor people" (McIntyre et al. 2008).

There is a large body of literature describing the complex, diverse, and risk-prone small-scale farming systems and the practices they use and which occur in areas where most biodiversity occurs and which are hotspots for most underutilized species (Altieri 1987; Pretty 2009; Holt-Giménez 2006, 2009). Such mixed cropping systems are inherently more stable and resilient compared to monocultures or simplified agroecosystems. There is also evidence they are biologically more productive than monocultures (Jarvis et al. 2007), which can be explained by more efficient patterns of resource capture and use by component species. However, the question remains, which underutilized species are best suited to the resilience requirements for agroecosystems in future volatile environments such as those that will be found in many parts of Africa. Although there has been work in the past on the prioritization of underutilized species (Padulosi 1999; Akinnifesi et al. 2008; Schmidt et al. 2010), this has not been done in the context of climate change. Whether there should be a detailed (inclusive) or a definitive (exclusive) list of priority underutilized species for variable environments has been the subject of much debate and there seems to be no agreement on which species are best suited for particular contexts or scenarios.

Assuming there are criteria and processes that we can use to prioritize underutilized species, answering the question of what approaches we might use to evaluate or assess candidates for their adaptation potential to climate change calls for greater investments in research and development (Tanton and Haq 2008). As changes in climate are expected to be more significant in Africa than other regions (Collier et al. 2008), priority setting should assign

P1: SFK/UKS P2: SFK Color: 1C
BLBS082-26 BLBS082-Yadav June 29, 2011 17:56 Trim: 246mm X 189mm

proper attention to drought-tolerant forages (such as *Stylosanthes scabra*) that could provide also soil cover and protection from degradation in the face of increased grazing (Batjes and Sombroek 1997).

The ex situ conservation challenge

Today, some 7.4 million accessions of plant genetic resources for food and agriculture are stored in around 1700 germplasm collections around the world (FAO 2010a). The poor representation of underutilized crops in ex situ gene bank collections (Padulosi et al. 2002; FAO 2010) has dramatic repercussions on access to this diversity by users, besides representing a major constraint for those interested in so-called gene mining aimed at identifying potential source of resistance in samples originating from areas affected by severe climatic and/or marginal growth conditions. While botanic gardens may do a better job of ex situ collection of underutilized species, many of the botanic garden accessions are small and genetically poorly sampled (Heywood 1999b). Not enough attention is paid to the ongoing (and unrecorded) erosion affecting underutilized species, resulting from the widespread use of a handful of commodity crops, monoculture practices, standardization of market systems, and other globalization trends such as nutrition transition, all affecting local crops and local diets (Frison et al. 2006; Smith and Longvah 2009).

The issue of broadening the mandate of national and international gene banks with the objective of including the thousands of neglected and underutilized species used locally around the world should thus receive the urgent attention of policy makers. Unfortunately, the focus of the international community continues to be geared towards major crops and in particular those species listed in Annex I of the International Treaty on Treaty on Plant Genetic Resources for Food and Agriculture (PGRFA) (Fujisaka et al. 2009; Padulosi et al. 2009). Very little attention is paid to safe-guarding all other species, including underutilized species. The work of the Royal Botanic Garden Kew Millennium Seed Bank, which has already sampled 10% of all plant species and aims to achieve 25% by 2020,, is an important contribution in that direction.[4] Another interesting approach is that of the "climate ready" collections, being practiced by the Centre for Pacific Crops and Trees in Fiji, where underutilized crops such as the aroids *Xanthosama*, *Alocasia*, and *Cyrtosperma chamissonis (*swamp taro) (of known tolerance and/or resistance to biotic stresses) are being multiplied and maintained in dedicated in vitro collections for promoting their access by countries of the region.[5] While broadening the mandate of gene banks to include underutilized species is important, it should be also noted that for many species (that reproduce asexually, or having recalcitrant seeds) this conservation method is not always a viable option. Other disadvantages of ex situ conservation include its costs, possibility to maintain only a limited amount of the diversity of the gene pool, and loss of the natural and anthropocentric processes that accompany in situ conservation (Fowler and Hodgkin 2004). The safeguard also of fast-disappearing local knowledge and wisdom related to underutilized species need to be also stressed if we are to promote effective appreciation and use of these species in the future (Genetic Resources Policy Committee 1999).

The in situ conservation challenge

Consumption of underutilized species is more diffused among poor households, in marginal areas and communities isolated from markets, where difficult communication hamper regular access to food and other products. The little attention dedicated to on-farm conservation represents a major shortcoming of the world's approach to safeguarding the agricultural biodiversity as it has also been recently acknowledged during the preparatory meeting for the development of the Convention on Biological Diversity global conservation strategy.[6] The widespread cultural erosion and changes in food diets taking place even in remote areas is, however, changing these centuries-old food traditions at a fast pace with negative effects on sustainability of agricultural practices and healthy nutrition (Drewnowski and Popkin 1997; Hwalla and El Khoury 2008). Compared to major crops, underutilized species are low-risk crops. Less investment is made in them by farmers with regard to land and agricultural inputs, labour (mainly from family members) being the major investment for the cultivation. These are mostly of a traditional type and rely largely on local knowledge transferred orally from one generation to the next. The yield stability is dependent more on the intrinsic genetic diversity of the diverse populations grown and traditional practices employed rather than the use of improved varieties (scarcely available). Underutilized species are generally deployed in multicropping systems and grown (or harvested in the wild) by people because of the multiple nature of their uses and benefits to the household.

Because of their localized use, underutilized species have been adapting to limited ecological niches and little information is known of their performance outside those areas of traditional cultivation. Many of them may be also part of the natural vegetation (e.g., agroforestry systems) and in that case their ecological role in production systems should be also acknowledged as an additional contribution to all other specific values (food, fiber, medicine, wood, etc). Underutilized species mostly rely on local seeds that are usually saved either by the family or through local seed networks active within the community. Extension work on these species is very limited, since both governments and development agencies have traditionally focused on commercial crops, which are more competitive in the market and/or supported by government policies that make their cultivation more convenient to farmers (Veteläinen et al. 2009). An interesting case in point is that of subsidies and procurements mobilized to rice and other staple crops in India which makes minor millets less economically advantageous for local communities (Padulosi et al. 2009). The impact, therefore, of climate change on the seed systems of underutilized species should be another area of serious concern for policy makers, and efforts should be made to facilitating informal seed networking outside original areas of their diffusion (De Schutter 2009). In view of the fact that climate change impact would vary across the landscape, specific adaptation programs and policy measures should be thus developed in close collaboration with communities where farmer-managed seed networks will need to be properly assessed and strengthened.

Serious concern over the loss of local biodiversity on farm, which affects both landraces of major crops and underutilized species, has been voiced at national and international level (FAO 1996; SCAR 2008; Veteläinen et al. 2009). The highly localized cultivation of underutilized species and their consequent appeal mainly to local populations familiar with their diversity benefits and uses, make them a difficult case for wider promotion beyond their centre of main diversity and origin. While this has been always a limit for canvassing greater support on their conservation, current calls for greater crop diversification in the context of climate change are seen as an emerging opportunity to promote their local uses in harmony with community-led and livelihood based adaptation strategies.

Although protected areas offer a degree of protection for underutilized species, how effective this might be in the future under climate change has been called into question (Lira et al. 2009). More efforts are, therefore, needed on in situ conservation. There is an urgent need to scale up the work of the UNEP/GEF-supported project, “in situ” conservation of CWR through enhanced information management and field application, coordinated by Bioversity International in five countries—Armenia, Bolivia, Madagascar, Sri Lanka, and Uzbekistan[7]—to other target species and protected areas, countries, and regions (Hunter and Heywood 2011).

Perfecto et al. (2009) elaborate in detail the sort of paradigm shift and partnerships that may be necessary, working through traditional agroecosystems and indigenous and social movements, to ensure the conservation of thousands of underutilized species.

The most important point to emphasize here is that to enhance in situ conservation it is important to recognize that conservation strategies are more likely to be successful if national governments, on-the-ground agencies, and local people set the agenda, as it is they who will be responsible for their implementation, with international NGOs and IGOs playing a supporting role (Smartt and Haq 2008; Smith et al. 2009).

The use enhancement challenge

Enhancing the use of underutilized species to strengthen adaptation and resilience of agricultural systems is a complex endeavor that requires a highly multidisciplinary and multistakeholder approach (Hoeschle-Zeledon and Jaenicke 2007). Efforts are highly interlinked internally and with crosscutting themes such as germplasm conservation, capacity building, policies, and public awareness (Jaenicke and Höschle-Zeledon 2006; Rojas et al. 2009; Padulosi et al. 2009).

We should be also aware of the negative impact that some underutilized species may have on people's livelihood when their diffusion is not accompanied by parallel dissemination of practices for their proper management and use as in the case of the invasive *Solidago canadensis* in Poland (Polok et al. 2008). An area emerging also as highly strategic for deployment of underutilized species is that of biofuel (and in particular those of the second and third generation) in view of the perspective to deploying hundreds of hardy species in marginal or abandoned areas.

With regard to needs related specifically to climate change and use enhancement research for underutilized species, the following seem to emerge as priority areas of intervention: (1) comparative studies to assess/confirm adaptation and resilience capacities of species and varieties in different contexts, (2) capacity building of research in modeling for climate change adaptation using the experience developed on major crops and wild species, and (3) socioeconomic studies to predict impact of climate change on seed systems and local markets.

The awareness and knowledge challenge

One of the limitations in the popularization of underutilized species is that related to poor understanding and perception of their roles and importance by various elements of society. Despite their enormous economic importance, and the fact that the survival of many are severely threatened, there is no way we can say that CWR are considered as flagship or iconic species in a way that corresponds to similarly threatened species of animals. This is a major contributing factor to their current poor state of conservation. Likewise, underutilized cultivated species often carry a "food-of-the-poor" image (Blench 1997; Padulosi et al. 2009). This is a phenomenon recorded across continents and cultures and it is found to strongly discourage their wider promotion and adoption, unless adequate campaigns are made to change people's perceptions. Great efforts are indeed often required to show that species perceived as inferior ("low status food") are in fact very relevant to food security and micronutrition as well as for many other social, cultural, and environmental purposes. From a social perspective, the vulnerability of people in the context of climate change and biodiversity should not be exclusively seen from the physical angle (threats on genetic diversity, loss of nutrition or income opportunities, etc.), but also from the nonmaterial benefits that species, including those underutilized, may provide to people.

If we limit our analysis to food, biodiversity is an essential conduit to our food culture, traditions, the sense of belonging to the territory and shared history, intimate association with people, sharing of similar emotions and identity.

Centuries of natural and human-driven selection have resulted into a vast array of diversity in agricultural crops in each region that is enriched by a parallel cultural diversity related to identification and classification of species, knowledge on where to find and how to harvest them (in the case of wild species), where-when-how to grow them (case of cultivated species), how to make the best use of their products, etc. Climate change is expected to have a wide range of negative consequences on local knowledge, and we should be prepared to prevent that from happening by devising methods and tools that would make people less affected. For instance, the changing of cultivating patterns arising from changes in rainfall regimes will induce people to drop some crops and select others. On the hypothesis that underutilized species will hold comparative advantages in such a change, we need to devise ways through which these changes can be facilitated and thus precious knowledge currently disappearing is documented, safeguarded, promoted, and disseminated through social networks. The role of single community members as well as that of collective actions will be equally relevant in the context of coping strategies. To that regard, empowerment of women through incentives and programs aimed at enhancing their skills and capacities related to nutrition and income generation from local biodiversity need to also receive greater attention from Governments and relevant agencies (Balakrishnan 2000; Padulosi et al. 2009).

Conclusions

The vulnerability of people to climate change is a function of the natural, social, economic, and political context in which they live. The diversification of agricultural production systems through the promotion of underutilized species offers opportunities for strengthening adaption, mitigation, and resilience of both the natural and socioeconomic systems. While scientific evidence on the comparative advantages of underutilized crops over commodity crops is yet to be fully demonstrated, the experience acquired by farmers and other interdisciplinary considerations strongly support a call for more investments on these species at the local, regional, national, and international level. As the debate over the future of agriculture under climate change intensifies, crop diversification is being advocated as a key component for enhancing adaptation and resilience of production systems. Greater demand of underutilized species is expected to fulfill diversification and maintain at the same time livelihood options of people, particularly the rural and urban poor. The complexity of the promotion of underutilized species requires a paradigm change in agricultural research so far. Greater multidisciplinary and intersector linkages will be needed to face this challenge. Other strategic interventions toward the realization of greater benefits from underutilized species include (1) map their geographic distribution and shed more light on the complex linkages between their diversity, production, and stability of agroecosystems in the context of climate change; (2) explore trade-offs between the role of a few species with important traits over that of many species with less important traits in view of the fact that too many species may lead to high transaction costs in accessing markets, particularly for the poor; (3) promote nation-wide campaigns to remove the image of food of the poor attached to underutilized species as a way to reinforce food and nutrition security in climate change scenarios; (4) raise awareness among the younger generation over the importance of safeguarding healthy food habits and traditions associated with local crops as a way to move away from the current dependency over few crops and species; (5) establish monitoring and early warning systems for underutilized species in the context of greater interventions in support of in situ/on farm conservation of local biodiversity; (6) promote greater access and exchange of diversity of underutilized (including expansion of Annex I list of the International Treaty on PGRFA[8]) as a critical element in support of crop diversification strategies; (7) take advantage of the mounting climate change awareness as an opportunity to mainstream underutilized species into national and local development plans and strategies and use them as an engine for rural and urban growth.

Endnotes

1. See the 395 species listed as examples at www.underutilized-species.org/species/specieas_mask.asp.
2. http://www.donorplatform.org/content/view/289/157. Accessed December 10, 2009.
3. Moringa is reported to have seven times richer vitamin C content than oranges, four times more vitamin A content than carrots, and four times more Ca than milk (plus double of its protein) and three times more potassium than bananas (http://www.moringanews.org/doc/GB/Posters/Broin_poster.pdf).
4. http://www.kew.org/science-conservation/conservation-climate-change/millennium-seed-bank/index.htm
5. http://www.agrobiodiversityplatform.org/blog/?p=96
6. "Especially in the light of biodiversity and climate change, it is now particularly important to emphasize other socio-economically valuable plants, including medicinal plants, nontimber forest products, local land races, wild relatives of crops, and neglected and underutilized plant resources. Priority species can be selected on a case-by-case basis at the local, national, and regional level" (source: UNEP/CBD/LG-GSPC/3/4. 2009).
7. http://www.cropwildrelatives.org/
8. http://www.planttreaty.org/texts_en.htm

References

Achinewhu SC, Ogbonna CC, Hart AD (1995) Chemical composition of indigenous wild herbs, fruits and leafy vegetables used as food. *Plant Foods for Human Nutrition* 448: 341–348.

Akinnifesi FK, Aiayi OC, Gudeta S et al. (2008) Domesticating and commercializing indigenous fruit and nut tree crops for food security and income generation in sub-Saharan Africa. In J Smartt and N Haq (eds) *New Crops and Uses: Their Role in a Rapidly Changing World. Centre for Underutilized Crops*. University of Southampton, Southampton, UK.

Ali, M, Wu SN, Wu MH (2000) *Evaluation of the Net Nutritive Gain of Policy Interventions: An Application to Taiwan Household Survey Data*. Asian Vegetable Research and Development Center, Tainan, Taiwan.

Altieri, MA (1987) *Agroecology: The Scientific Basis of Alternative Agriculture*. Westview Press, Boulder, CO.

Andika DO, Onyango MOA, Onyango JC (2008) Role of Bambara groundnut (*Vigna subterranea*) in cropping systems in Western Kenya. In: J Smartt and N Haq (eds) *New Crops and Uses: Their Role in a Rapidly Changing World*. Centre for Underutilized Crops, University of Southampton, Southampton, UK.

Anonymous (2007) The Conservation of Global Crop Genetic Resources In the Face of Climate Change. Summary Statement from a Bellagio Meeting organized by the Global Conservation Trust, held on September 3–7, 2007. Available from: http://www.croptrust.org/documents/WebPDF/Bellagio_final1.pdf. Accessed December 10, 2009.

Asaha S, Tonye MM, Ndam N et al. (2000) State of knowledge on *Gnetum africanum* Welw and *Gnetum bucholzianum* Engl. A report for the Central African Republic Program for the Environment. Limbe Botanic Garden, Limbe, Cameroon.

Bahorun, T, Luximon-Ramma A, Crozier A et al. (2004) Total pieno, flavonoid, proanthocyanidin and vitamin C levels and anti-oxidant activities of Mauritian vegetables. *Journal of the Science of Food and Agriculture* 84: 1553–1561.

Bala Ravi S (2004) Neglected millets that save the poor from starvation. *LEISA India* 6(1): 34–36.

Balakrishnan R (2000) Gender-defined strategies for biodiversity management for household food security. In FAO Regional Technical Consultation: Gender Dimensions in Biodiversity Management and Food Security: Policy and Programme Strategies for Asia. M.S. Swaminathan Research Foundation, Chennai, India.

Batjes NH, Sombroek WG (1997) Possibilities for carbon sequestration in tropical and subtropical soils. *Global Change Biology* 3: 161–73.

Bhardwaj R, Rai AK, Sureja AK et al. (2007) Nutritive value of indigenous vegetables of Arunchal Pradesh. In: Paper presented at Proceedings of 2nd Indian Horticulture Congress 2007—Opportunities and Linkages for Horticulture research and development, ICAR-complex for NE region. April 18–21. Barapani, Meghalaya, India.

Blench R (1997) Neglected species, livelihoods and biodiversity in difficult areas: how should the public sector respond? Overseas Development Institute. *Natural Perspectives Magazine*. No. 23. Available from: http://www.odi.org.uk/resources/download/2134.pdf. Accessed December 10, 2009.

Chadha ML, Oluoch MO (2007) Healthy diet gardening kit for better health and income. *Acta Horticulturae* 752: 581–583.

Cavaliere C (2009) The effects of climate change on medicinal and aromatic plants. *HerbalGram* 81: 44–57.

Cavatassi R, Lipper L, Hopkins J (2006) *The role of crop genetic diversity in coping with agricultural production shocks: Insights from Eastern Ethiopia*, Working Papers 06–17, Agricultural and Development Economics Division of the Food and Agriculture Organization of the United Nations. Available from: http://ideas.repec.org/p/fao/wpaper/0617.html. Accessed December 10, 2009.

Cleveland DA, Soleri D, Smith SE (1994) Do folk crop varieties have a role in sustainable agriculture? *Bioscience* 44(11): 740–51.

Collinson ST, Azam-Ali SN, Chavula KM et al. (1996) Growth development and yield of bambara groundnut (*Vigna subterranea*) in response to soil moisture. *Journal of Agricultural Science* 126: 307–318.

Dawson IK, Guarino L, Jaenicke H (2007) Underutilized plant species; impacts of promotion on biodiversity. Position Paper 2. ICUC, Sri Lanka.

Diffenbaugh N, Krupke CH, White MA et al. (2008) Global warming presents new challenges for maize pest management. *Environmental Research Letters* 3(4). doi:10.1088/1748-9326/3/4/044007. Available from: http://www.iop.org/EJ/article/17489326/3/4/044007/erl8_4_044007.pdf. Accessed December 10, 2009

De Schutter O (2009) The right to food. Seed policies and the right to food: enhancing agrobiodiversity and encouraging innovation. UN general Assembly, sixty-fourth session. A/64/170. July 23, 2009.

Drewnowski A, Popkin B (1997) The nutrition transition: new trends in the global diet. *Nutrition Reviews* 55(2): 31–43.

Dwivedi SL, Upadhyaya HD, Stalker T et al. (2008) Enhancing crop gene pools with beneficial traits using wild relatives. *Plant Breeding Reviews* 30: 180–230.

Erlund, I, Raika Koli Alfthan G et al. (2008) Favorable effects of berry consumption on platelet function, blood pressure, and HDL cholesterol. *The American Journal of Clinical Nutrition* 87: 323–31.

Eyzaguirre P, Padulosi S, Hodgkin T (1999) IPGRI's strategy for neglected and underutilized species and the human dimension of agrobiodiversity. In: S Padulosi (ed) *Priority Setting for Underutilized and Neglected Plant Species of the Mediterranean Region*. Report of the IPGRI Conference, February 9–11, 1998, ICARDA, Aleppo, Syria. International Plant Genetic Resources Institute, Rome, Italy.

FAO (1996) Global Plan of Action for the Conservation and Sustainable Utilisation of Plant Genetic Resources for Food and Agriculture and Leipzig Declaration, adopted by the International Technical Conference on Plant Genetic Resources, Leipzig, Germany, June 17–23, 1996. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2010a) Second report on the state of the world's plantgenetic resources for food and agriculture. Commission on genetic Resources and Agriculture. FAO, Rome, Italy.

FAO (2010b) The state of food insecurity in the world. Addressing food insecurity in protracted crises. FA0, Rome.

Fowler C, Hodgkin T (2004) Plant genetic resources for food and agriculture: assessing global availability. *Annual Review of Environmental Resources* 29: 143–79.

Frison EA, Smith IF, Johns T et al. (2006) Agricultural biodiversity, nutrition and health: making a difference to hunger and nutrition in the developing world. *The Food and Nutrition Bulletin* 27: 167–179.

Frison EA, Cherfas J, Hodgkin T (2011) Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability* 3, 238–253. Doi:10.3390/su3010238.

Fujisaka S, Williams D, Halewood M (eds) (2009) The impact of climate change on countries' inter-dependence on genetic resources for food and agriculture. Background paper no. 48 prepared for the twelfth regular session of the FAO Commission on Genetic Resources for Food and Agriculture. FAO, Rome, Italy. 79pp.

Genetic Resources Policy Committee (1999) Enlarging the basis of food security: role of underutilized species, proceedings of the international consultation organized by the Genetic Resources Policy Committee of the CGIAR at the M.S. Swaminathan Research Foundation, Chennai, India from February 17–19, 1999.

Hassan R, Nhemachena C (2008) Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. *The African Journal of Agricultural and Resource Economics* 2: 83–44.

Hawtin G (2007) Underutilized plant species research and development activities—review of issues and options. GFU/ICUC. International Plant Genetic Resources Institute, Rome, Italy.

Hegde NG (2009) Promotion of underutilized crops for income generation and environmental sustainability. *Acta Horticulturae* 806: 563–577. ISHS.

Heller J, Begemann, FL, Mushonga J (1997) Promotion, conservation and use of underutilized neglected crops. Bambara groundnut. Proceedings of the workshop on conservation and improvement of Bambara groundnut, November 14–16, 1995.

Henry R (2009) *Plant Resources for Food, Fuel and Conservation*, 200pp. Earthscan, London.

Hernández Bermejo JE, León, J (1992) Cultivos Marginados. Otra Perspectiva de 1492. FAO, Rome.

Heywood V (1999a) Use and Potential of Wild Plants in Farm Households. FAO, Rome, Italy.

Heywood VH (1999b) The role of botanic gardens in ex situ conservation of agrobiodiversity. In: T Gass, L Frese, F Begemann and E Lipman (eds) *Implementation of the Global Plan of Action in Europe—Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture*, pp. 102–107. Proceedings of the European Symposium, June 30–July 3, 1988, Braunschweig, Germany. International Plant Genetic Resources Institute, Rome.

Heywood VH (2008) The use and economic potential of wild species: an overview. In: N Maxted, BV Ford-Lloyd, SP Kell, JM Iriondo, ME Dulloo, and J Turok (eds) *Crop Wild Relative Conservation and Use*, Chapter 43. CABI, Wallingford.

Heywood VH (2011a) An outline of the impacts of climate change on endangered species in the Mediterranean region. *Naturalista sicil* 35(1): 107–119.

Heywood V (2011b) *The impacts of climate change on plant species in Europe*. Report prepared by Professor Vernon Heywood School of Biological Sciences, University of Reading with contributions by Dr Alastair Culham.

P1: SFK/UKS P2: SFK Color: 1C
BLBS082-26 BLBS082-Yadav June 29, 2011 17:56 Trim: 246mm X 189mm

Cahiers Nature and Environment, Council of Europe, Strasbourg (in press).

Heywood V, Casas A, Ford-Lloyd B et al. (2007) Conservation and sustainable use of crop wild relatives. *Agriculture, Ecosystems and Environment* 121: 245–255.

Heywood VH, Dulloo ME [2006 (2005)] In situ *Conservation of Wild Plant Species—a Critical Global Review of Good Practices*. IPGRI Technical Bulletin No. 11. FAO & IPGRI. IPGRI, Rome.

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.

Hoeschle-Zeledon I, Jaenicke H (2007) A strategic framework for global research and development of underutilized plant species: a contribution to the enhancement of indigenous vegetables and legumes. *Acta Horticulturae* (ISHS) 752: 103–110.

Holt-Giménez E (2006) Campesino a Campesino: Voices from the farmer-to-farmer movement for sustainable agriculture in Latin America. Food First, Oakland.

Holt-Giménez E, Patel Raj (2009) Food Rebellions: Crisis and the Hunger for Justice. Bottom of Form The real story behind the world food crisis and what we can do about it. Fahumu Books and Grassroots International.

Hughes J (2009) Just famine foods? What contribution can underutilized plants make to food security? *Acta Horticulturae* 86: 39–47. ISHS.

Hunter D, Heywood V (eds) (2011) *Crop Wild Relatives. A manual of in situ conservation*. Earthscan, London.

Hwalla N, El Khoury DTD (2008) Lebanese traditional diets and health effects. In: F De Meester and R Ross Watson (eds) *Wild-Type Food in Health Promotion and Disease Prevention. The Columbus Concept*. Humana Press, Totowa, NJ.

Intergovernmental Panel on Climate Change (2007) In: ML Parry, OF Canziani, JP Palutikof, PJ Van der Linden, and CE Hanson (eds) Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge.

Jaenicke H, Höschle-Zeledon I (eds) (2006) Strategic Framework for Underutilized Plant Species Research and Development, with Special Reference to Asia and the Pacific, and to sub-Saharan Africa. International Centre for Underutilised Crops, Colombo, Sri Lanka and Global Facilitation Unit for Underutilized Species, Rome, Italy. 33pp.

Jarvis DI, Padoch C, Cooper HD (eds) (2007) *Managing Biodiversity in Agricultural Ecosystems*. Columbia University Press, New York, USA; Bioversity International, Rome, Italy. 492pp.

Jarvis A, Lane A, Hijmans RJ (2008) The effect of climate change on crop wild relatives. *Agriculture, Ecosystem and Environment* 126: 13–23.

Jarvis A, Gaiji S, Ramirez J et al. (2009) GBIF: Mobilising information for adapting agriculture to climate change. Poster presented at the International Scientific Congress on Climate Change, March 10–12, 2009, Copenhagen, Denmark. Available from: http://www2.gbif.org/PosterCCC37hi-res.pdf. Accessed December 10, 2009.

Joordan D du PS, Akinnifesi FK, Ham C, Ajayi OC (2007) The feasibility of small-scale indigenous fruit processing enterprises in Southern Africa. In: FK Akinnifesi, RRB Leakey, OC Ajayi, G Sileshi, Z Tchoundjeu, P Matakala, and FR Kwesiga (eds) *Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization*. World Agroforestry Centre: Nairobi. CAB International Publishing, Wallingford, UK.

Kamayama W Ohkawa, Chiba E, Sato K et al. (2009) Nutritional component and nitrogen fixation in seabuckthorn (*Hippophae rhamnoides* L.). *Acta Horticulturae* 806: 309–322. ISHS.

Lane A, Jarvis A (2007) Changes in climate will modify the geography of crop suitability: agricultural biodiversity can help with adaptation. *Journal of Semi-arid Tropical Agricultural Research* 4(1): 1–12. Available from: http://www.icrisat.org/Journal/specialproject.htm. Accessed December 10, 2009.

Lobell DB, Cahill KN, Fieldet CB (2007) Historical effects of temperature and precipitation on California crop yields. *Climatic Change* 81: 187–203. Available from: http://iis-db.stanford.edu/pubs/21963/lobell_cahill_field_2007.pdf. Accessed December 10, 2009.

Lobel DB, Burke MB, Tebaldi C et al. (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* 319: 607–610.

Lovejoy TE (2006) *Climate Change and Biodiversity*, Earthscan, London.

Lira R, Téllez O, Dévila P (2009) The effects of climate change on the geographic distribution of Mexican wild relatives of domesticated Cucurbitaceae. *Genetic Resources and Crop Evolution* (2009) 56: 691–703.

Longvah T, Deosthale YG (1998) Nutrient composition and food potential of *Parkia roxburghii*, a less known tree legume from northeast India. *Food Chemistry* 62: 477–481.

Lora Cabrera J (2008) Biología reproductiva del chirimoyo (*Annona cherimola* Mill.). Tesis doctoral. Universidad de Malaga. España (in Spanish).

Mahyao A, Agbo E, Fondio L et al. (2009) Socio economic importance of urban markets supply chains of indigenous leafy vegetables in Cote d'Ivoire. *Acta Horticulturae* 806: 489–496. ISHS.

Maxted N, Kell SP (2009) Establishment of a global network for the *in situ* conservation of crop wild relatives: status and needs. FAO Commission on Genetic Resources for Food & Agriculture, Rome, Italy. 266pp.

Maxted N, Kell SP (2009) *Establishment of a Global Network for the In Situ Conservation of Crop Wild Relatives: Status and Needs,* 266pp. FAO Commission on Genetic Resources for Food and Agriculture, Rome, Italy.

Mayes S, Basu S, Murchie E et al. (2009) BAMLINK. A cross disciplinary programme to enhance the role of bambara groundnut (*Vigna subterranea* L. Verdc.) for food security in Africa and India. *Acta Horticulturae* 806: 39–47. ISHS.

McIntyre B, Herren HR Wakhungu J et al. (eds) (2008) Global Report. International Assessment of Agricultural Knowledge, Science and Technology for Development. IAASTD. ISBN 978-1-59726-538-6.

Mulokozi G, Hedren E, Svanberg U (2004) In vitro accessibility and intake of beta-carotene from cooked green leafy vegetables and their estimated contribution to vitamin A requirements. *Plant Foods for Human Nutrition* 59: 1–9.

Mwangi S, Kimathi M (2006) African leafy vegetables evolves from underutilized species to commercial cash crops. Research Workshop on Collective Action and Market Access for Smallholder. Cali, Colombia.

Padulosi S (1988) Plant Exploration and Germplasm Collection in Chad 1987. Genetic Resources Unit, International Institute of Tropical Agriculture, Oyo Road PMB 5320, Ibadan, Nigeria.

Padulosi S (1999) Criteria for priority setting in initiatives dealing with underutilized crops in Europe. In: T Gass, F Frese, F Begemann, and E Lipman (compilers) *Implementation of the Global Plan of Action in Europe – Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture*. Proceedings of the European Symposium, June 30–July 3, 1998, Braunschweig, Germany. International Plant Genetic Resources Institute, Rome.

Padulosi S, Hodgkin T, Williams JT et al. (2002) Underutilized crops: trends, challenges and opportunities in the 21st Century. In: JMM Engels et al. (eds) *Managing Plant Genetic Resources*, pp. 323–338. CAB International, Wallingford, UK and IPGRI, Rome, Italy.

Padulosi S, Hoeschle-Zeledon I (2004) Underutilized plant species: what are they? *LEISA* 20(1): 5–6.

Padulosi S, Hoeschle-Zeledon I, Bordoni P (2008) Minor crops and underutilized species: lessons and prospects. In: N Maxted, BV Ford-Lloyd, SP Kell, JM Iriondo, ME Dulloo, and J Turok (eds) *Crop Wild Relatives Conservation and Use*, pp. 605–624 CAB International, Wallingford, UK. ISBN 978-1-84593-099-9.

Padulosi S, Bhag Mal, Bala Ravi S et al. (2009) Food security and climate change: role of plant genetic resources of minor millets. *Indian Journal of Plant Genetic Resources*22(1): 1–16.

Pasiecznik NM, Felker P, Harris PJC et al. (2001) *The Prosopis juliflora-Prosopis pallida* Complex: A Monograph, 162pp. HDRA, Coventry, UK.

Perfecto I, Vandermeer J, Wright A (2009) Nature's Matrix. Linking Agriculture, Conservation and Food Sovereignty. Earthscan, London.

Phillips OL, Meilleur B (1998) Economic potential of the rare and endangered plants of North America. *Economic Botany* 52: 57–67.

Polok K, Korniak T, Zielinski R (2008) Contribution of molecular genetics for new crops development. In: J Smartt and N Haq (eds) *New Crops and Uses: Their Role in a Rapidly Changing World*. Centre for Underutilized Crops, University of Southampton, Southampton, UK.

Prescott-Allen C, Prescott-Allen R (eds) (1996) Assessing the Sustainability of Uses of Wild Species: Case Studies and Initial Assessment Procedure. International Union for Conservation of Nature and Natural Resources. Specialist Group on Sustainable Use of Wild Species. Gland, Switzerland and Cambridge, UK, IUCN.

Pretty J et al. (2010) The top 100 questions of importance to global agriculture. *International Journal of Agricultural Sustainability* 8(4):219–236, doi:10.3763/ijas.2010.0534.

Reidsma P, Ewert F (2008) Regional farm diversity can reduce vulnerability of food production to climate change. *Ecology and Society* 13(1): 38.

Rojas W, Valdivia R, Padulosi et al. (2009) From neglect to limelight: issues, methods and approaches in enhancing sustainable conservation and use of Andean grains in Bolivia and Peru. In: A Buerkert and J Gebauer (eds), *Agrobiodiversity and Genetic Erosion*, Contributions in Honor of Prof. Dr. Karl Hammer. Supplement 92 to the Journal of Agricultural and Rural Development in the Tropics and Subtropics, Kassel University Press GmbH, Kassel, pp. 87–117. ISBN: 978-3-89958-680-0.

SCAR (2008) The 2nd SCAR Foresight Exercise. New challenges for agricultural research: climate change, food security, rural development, agricultural knowledge systems. EU Commission Committee on Agricultural Research. December 2008. Available from: http://www.agr.unipi.it/labrural/scar_2nd_foresight_exercise_ver-_4-5_7_feb_2009.pdf. Accessed December 10, 2009

Schmidt M, Lam NT, Hoanh MT et al. (2010) Promoting neglected and underutilised tuberous plant species in Vietnam. In: R Haas, M Canavari, B Slee, C Tong, and B Anurugsa (eds) *Looking East Looking West: Organic and Quality Food Marketing in Asia and Europe*. Wageningen Academic Publishers Security Research Kassel, Wageningen.

Smartt J, Haq N (eds) (2008) New Crops and Uses: Their Role in a Rapidly Changing World. Centre for Underutilized Crops, University of Southampton, Southampton, UK.

Smith SA, Beaulieu JM (2009) Life-history influences rates of climatic niche evolution in flowering plants. Proceedings of the Royal Society B, September 23, 2009, doi: 10.1098/rspb.2009.1176.

Smith IF, Longvah T (2009) Mainstreaming the use of nutrient-rich underutilized plant food resources in diets can positively impact on family food and nutrition security—data from Northeast India and West Africa. *Acta Horticulturae* 806: 375–384. ISHS.

Smith IF (1982) Leafy vegetables as source of minerals in southern Nigerian diets. *Nutritional Reports International* 26: 679–688.

Smith IF, Eyzaguirre PB, Eyog-Matig O, Johns T (2006) Managing biodiversity for food and nutrition security in West Africa: building on indigenous knowledge for more sustainable livelihoods. *SCN News* 33: 22–26.

Smith RJ, Verissimo, Leader-Williams D et al. (2009) Let the locals lead. *Nature* 462: 280–281.

Tanton T, Haq N (2008) Climate change: an exciting challenge for new and underutilized crops. In: J Smartt and N Haq (eds) *New Crops and Uses: Their Role in a Rapidly Changing World*. Centre for Underutilized Crops, University of Southampton, Southampton, UK.

Thomas CD, Cameroon A, Green RE et al. (2004) Extinction risks from climate change. *Nature* 427: 145–148.

Tsegaye D, Balehegn M, Gebrehiwot K et al. (2007) The Role of *Dobera glabra* for Household Food Security at Times of Food Shortage in Abaàla Wereda, North Afar: Ecological Adaptation and Socio-economic Value. A Study from Ethiopia. Dry lands Coordination Group, Miljøhuset G9, Norway.

UNEP/CBD/LG-GSPC/3/4 2009. Report of the third meeting of the Liaison Group on the Global Strategy for plant conservation. May 26–28, 2009. Dublin, Ireland. Available from: http://www.cbd.int/doc/?meeting=GSPCLG-03. Accessed December 10, 2009.

van Zonneveld MJ, Jarvis A, Dvorak et al. 2009. Validation of climate change impact predictions on Mexican and Central American pine species. *Forest Ecology and Management* 257(7): 1566–1576.

Veteläinen M, Negri V, Maxted N (2009) European landraces: on-farm conservation, management and use. Bioversity technical bulletin no. 15. Bioversity International, Maccarese (RM), Italy.

Yang RY, Hanson PM, Lumpkin TA (2007) Better health through horticulture—the wild vegetable center's approach to improved nutrition for the poor. The world vegetable center. *Acta Horticulturae* 744: 71–78.

Weinberger K, Swai I (2006) Consumption of traditional vegetables in central and North-Eastern Tanzania. *Ecology of Food and Nutrition* 45: 87–103.

WRI (2005) World Resources 2005 – The Wealth of the Poor: Managing Ecosystems to Fight Poverty. United Nations Development Programme, United Nations Environment Programme, The World Bank, World Resources Institute. Available from: http://www.wri.org/publication/world-resources-2005-wealth-poor-managing-ecosystems-fight-poverty. Accessed December 10, 2009.