Open access • Journal Article • DOI:10.1007/S13593-013-0147-8

Agrobiodiversity for food security, health and income — Source link

Rémi Kahane, Toby Hodgkin, H. Jaenicke, Coosje Hoogendoorn ...+5 more authors

Institutions: Bioversity International, International Network for Bamboo and Rattan, World Vegetable Center, Agriculture and Agri-Food Canada

Published on: 18 Apr 2013 - Agronomy for Sustainable Development (Springer Paris)

Topics: Food security, Food systems, Sustainability, Agricultural productivity and Agriculture

Agrobiodiversity for food security, health and income

Rémi Kahane, Toby Hodgkin, Hannah Jaenicke, Coosje Hoogendoorn, Michael Hermann, J. (dyno) Keatinge, Jacqueline D'arros Hughes, Stefano Padulosi, Norman Looney

Agron. Sustain. Dev. (2013) 33:671–693
DOI 10.1007/s13593-013-0147-8

REVIEW ARTICLE

Agrobiodiversity for food security, health and income

Rémi Kahane · Toby Hodgkin · Hannah Jaenicke · Coosje Hoogendoorn · Michael Hermann · J. D. H. (Dyno) Keatinge · Jacqueline d'Arros Hughes · Stefano Padulosi · Norman Looney

Accepted: 22 March 2013 / Published online: 18 April 2013

Abstract By the year 2050, agriculture will have to provide the food and nutrition requirements of some 9 billion people. Moreover, to maintain that level of productivity indefinitely it must do so using environmentally sustainable production systems. This task will be profoundly complicated by the effects of climate change, increasing competition for water resources and loss of productive lands. Agricultural production methods will also need to recognize and accommodate ongoing rural to urban migration and address a host of economic, ecological and social concerns about the 'high inputs/high outputs' model of present-day industrial agriculture. At the same time, there is a need to confront the unacceptable levels of continuing food and nutrition insecurity, greatest in the emerging economy countries of Africa and Asia where poverty, rapid population growth and climate change present additional challenges and where agriculture is practiced primarily by small-scale farmers. Within this context, we here review science-based evidence arguing that diversification with greater use of highly valuable but presently undervalorised crops and species should be an essential element of any model for sustainable smallholder agriculture. The major points of these development opportunity crops are presented in four sections: agricultural farming systems, health and nutrition, environmental sustainability and prosperity of the populations. For each section, these crops and their associated indigenous knowledge are reported to bring benefits and services when integrated with food systems. In this paper, we conclude that not only a change in policy is needed to influence behaviours and practices but also strong leadership able to synergize the various initiatives and implement an action plan.

Dedicated to the memory of Dr Lois Englberger, 1949–2011, a champion of local foods for better nutrition

R. Kahane (✉)
c/o FAO-AGPM, GlobalHort, Via delle Terme di Caracalla,
00153 Rome, Italy
e-mail: rkahane@globalhort.org

R. Kahane
UR Hortsys, CIRAD, 34398 Montpellier, France
e-mail: remi.kahane@cirad.fr

T. Hodgkin
Platform for Agrobiodiversity Research, c/o Bioversity International, via dei Tre Denari 472a,
00057 Maccarese, Italy

H. Jaenicke
Burghof 26,
53501 Grafschaft, Germany

C. Hoogendoorn
INBAR–International Network for Bamboo and Rattan,
PO Box 100-102-86, Beijing, China

M. Hermann
Crops for the Future, Serdang, Malaysia

J. D. H. (Dyno) Keatinge · J. d'Arros Hughes
AVRDC–The World Vegetable Center, Shanhua,
Tainan, Taiwan

S. Padulosi
Bioversity International, via dei Tre Denari 472a,
00057 Maccarese, Italy

N. Looney
Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Summerland, BC V0H 1Z0, Canada

Keywords Environmental services · Family farming system · Neglected and underutilized species · Development opportunity crops · Secondary crops

Contents

1 Introduction

By the year 2050, the world population is projected to reach over 9 billion. In a world where more than 900 million (some 16 % of the world population) are already malnourished, this continuing growth presents a major challenge to achieving food and nutrition security. Meeting the needs of this increasing population, overcoming shortfalls in food production, and ensuring that available produce reaches people in need are major challenges to global agriculture (FAO 2010a). These challenges must be met in ways that are sustainable and ensure the availability of resources for future generations. At the same time, agriculture needs to confront the effects of climate change, increasing competition for water, loss of productive land and competition for available land, continued migration from rural to urban areas and the growing social concerns about the nature of the food production system.

In light of these multiple challenges to food security, achieving greater diversity within agricultural systems is increasingly recognized as an important pillar of sustainable development (IAASTD 2008; Royal Society 2009; FAO 2011b) and an outcome that will be difficult to achieve over the next 40 years (Pardey and Pingali 2010). Relying on only 82 crop species to provide 90 % of the energy consumed by humans (Prescott-Allen and Prescott-Allen 1990) is probably unwise, and certainly unnecessary given that the world has at least 12,650 edible plant species (Kunkel 1984) and about 7,000 species that have been used to a significant extent by humans at some point in time (Hammer 1998; Fig. 1).

Furthermore, agricultural production must embrace strategies beyond exploiting the 'Green Revolution' technologies of the last half-century based on genetic improvement and higher inputs. While these technologies increased yields of the key staple crops (rice, maize and wheat) needed to avoid widespread famines, the costs have included inappropriate and excessive use of agrochemicals, wasteful use of water in inappropriate and often unsustainable irrigation schemes, loss of beneficial biodiversity (pollinators, soil fauna, etc.) and significantly reduced crop and varietal diversity.

The focus of agricultural improvement on achieving caloric sufficiency has left many hundreds of millions of people still suffering from deficiencies in essential vitamins and micronutrients in their diet (FAO 2010a). The Food and Agriculture Organization of the United Nations (FAO) has calculated that in 1990 the global loss of productivity through hunger and malnutrition was 46 million person years (FAO 2001). The World Health Organization (WHO 2008) estimates that over 1.62 billion people—of whom 600 million are children—suffer from anaemia, caused in over half of the cases by deficiencies in essential minerals and micronutrients. While the introduction of fortified food products and increased consumption of fish and animal products have proved effective means of addressing some nutrient deficiencies, these products are often out of reach for the poorest in society. Alternative strategies based on diverse local food crops can provide a valuable and sustainable complement to other means of tackling malnutrition (Frison et al. 2011; Keatinge et al. 2011).

Many small-scale farmers still make extensive use of the plant diversity present in their surroundings. They depend on the provisioning, regulating, supporting and cultural ecosystem services that biodiversity brings (Millennium Ecosystem Assessment 2005) as part of their livelihood strategies. This includes use for home consumption, as dietary sources during crises, provision of medicines, providing additional sources of income through e.g. road side and local market sales, and in landscape management. However, these traditional plants, crops and crop varieties and their use have often been the victims of progress. They are deemed to be old fashioned and unattractive in comparison to modern, exportable crops produced in much simpler (and potentially more vulnerable) production systems. All too often, such valuable genetic resources can be lost before they can be fully characterized and effectively used (Bhag Mal 2007; Jaenicke 2009).

The harvest failures and other factors that led to the dramatic rice and wheat price increases in 2008 revealed the continuing fragility of the agriculture and food economy in many developing countries. Providing *long-term* food and nutritional security should be an objective with the highest priority. This can be achieved with an enhanced local productivity and yield stability strategy that fully embraces the benefits of both between- and within-crop diversification. While the bulk of the calories in the global diet will continue to come from a limited (but preferably increasing) number of staple

Fig. 1 Tropical fruit diversity in Costa Rica promoted at the International Center for Tropical Agriculture (CIAT) in a research program closed at the end of 2012 (Photo courtesy of Alonso Gonzalez)

grains and oilseeds, other food sources—which range from minor grains and pulses, root and tuber crops and fruits and vegetables to non-timber forest products—should be used to a much larger extent to provide a balanced diet, protection from internal and external market disruptions, better ecosystem function, and hence sustainability (Keatinge et al. 2010). Enhancing diversity through the use of these alternative food and forage crops will not only diversify agro-ecosystems and rotations, it is also likely to improve adaptability to extreme climatic conditions, provide resilience to biotic and abiotic stresses and produce harvestable yields where major crops may fail (Padulosi et al. 2002).

This paper argues that these neglected and under-valorised crops and species, what we prefer to call development opportunity crops (DOCs), have great untapped potential to support smallholder farmers and rural communities by improving their incomes and food and nutritional security while also sustaining the genetic resources needed to address present and future environmental challenges. Through selected examples and analyses, we illustrate the ways in which these crops are benefiting smallholder farmers and the potential that exists for them to play a greater role in future agricultural development. The following sections provide evidence of the benefits of increasing agrobiodiversity through the use of these DOCs and the potential that exists in four key realms for international development: food security, human health, environmental sustainability and economic prosperity. The strong desire for collaborative and coordinated action in and across regions to achieve development impact at scale and the steps taken to achieve this are also described.

2 Capitalizing on agrobiodiversity to improve food security

Numerous papers in the past two decades have highlighted the role of agrobiodiversity within the context of sustainable production (e.g. Cleveland et al. 1994; Thrupp 1998; Altieri 2002; Bhag Mal 1994, 2007; FAO/PAR 2010), providing enhanced nutrition (Beaglehole and Yach 2003; Yenagi et al. 2010), environmental benefits (Perrings et al. 2006; Jackson et al. 2007), improved livelihoods of small-scale farmers (Keatinge et al. 2009; Jackson et al. 2010) and increased resilience to climate change (Padulosi et al. 2011; Ortiz 2011a; Guarino and Lobell 2011). Diversification of crops and crop varieties plays an essential part in delivering the benefits of agrobiodiversity. However, research and development funding for agriculture—in itself already being only a fraction of overall research and development spending (Pardey and Pingali 2010)—is largely targeting the already well-researched world staple crops and cereal-based cropping systems (Ortiz 2011b). Whilst the 1990s and early 2000s saw a relative increase in attention to crop diversification and sustaining agrobiodiversity, one of the results of the 2008 food crises was a call for greater focus on the key staple crops (Renkow and Byerlee 2010; Lenné and Wood 2011). Even if valid in the short term, such an emphasis is likely to be dangerous to long-term food security and stability (Pardey and Pingali 2010) and risks limiting the capacity of agriculture to respond to increased climate variability, social insecurity, urbanisation, land use and ownership changes and resource (esp. water and soil) degradation.

"*Agricultural development and biodiversity conservation are sometimes perceived as opposing interests. But in many cases, such conflicts do not exist and they are certainly not inevitable. In fact, evidence shows that integrating biodiversity and agriculture is beneficial for food production, ecosystem health, and for economically and ecologically sustainable growth*" (Thrupp 1998). Better utilization of local and often only locally known plant species in diversified cropping systems can be an important first step toward secure food provision in times of uncertainty. It is also likely to contribute to the resilience of rural communities and to 'sustainagility'—the capability for dynamic and intelligent responses to future unpredictable events (van Noordwijk 2010; Jackson et al. 2010). Such local crops are directly consumed as staple foods, can provide valuable nutrients as part of a healthier diet, are sometimes also used as fodder and thus can be converted into meat, milk or eggs, and can be processed into other products and sold to increase income and thus provide greater flexibility to producers and consumers (Yenagi et al. 2010; Padulosi 2011). These crops are also important components of diversified cropping systems where they help spread the risks inherent in agricultural production. While the value of the DOCs is often accrued at local, traditional and small-scale enterprise, and thus constitutes a sensible insurance or provision (future option value), it is in practice usually difficult if not impossible to value this in classic economic terms (Jaenicke 2009).

The approach of the Green Revolution, successful in Asia and Latin America but much less so in Africa, focussed on increased production of maize, wheat and rice in favoured environments such as India's Punjab. The production increase was attributable to higher yields coming from the deployment of new varieties with more efficient light interception and higher harvest indices combined with a substantial increase in the use of external inputs—water, fertilizers and pesticides. As noted above, this increased production was associated with a number of negative environmental and social effects (Matson et al. 1997). While food production kept pace with rising populations and many areas in Asia and Latin America benefitted significantly, the overall numbers of malnourished people in the world remained stubbornly high reflecting the fact that food security depends not only on production but also on the accessibility and availability of food to the rural and urban poor (De Bon et al. 2009; FAO 2011a).

The Green Revolution provided lessons on the need to develop rather different approaches in more diverse and less favoured agricultural environments (Holt-Gimenez et al. 2006). Thus sub-Saharan Africa, which benefitted little from Green Revolution technologies, contains a great heterogeneity of agro-ecosystems with abrupt changes over small distances and almost all agriculture is rain-fed (Parr et al. 1990). While the Green Revolution showed how much progress could be made in improving plant productivity and how improving plant type can boost area productivity, the focus on a few crops led to the neglect of a large number of others that are likely to be needed in marginal and more heterogeneous environments (Altieri 2002; FAO 2011b).

External drivers, such as world financial markets and the use of agricultural land for biofuel production, have become powerful determinants of food commodity prices. In turn, the unrest in several Asian and African countries in 2008 was believed to be directly linked to rising staple food prices. The drivers for the food price increases in the period up to 2008 were a complex mix of increased demand, poor harvests—through a combination of climatic effects and reduced produce available due to increased land use for biofuel production—export bans, high energy prices and speculation on the commodity markets. It is to be expected that these determinants and issues will persist and even increase in importance in coming years (McKay 2009). There will be an increasing need to develop approaches that can improve market stability in the face of continuing or even increasingly fluctuating production and other related shocks affecting dramatically the livelihood of millions of people.

With the demand for food certain to increase over the next 40 years and with nearly all the agriculturally suitable land under cultivation, sustainable intensification of crop production on the current land base is the only practical solution. While further conversion of forests and other wilderness areas into agricultural lands can contribute to the required increase in food production, this approach risks damaging the earth's ecosystems and biodiversity beyond repair (Royal Society 2009; Rockström et al. 2009).

One key component of sustainable intensification will be improving yields through plant breeding using both conventional and molecular approaches; a number of lines of evidence suggest that this is eminently possible. Unfortunately, few underutilized crops have yet to benefit from sustained breeding efforts at the scale required to make significant advances. However, they are often related to crops that *have* been the subject of intense molecular genetics research and can therefore benefit from second-generation molecular approaches. There are also important genetic resources present in the traditional varieties and wild relatives of many DOCs available for use in crop breeding programmes. These crops also represent a pool of resiliency ready to be deployed in areas where other commodity crops cannot grow, a valuable resource when there is hardly any additional land left that is suitable for highly mechanized and high input agriculture.

The complexity of the issue demands more than just one approach. The International Assessment of Agricultural Knowledge, Science and Technology for Development put forward a new agricultural framework which incorporates adaptation and mitigation measures that seek to further address problems like water deficiencies or excesses, poor soil fertility and increasing salt levels, and crop intolerances to wind and high temperature. Given the uncertainty about the possible effects of climate change, this assessment suggested embedding agriculture into an "ecosystem approach" (IAASTD 2008). Within such an approach, techniques such as participatory variety selection (Witcombe et al. 1996) and client-oriented breeding (Witcombe et al. 2005) would be ideally suited to DOCs for farmers in marginal areas. These have already been used with success in, for example, Horse gram (*Macrotyloma uniflorum*) (Virk et al. 2006), rapidly identifying varieties that are adapted to local environments and possess farmer-preferred traits. Tester and Langridge (2010) note the increased use of crop wild relatives and landraces in staple crop breeding, and state that "developing countries critically need support for the development of crops, for which there has been little interest from the developed world and, consequently, little investment". In many areas, these crops are already of critical importance for achieving food security.

A large number of studies and field experiments have also been reported describing the agronomic value of mixed cropping, crop rotation, or intercropping using minor crops. In such cropping systems, legumes are most generally used to improve soil nutrition or break disease cycles (Schulz et al. 2001). These systems provide openings for alternative crops that might also improve the diet and health of the farmer, generate income and create value-added opportunities. Traditional and diverse farming systems have also attracted interest for the environmental services offered such as weed or pest and disease management (Altieri 2004).

Many crops have been identified where there is potential for achieving significant increases in productivity and thus

Fig. 2 Mrs. Adelaja, a champion custodian of quinoa, maintains 125 accessions in her farm in Puno, Peru. Hundreds of local varieties are underutilized as markets focus predominantly on Quinoa Real types (Photograph: 2009, Stefano Padulosi)

improvements in food security at local and regional levels. These include cereals such as tef (*Eragrostis tef*) and fonio (*Digitaria exilis*); non-cereal grains such as amaranth (*Amaranthus caudatus*), quinoa (*Chenopodium quinoa*; Fig. 2) and the 'minor millets' (*Eleusine coracana*, *Setaria italica*, *Paspalum scrobiculatum*, *Panicum miliaceum*, *Panicum sumatrense*, *Echinocha utilis*); pulses such as lentils (*Lens culinaris*) or the different *Vigna* species (e.g. mungbean (*Vigna radiata*), adzuki bean (*Vigna angularis*) and ricebean (*Vigna umbellata*)); oilseeds such as noug (*Guizotia abyssinica*); roots and tubers such as cassava, yams (*Dioscorea* spp.), yacon (*Smallanthus sonchifolius*) or ulluco (*Ullucus tuberosus*); fruits such as breadfruit (*Artocarpus altilis*), plantain and cooking bananas, baobab (*Adansonia digitata*) or jujube (*Ziziphus mauritiana*); various edible seeds such as Bambara groundnut (*Vigna subterranea*) or Malabar chestnut (*Pachira aquatica*); and vegetables such as African eggplant (*Solanum aethiopicum*), leaf amaranth (*Amaranthus* spp.), the greens from *Brassica rapa* varieties or the sprouts of various seeds (wild mustard, mung bean, etc.; see Chadha et al. 2007).

The potential for gains in the production of a wider range of crops is illustrated in South Asia. In this region, the production of most of the important groups of food plants, except pulses, has increased at a comparable or even higher rate during the past 40 years to that of the three key staple crops. However, except in the case of root and tuber crops, increases in productivity have in most cases been substantially below that achieved for cereals. The increased production reported largely reflected increases in the area devoted to these crops (Table 1).

The importance of local food production has also been highlighted by the UN Standing Committee for Nutrition in its sixth report on world nutrition (UNSCN 2010). In Africa, where the topography calls for more localised approaches, local food crops still play a relatively large role in many societies and 'wild' or marginally developed plant species

Table 1 Changes over time in area, yield and production by type of food crop in South Asia in early 1960s and early twenty-first century from FAO data

Group	Aggregate 40-year change (% over 1960)		
	Area	Yield	Production
Cereals	10.0	143.8	168.2
Pulses	−8.1	19.6	10.0
Oilseeds	40.9	75.5	148.1
Vegetables and melons	129.8	76.0	303.7
Fruits	128.5	45.4	232.4
Roots and tubers	129.3	146.4	464.4
Nuts	254.1	26.0	346.2

Countries included are Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka (from Jat et al. 2006)

contribute significantly to food security and nutrition. Grivetti and Ogle (2000) mention up to 800 plant species used in the Sahel region, while Bharucha and Pretty (2010), studying wild food systems (including fish and animal sources) of indigenous communities, report an average of 120 wild species per community in both industrialized and developing countries. These numbers indicate the continuing importance of local crops and species. Crop and dietary diversity has been closely linked to food security in Bangladesh, Egypt, Ghana, India, Kenya, Malawi, Mali, Mexico, Mozambique and the Philippines (Hoddinott and Yohannes 2002) where the authors report that a 1 % increase in dietary diversity was linked to a 0.65 to 1.11 % increase in household per capita consumption, a 0.37 to 0.73 % increase in household per capita caloric availability, a 0.31 to 0.76 % increase in caloric availability from staples and a 1.17 to 1.57 % increase in caloric availability from non-staples.

Minor crops and species, many indigenous to the region, have provided enhanced food security during periods of stress and following disasters and other emergencies. Examples include recovery after a drought in Papua New Guinea (Mogina 1999) and Kenya (Simitu et al. 2009) and recovery after the 2004 tsunami in Sri Lanka (Harvey 2006). Traditional varieties of local crops are also important to food security during war and civil strife (Richards and Ruivenkamp 1997).

3 Diet diversification to improve nutrition and health

Large parts of the world's population, especially in South Asia and Sub-Saharan Africa, suffer from nutrient deficiencies, often termed 'hidden hunger' because the affected people receive enough calories but have an insufficient intake of vitamins and minerals. Of the world's estimated 7 billion people, half a billion still suffer from protein-energy malnutrition but over 1.6 billion suffer from iron deficiency, over 200 million from vitamin A insufficiency (WHO 2008, 2009), and it has been estimated that over 400,000 children die each year from the effects directly related to zinc deficiency (Megha Das and Ratnesh Das 2012).

It is widely accepted (see Desjardins 2007) that increased consumption of fruits and vegetables can positively influence nutrition status and thus increase human productivity. However, fruit and vegetables are difficult to find and afford for many people in developing countries (Ruel et al. 2005), and many of the locally available fruit and vegetable species have not yet been adequately researched, marketed or improved by plant breeding. Furthermore, many traditional and locally adapted food crops with high nutritive value are slowly but surely disappearing. For example, local grain crops with a proven high mineral content, such as *Digitaria exilis* (fonio) or *Panicum miliaceum* (proso millet), are not effectively marketed and are being replaced by modern high-yielding crops such as maize and wheat (Adoukonou-Sagbadja et al. 2006). Increased mechanisation and market demands lead farmers to concentrate on fewer and fewer crops. The result is a steady loss of biodiversity (Smale et al. 2009) often associated with a loss of traditional knowledge (Padulosi et al. 2002).

The neo-tropical peach palm (*Bactris gasipaes*) is an example of a DOC that combines nutritional excellence with robustness. In conditions of poor soil fertility and excessive rainfall, this species can yield large amounts of starchy fruits, which have notable concentrations of protein, mono-unsaturated oleic acids, carotenoids, vitamin E and potassium (Graefe et al. 2012). Furthermore, in pure stands or as an agroforestry species, peach palm has significant potential to serve as a carbon sink owing to the species' abundant biomass production (Schroth et al. 2002). Traditionally grown by Amazonian Amerindians for subsistence and as animal feed, cooked peach palm fruits have for many years also been available as a street food in Colombia (see Fig. 3). Although there is no international demand for the fruits or its derivatives (Graefe et al. 2012), peach palm which grows fast and has the ability to form basal offshoots has become a significant source for palm hearts in Brazil, Costa Roca and other countries (Mora-Urpí et al. 1997), vastly exceeding the market value of the fruits.

Fig. 3 Cooked fruits of peach palm (*Bactris gasipaes*) on sale at the airport of Cali, Colombia (Photograph: 2004, Michael Hermann)

Numerous reports have provided evidence of the nutritional benefits of a diversified diet including fruits and vegetables, epitomized by the WHO's "Five-a-Day" campaign to indicate the desired daily intake of approximately 400 g of fruits and vegetables for a healthy diet (Block et al. 1992; Van't Veer et al. 1999). Whilst originally focussing on the populations of the developed world, this message is now repeated in the developing countries, for two reasons:

1. The incidence of "Western style" non-communicable diseases has been rising significantly in developing countries due to a dietary transition (Drewnowski and Popkin 1997; Popkin 2003);
2. Despite an increasingly improved supply of nutrient-dense staple crops at a global level, malnutrition-related mineral and vitamin insufficiencies are still widespread amongst large parts of the population in developing countries (Table 2, Gopalan 1996).

Two interrelated strategies emerge; the first is to promote a general increase in fruit and vegetable consumption; the second is to promote an intelligent diversification of the diet (Keatinge et al. 2010; Lutaladio et al. 2010). Indeed, a recent publication claiming that a biodiversity rich environment is not directly correlated to a better diet (Termote et al. 2012) highlights the role of awareness raising and nutritional education for alerting populations about the benefits that come from agrobiodiversity and the increased use of nutrient-rich crops. The potential synergy between these strategies needs to be directly addressed by both scientists and policy makers (Toledo and Burlingame 2006).

An important element in the use of agrobiodiversity and DOCs in particular to address micronutrient/vitamin deficiency will be the availability and use of local products (see Fig. 4). The crops themselves may not always be of local origin. Local availability may be more important than the historic geographical origin of a crop, although this latter aspect can play an important role as a cultural value as exemplified by the 'Go Local' campaign in Micronesia (e.g. Englberger and Lorens 2009). A practical approach is needed that recognizes the values inherent in the diversity of these plants. Many DOCs possess high genetic variability, and there is great potential for exploring this and comparing local and exotic crops in ways that include ranges of cultivars or landraces rather than just averages or a limited number of random selections (Bioversity International 2011).

Consuming fruits and vegetables has different status across cultures. In Southeast Asian diets, green vegetables and fresh fruits play a rather prominent role, whereas this is less so in most African countries where fruits are often considered 'for the women and children' only (Ruel et al. 2005; Bharucha and Pretty 2010). Whilst it is accepted that women and children are the most vulnerable groups, micronutrient deficiencies are

Table 2 Key nutrient deficiencies (Sources: FAO 2001; WHO 2008, 2009; UNSCN 2010; ACC/SCN 1997)

Vitamin/mineral/nutrient	Symptoms of severe deficiency	Number of people suffering deficiency worldwide	Crops that can contribute to alleviate deficiency	Issues
Iron	Weak immune system, impaired mental development	1,600 million	Green leafy vegetables, pulses, small grains and pseudo grains	Bioavailability low from a number of green leafy vegetables due to interaction with phytates and tannins
Protein-energy	Weak immune system, stunting	500 million	Nuts, pulses, soy, algae	
Vitamin A/pro-vitamin A carotenoids	Vision impairment	100–140 million	Yellow and orange fleshed fruits; green leafy vegetables	Bioavailability low from a number of green leafy vegetables due to interaction with phytates
Vitamin C	Weak immune system		Fresh fruits	Needs to be consumed frequently as body doesn't build up a store
Zinc	Weak immune system, stunting	1/3 of world population lives in high-risk areas	Mostly animal sources; but also some protein-rich grains, especially pulses, sesame, pumpkin, nuts, some wheat varieties	Bioavailability low from most staple grains; phytate can reduce bioavailability
Vitamin B complex	Neurological disorders, weak immune system	Highly prevalent where diets are low in animal products, fruits and vegetables, and where cereals are milled prior to consumption	Pulses, green leafy vegetables, unprocessed cereal grains	Needs to be consumed frequently as body doesn't build up a store. Vitamin B12 does not occur in plant-based foods

also widespread amongst the male population. It is therefore important to stimulate consumption, based on factual information about the health and nutrition benefits of local crops (Robson 1976). This is an area where substantial further research is needed for many DOCs.

Despite the above caveats, a number of studies have shown the importance of locally available indigenous or traditional fruits, vegetables, grains, and roots and tubers to nutrition and health of rural and indigenous communities (Grivetti and Ogle 2000; Flyman and Afolayan 2006; van Rensburg et al. 2004;

Fig. 4 Rural children in the Peruvian Amazon gathering fruits of a wild *Physalis* species (Photograph: 2005, Michael Hermann)

Bharucha and Pretty 2010). Studies abound that report analyses of the nutrient content of locally important plant species. They can be found for nearly every country, for example Botswana (Legwaila et al. 2011) on a range of traditional food plants, India on bitter gourd in connection with mildew resistance (Yadav et al. 2009) and on minor millets (Yenagi et al. 2010), Micronesia (Englberger et al. 2006, 2008) on local bananas and swamp taro, respectively, Nigeria on medicinal plants (Ekpa 1996), leafy vegetables (Aletor et al. 2002) and amaranth (Akubugwo et al. 2007), Papua New Guinea on the mineral composition of a range of locally available plants (Hongo et al. 1989), South Africa (Flyman and Afolayan 2006; Odhav et al. 2007) on wild and leafy vegetables, respectively, Tanzania on iron, zinc and β-carotene content of indigenous vegetables (Msuya et al. 2009) and Zimbabwe on amaranth (Makobo et al. 2010).

On the other hand, relatively little information is available about possible anti-nutritional factors or detrimental nutrient interactions which could inhibit the bio-availability of nutrients (ACC/SCN 1997; Sandberg 2002; Gupta et al. 2005; Gibson et al. 2010). In the case of pulse crops, the content of anti-nutrients such as phytic acid, trypsin inhibitor and tannins is relatively well documented (Akroyd and Doughty 1982), and a range of toxic substances such as cyanogenic glycosides and lectins, in addition to flatulence producing substances, have been described. However, studies on varietal variation in content of undesired components, as a basis for breeding programmes, are often lacking.

Realizing the nutritional and health benefits of DOCs will require an integrated approach that goes beyond simple analyses of nutritional content as a basis for their possible promotion. This has been shown to be possible and to deliver benefits. Thus, AVRDC–The World Vegetable Centre has worked on vegetables such as amaranth, African eggplant and a few other African indigenous vegetables (Weinberger and Msuya 2004), mungbean (Chadha 2010) and Asian green vegetables (Hughes 2009), combining genetics and germplasm collection, cropping systems with a focus on soil fertility and water management, and nutrition also related to socio-economics (Keatinge et al. 2011). A successful taro project has been spearheaded by the Papua New Guinea National Agricultural Research Institute (Yalu et al. 2009), the DADOBAT project (Domestication and development of baobab and tamarind: http://www.dadobat.soton.ac.uk/English/flash/default.aspx) is spearheading work on *Adansonia digitata* and *Tamarindus indica*, and the FOSRIN project (Food security through ricebean research in India and Nepal: http://www.ricebean.org) pioneered a holistic approach in ricebean (Khanal et al. 2007; Hollington et al. 2010).

The relationships between and among crop diversity, dietary diversity, nutrition and health remain complex and have been the subject of many, apparently often conflicting studies (see for example studies by Englberger et al. 2009; Keding 2010; Hatløy et al. 2000; de Pee and West 1996). However, the benefits of increasing consumption of fruit and vegetables continue to be favoured. As a recent report from the British Royal Society stated, "The preferred strategy to eliminate hidden hunger will always involve strategies to increase the diversity of diet with increased access to fruit and vegetables" (Royal Society 2009). DOCs, especially those which are locally available and culturally acceptable, would seem to be ideally placed to play a much greater role in contributing to improved nutrition and health.

4 Environmental services and resilience of farming systems

The erosion of agricultural genetic diversity across farmlands throughout the world and accompanying loss of resilience to climatic, economic or societal extreme events has been the topic of numerous publications and debates over several decades. There are a number of cases where lack of within crop diversity has resulted in substantial production losses such as maize in the USA (leaf blight sensitivity of hybrids due to the unique Texas cytoplasmic male sterility gene in the 1970s), taro in Samoa (leaf blight fungus damaged all taro crops in 1993, Lebot et al. 2001) and coffee in Sri Lanka (due to rust fungus in 1875). There is clearly a need to have production systems that maintain both within and between crop diversity, although the form that this should take and the scale where diversity is most important are subjects of debate (see e.g. Harlan 1975; Wood and Lenné 1999; Frison et al. 2011; Lenné and Wood 2011).

Mono-cropping systems are widely used in industrialised countries to increase productivity and consolidation of farms into ever larger holdings facilitates mechanization and reduces labour costs (Azam-Ali 2003). This strategy requires relatively uniform soil types, stable markets and policy support through subsidies and insurance against crop loss. Breeding and selection have led to uniformity of plant type, irrespective of species, towards a modern 'ideotype' which includes common characteristics such as semi-dwarf, restricted branching, short duration, angular leaved and high harvest index varieties (Donald 1968; Azam-Ali and Squire 2002). It is becoming increasingly apparent that this uniformity at intra- and inter-specific levels may actually weaken agro-ecosystem resilience because it makes the systems more susceptible to external shocks (pest and disease outbreaks, droughts, etc.). In pure mono-cropping systems, intensive external inputs are commonly used to counterbalance this weakness (Frison et al. 2011). In small-scale farming (as well as in more intensive) systems, integrated land management, the existence of complex mosaics and the use of multiple crop livestock and variety management strategies may lead to the maintenance of high levels of agrobiodiversity despite the replacement of landraces with modern varieties (Steele et al. 2009; FAO 2010b).

Agrobiodiversity contributes to provisioning, regulating and supporting cultural ecosystem services (Millennium Ecosystem Assessment 2005), and in many developing countries, small-scale farmers use diversity as an integral part of their livelihood strategies. Jarvis et al. (2011) reviewed the evidence on the use of within crop diversity and list adaptation to marginal ecosystems and heterogeneous environments, insurance against environmental and other risks, pest and disease management, yield stability, socio-economic factors such as labour availability and income generation as reasons for the maintenance of high levels of traditional varietal diversity.

Complex agroecosystems exhibit great variation in times of crop maturity, resource capture and resistance to external influences, especially where they contain underutilised and under-researched species (Perrings et al. 2006). They are difficult to manage, mechanize and manipulate, and the performance of the constituent species is difficult to predict. Despite this, they often continue to be favoured by farmers for the reasons noted above for varietal diversity. Where farmers have been able to counter negative external influences by choosing the best locations (soils and climates) and/or adding inputs to more favoured crops, crop yield has usually taken precedence and negative consequences (reduced system resilience) have been able to be ignored. This is especially true where national economic policies create artificial pricing which does not include the negative externalities of damage to the environment and loss of diversity for future use. The dominant priority has been the harvesting of specific crop products (usually grain) rather than production of overall biomass. In many industrialized countries, by-products such as straw have been viewed as an inconvenience rather than a useful resource. Given their managerial difficulties, and the limited published evidence on the economic benefits of complex agroecosystems (Wojtkowski 2008), it is not surprising that the economic, management and research support for monoculture systems remains strong.

Nonetheless, recognition of the need to maintain ecosystem services and increase resilience in agro-ecosystems is now encouraging a reconsideration of complex systems and what they have to offer (Perrings et al. 2006). Jackson et al. (2010) provide an overview of the interrelationship of agrobiodiversity and improved resilience and argue that recognition should be given to the importance of what they describe as the "sustainagility" of an ecosystem. The key to developing such an agile, flexible system is to build and maintain assets that keep multiple options open for responding to unknown future influences. However, the quantitative examination and improvement of complex systems is daunting because field experiments are more difficult to construct, analyse and interpret on complex agroecosystems than on monocultures. A few studies on more or less complex mixed cropping systems have been conducted, and several are described in Wojtkowski (2008).

While evidence of benefits from within and between crop diversity is substantial (Jarvis et al. 2011; Frison et al. 2011), there is much less clarity about the form this diversity should take and the ways in which the optimum benefits can be achieved. For example, the economic benefits of genetic diversity were studied by Smale et al. (1998) who found that genealogical distance and increased number of varieties are associated with higher mean yield of wheat in the Punjab, but just how much diversity is desirable is less clear. Di Falco and Perrings (2005) found a positive relationship between interspecific crop biodiversity and agricultural production in a case study on cereal production in southern Italy. Importantly, these studies did not consider 'resilience' as one of the side effects of increased agro-biodiversity. A later study by Di Falco and Chavas (2008) considered the dynamic effects of changing external events (in this case, rainfall) and crop biodiversity on productivity. The authors could show that increasing biodiversity by 3 % allowed a rain-fed system to recover beyond the original yield within 3–4 years of the rainfall decline. Other important analyses of the economic and social benefits of within crop diversity include those by Smale (2006) and Brush and Meng (1996).

Overall resilience and ecosystem functionality is also favoured by agricultural practices based on the use of an increased number of crops and the strategic use DOCs. Kumaraswamy (2012) has argued that the farm needs to be seen as an ecologically sustainable unit, and De Schutter (2010) has reviewed recent evidence to argue the importance of agroecological approaches and of ensuring improved availability of a much wider range of agrobiodiversity as part of ensuring food security through more resilient agroecosystems.

Analyses of the mutual benefits of crop and associated non-crop biodiversity have also been undertaken, but to a more limited extent. Looking into the effects of increased management and crop yield on biodiversity levels of companion species in smallholder cocoa agroforestry settings in Indonesia, Clough et al. (2011) found that different types of species (trees, rats, birds, insects, fungi, etc.) were unaffected by the different management and yield levels, suggesting that moderate crop management and biodiversity conservation can be combined. Maikhuri et al. (1996) studied grain and by-product yield in traditional systems in the Central Himalaya and found that the yield efficiency between staple crops and traditional crops varied by season. Generally, traditional crops were more eco-efficient, had higher energy efficiency rates and a higher nutritive value than the staples.

It is often said that local crops are 'better adapted to climate change'. However, only a few research studies between local species and comparable improved crops seem to have been carried out to compare their resilience to various climatic extremes (drought, floods, peak temperatures, etc.) or gradual changes of environmental conditions. More often, we find comparisons between related subspecies of commercial crops, for example Condori et al. (2010) who compared native potato cultivars (*Solanum tuberosum* ssp. *andigenum*) with modern *S. tuberosum* in the Andes. Other studies have shown a relative ruggedness of unimproved species to climatic extremes, but these are often reported without comparable yield data. Padulosi et al. (2009) reported that minor millets in India having short biological cycle and an efficient root system have a comparative advantage for successful cultivation under scarce water/low rainfall conditions. Their ability to offer a modest yield under marginal/poor soils with low inputs has made them prominent in mountain, tribal and hill agriculture. This adaptive feature is more pronounced in barnyard millet (*Echinochloa colona* L.) which is the fastest growing, very early maturing and most resilient species among millets, providing food, feed and fodder under harsh growing conditions.

There is also evidence that agrobiodiversity rich approaches can provide adaptation to climate change. Under the '*Akdi*' system in some parts of Karnataka State, minor millets are mixed with maize, sorghum, chickpea, pigeon pea, lablab bean, mustard and niger (*Guizotia abyssinica*) to provide a buffer against the failure of major crops due to erratic rainfall, pests or diseases. A similar system called '*Barahnaja*' (literally, a dozen crops or grains) is still prevalent among the farmers in the Himalayan region in Uttarakhand State

(Padulosi et al. 2009). Diversity in traditional varieties of sorghum and pearl millet appears to have been an important component of survival strategies of poor farmers over the 20-year period of drought in Niger and Mali (from the mid-1980s). The total diversity was maintained, and plant materials became adapted to the changing environmental conditions with an increase in early maturing types.

For the improvement of minor crops and their increased use to provide resilience, the availability of genetic variability within the species will be essential. Such variability is often very high as these species have not been subject to plant breeding, except possibly for a few specific traits—this reinforces the importance of well-stocked and well-managed gene banks for a wide range of DOCs. An assessment of existing intra-specific variation is required, especially for wild or only partially domesticated species, in order to understand the width of environmental adaptation or production potential (in terms of nutrients or marketable characteristics) of the crop. This has been done for a few DOCs including *V. subterranea*, *Amaranthus* sp., *Abelmoschus* sp., *Xanthosoma* sp. and *Colocasia esculenta* in the context of breeding programmes (see IAEA 2004) and for some tree crops, where especially the groups around Roger Leakey have carried out extensive assessments of individual trees, e.g. for *Dacryodes edulis* (Waruhiu et al. 2004), *Irvingia gabonensis* (Leakey et al. 2005a), *Sclerocarya birrea* (Leakey et al. 2005b) and *Canarium indicum* (Leakey et al. 2008) with the aim of identifying preferred ideotypes for the selection and further propagation of high-yielding (for various traits) clones. Whilst these researchers assessed fruit tree accessions for their commercial suitability, for example on dietary oil content, similar within-species diversity can be expected in traits associated with suitability to soil or climate conditions. Comparisons with appropriate benchmark species however are largely missing; this is mainly due to the fact that few DOCs are represented in ex situ collections, and hence, such studies will be very hard to carry out (Padulosi et al. 2002). Padulosi et al. (2012) are convinced that the future of conservation of many DOCs and their associated indigenous knowledge lies within in situ or on farm conservation where adaptation to biotic and abiotic stresses in a continuous evolution is also ensured.

Forests and their biodiversity contribute to environmental resources, such as clean water and carbon sequestration. The use of non-timber forest products (NTFP) is often mentioned as a means to maintain forest biodiversity. NTFPs have been defined as encompassing 'all the biological material (other than industrial round wood and derived sawn timber, wood chips, wood-based panels and pulp) that may be extracted from natural ecosystems, managed plantations, etc., and be utilised within the household, be marketed, or have social, cultural or religious significance' (Wickens 1991). NTFPs are seen as contributing to poverty alleviation and income generation for forest margin communities. The role of NTFP in providing marginalised communities with supplementary food and nutrition from harvest of fruits, leafy vegetables, mushrooms, edible shoots like bamboo and rattan (and other products, such as bush meat) has been confirmed (Wollenberg and Belcher 2001; Sheil and Wunder 2002). However, whether forest biodiversity is being conserved through use of NTFPs is still under debate (Shanley et al. 2002; Marshall et al. 2003).

The realization of the full potential of DOCs for providing improved resilience and ecosystem services will require recognition of the economic value of these benefits to society at large as well as to farmers and rural communities. Investment in biodiversity—both natural and agricultural—can be enhanced through policy interventions and by providing incentives. Payment schemes for environmental services have been suggested, and various schemes have been tested, with generally positive though often localised results (see Engel et al. 2008; Wunder et al. 2008). More recently, payment for agrobiodiversity conservation services[1] is being tested by Bioversity International.

An important dilemma that will need to be confronted is exemplified by the finding of Baumgärtner and Quaas (2010). They looked into the effects of agri-environmental policies and insurances in such situations where risk-averse farmers invest in on-farm biodiversity and found that insurances can be detrimental to efforts to increase biodiversity. In other words, farmers chose either a financial insurance, or, in the absence of such a mechanism, chose to diversify their farming activities, in the process providing a public good, namely biodiversity.

DOCs have played an important role in improving pest and disease resistance. In the first instance, a number of such crops have provided useful resistance genes for more established crops. For example, ricebean (*V. umbellata*) has been found to be resistant to bruchid beetle (*Callosobruchus* spp.) which is a major pest of mung bean (*V. radiate*; Tomooka et al. 2000). Ricebean also carries genes for resistance to mung bean yellow mosaic virus, and has been successfully crossed with mung bean to introduce these genes (Singh et al. 2006).

However, they are also likely to be an increasingly important element in any strategy to limit damage by pests and diseases. Firstly, increasing crop diversification can reduce the frequency and severity of epidemics (Krupinsky et al. 2002; Ratnadass et al. 2011). Secondly, specific DOCs may be used in more complex disease control strategies. The International Center for Insect Physiology and Ecology has developed the concept of push–pull technology, or attractant-diversionary strategies, using minor crops or plant species to attract or repel a pest and decrease damage on a major crop (Herren and Löhr 2001). Applications to control cereal

[1] http://www.syngentafoundation.org/index.cfm?pageID=712

stemborers with Napier grass (*Pennisetum purpureum*) or Sudan grass (*Sorghum sudanense*) as trap crops together with a repellent crop like *Desmodium* spp. or *Melinus minutifolia* were found to be efficient in Kenya (Khan and Pickett 2004).

Of course, any newly introduced crop, despite its potential, may prove dangerous, and those involved in introducing non-indigenous species and crops will need to take the necessary precautions. Many plant species mentioned in the lists of potential DOCs are also on the lists of invasive species and as such can have a significant negative impact on rural livelihoods, albeit unintentionally. It is often stated that introduced crops do not bring their normal array of pests and diseases to their new environments and may be more resistant to local pests and diseases, thus forming a useful barrier resulting in increased system productivity (Lenné and Wood 2011). However, it is also possible that these new introductions can 'escape' and become invasive weeds that are difficult to control and can have extremely negative effects on rural people.

5 Source of income and risk management tools for smallholders

Poor and marginal farmers from East and South Asia depend on secondary crops (such as finger millet, green gram, Job's tears (*Coix lacryma-jobi* L.), lentils, mungbean, sesame, local soybean, sweet potato, yam, etc.) in particular as their main source of income as well as staple foods (Bourgeois 2006). Increased income to small-scale farmers and entrepreneurs is often quoted as one of the additional benefits of increased production of 'orphan' or 'underutilised' crops, specifically local fruits and vegetables (Chadha and Hasan Mndiga 2007; Hermann and Bernet 2009). Income generation is rarely the only benefit of increased utilization of such crops. Value addition can enhance food and nutritional security as well as income of the rural poor. In India, the ethnic millet *papad*, *chakli*, fermented breakfast food *paddu*, novel foods like biscuits, *laddu*, all prepared with minor millets proved to have a good scope for enhancing nutrition security and income generation of community members, particularly women (Yenagi et al. 2010). Value addition also proved to be a highly strategic intervention in popularizing nutritionally rich local crops which are currently largely neglected and underutilized. For example, the malt produced from little millet (*Panicum sumaterense*) has been found to be highly marketable (Bala Ravi et al. 2010). Little millet is the second best grain for malting after barley, and this malt is a traditional weaning food for children from 6 months age onwards in view of its high digestibility. This further processing of little millet enhanced the income of farmers threefold, generated additional employment in the villages, particularly for women, and enhanced their social status and self-esteem (Vijayalakshmi et al. 2010).

Development of markets or stimulation of demand at local, national and international level is a precondition for farmers to derive income from DOCs (Markelova et al. 2009). Demand-driven development interventions are more likely to be successful than attempts to push the supply alone. Giuliani (2007) assessed the emerging markets for six minor plant species in Syria, and Will (2008) collected and analysed eight further case studies for value chain development of neglected crops and their products. The rise of Kenyan supermarkets in the vegetable retailing system was reported to offer opportunities to small-scale farmers around cities (Reardon and Neven 2004). It becomes apparent that there are almost as many approaches as there are products. As far as indigenous vegetables are concerned, AVRDC considers them rather more undervalued than underutilized (Weinberger and Lumpkin 2007).

The gap between success (i.e. income generation, biodiversity conservation) and failure (i.e. market distortion, crowding-out of species) is narrow, and it is recommended that professional assistance is sought when developing value chains for new crops and their products. Whilst the potential for developing new markets may be large, Will (2008) suggested that this potential is often untapped for the following key reasons:

- Low competitiveness of actors along the entire value chain
- Limited knowledge of appropriate technology packages to promote the crops and their products
- Inappropriate rural development policies and programmes focussing on a limited number of commodities
- Widespread mistrust amongst value chain operators and between private and public stakeholders

In addition, there is a lack of reliable or stable sources of quality seed for many DOCs (Adebooye et al. 2005), although with sufficient training, particularly in marketing and managerial skills as well as in the technology of seed production, farmers' groups can successfully provide sustainable supplies of quality seed (Witcombe et al. 2010; Rojas et al. 2009).

Despite these constraints, there are important opportunities for markets for minor crops and their products to develop, for example by capitalizing on the development and growing wealth of the middle classes in many societies. These consumers are increasingly interested in sustainable, heritage and healthy or 'functional' food options (WBCSD 2008). There are also opportunities to find novel uses for plants, for example by exploiting particular traits that may not have been used so far. A case in point is edible canna (*Canna edulis*), quite an insignificant crop in its native Andean range because of demand and use limitations, particularly inconvenient use, and the competition from more attractive substitutes (Hermann et al. 1999). However, because of specific functional starch properties and its ability to yield well on marginal land, canna has replaced mungbean as the raw material for some transparent noodles in parts of Asia.

In a similar vein, the discovery of commercially relevant nutritional and health-promoting properties (Kang et al. 2011, Pacheco-Palencia et al. 2008) has been behind the rise of the Amazonian fruit acai (*Euterpe oleracea*) from a minor regional fruit to a fashion food on the booming market for 'nutraceuticals" (Brondizio 2004; Fig. 5). Brondizio et al. (2002) review the role of small producers in the recent expansion of acai production, the benefits that have accrued to local economies and the emergence of acai "as a symbol of cultural identity and regional pride for estuarine people" in Brazil as a consequence of this fruit's growing popularity in national and export markets.

The marketing of non-timber forest products (NTFP) received considerable attention during the 1990s as a possible means to alleviate poverty of forest margin or forest dwelling communities (for example see Leakey et al. 1996; Neumann and Hirsch 2000). Recent research has however shown that these claims may have been oversimplistic and that a chain of factors is necessary to arrive at economic success (Wollenberg and Belcher 2001; Marshall et al. 2003, 2006). Shanley et al. (2002), describing NTFP markets in the Brazilian Amazon, caution about overly optimistic plans to link forest dwellers to more profitable distant markets, primarily because many of the rural poor who are reliant on the extraction of NTFP have benefitted from little formal education, have scant market expertise and cannot afford to bear additional risk. Chronic transportation difficulties, perishable products, high variability in fruit and medicinal oil production and declining abundance of non-timber forest resources due to logging fire and overharvesting are a growing reality for many forest dwellers. More positively, Marshall et al. (2006) have identified 45 factors that contribute to successful commercialisation of NTFP in Bolivia.

Fig. 5 Small-scale processing unit of acai in a traditional market place of Belem, Pará, Brazil (Photograph: 2004, Decio Horita Yokota)

A key issue to be considered when aiming to develop markets for NTFP is that extraction of NTFP in many countries is illegal, mainly to stem poaching and the extraction of protected species. In Nepal, the collection of the 'Himalayan viagra' Yarsagumba (*Cordyceps sinensis*) was banned during the Maoist insurgency since its premium market value made it a major source of revenue for the guerrillas (Peter Andersen, personal communication). Close collaboration with the authorities is therefore necessary to develop mutually beneficial legal frameworks. Because the majority of NTFP have relatively low cash values and are used by communities for consumption rather than for sale, their more fundamental development value is to serve as important safety nets by providing food, dietary supplements or income in times of shortage.

A small number of NTFP already have high commercial value and can contribute significantly to rural incomes and act as entry points to rural development strategies (Wollenberg and Belcher 2001). These include rattan and bamboo species (Zhu at al. personal communication), resins (de Foresta et al. 2004), various fruits and nuts (Ramadani 2002; Leakey et al. 2005c) and medicinal plants (Nagpal and Karki 2004). The county of Lin'an in the Zhejiang province of China provides a good example of successful development with NTFP. Around 1980, Lin'an had 450,000 inhabitants, 64 % forest land and 60 % of the population living below the poverty line. The people and government of Lin'an County realized that their timber-dependent economy was deteriorating because of deforestation and land degradation. Therefore, they began to look at NTFP, and in particular at bamboo and hickory nuts as alternative sources of livelihoods. By 2009, Lin'an had become a prosperous place, with almost nobody living in poverty. While in 1990 NTFP counted for only 20 % of the earnings of rural people, in 2009 this had gone up to 47 %, with bamboo as a main contributor (60 %; Li and Xu 2009).

Dawson et al. (2007) have provided a good overview on issues relating to the marketing of DOCs and the impact on biodiversity (Table 3). Whilst experience shows that improved market access can lead to diversity loss, this does not always have to be the case. Tools have been developed to improve the alignment of market, societal and conservation goals in product value chains (Smale et al. 2002; Hellin and Higman 2005). The key factors are the speed and size of the development of a particular market, whether suitable

Table 3 Different markets with some of the possible advantages and disadvantages of each for promoting livelihoods and biodiversity (adapted from Dawson et al. 2007)

Market	Local	National	International
Possible advantages	•Traditional use and acceptance of products mean a ready market, with local use helping to maintain the identity of societies and reinforcing conservation.	•Some traditional use and acceptance of products, possible access to higher value 'internal' markets than those available locally.	•For specialised market niches (e.g. DO, Fair Trade), products may be of high value and bring considerable economic benefits to communities.
	•No or minimal regulatory requirements in bringing products to market.	•Although some regulatory/certification barriers, likely to be lower than for international markets.	•Specialised markets not only support diversity locally but also educate and interest the global community in the value and promotion of diversity.
	•Generally, the value chain from producers to consumers is short, meaning farmers should benefit more.	•Provides good opportunities for 'value addition' through processing (e.g. to improve longevity, spread the period of sale, facilitate transport).	•Specialised value chains are generally built around 'best practice' that ensures 'fair play' between producers and consumers.
	•Direct farmer consumption is possible in the absence of a market.		
Possible disadvantages	•Farmers may not receive the same premium for their crops as in other markets, especially with 'gluts' and low value during peak production.	•An absence of proper certification may make producers vulnerable to unscrupulous practice (e.g. 'misnaming' of lower quality product by large suppliers).	•Barriers to trade may be high, due, e.g. to regulations for market entry (e.g. the EU NFR), and/or certification costs (to certify product is sustainably produced, of a particular variety/origin, etc.).
		•Longer value chains than for local markets may decrease the benefits for farmers.	•International markets may be very sensitive to health scares (stringent health and safety regulations may come into operation if, e.g. disease or pollution problems).
		•Generally, markets at this level are more 'industrial', requiring more uniform product.	•Generally, entry into more 'industrial' (not niche) markets requires more uniform product.
Key ways to promote diversity	•Develop local networks that support exchange and innovative practice for germplasm and knowledge at a local community level (collective action).	•Increase consumer interest in products through the media and links with key commercial outlets (e.g. supermarkets).	•Lower barriers to markets (reduce costs and speed up processes) by developing simpler certification procedures and through relaxation of existing regulatory frameworks to food entry.
		•Training in value chain development (e.g. processing, packaging, book-keeping, accessing market information, dealing with different actors).	
		•Provision of credit to producers and micro-processors.	
Effectiveness for diversity	•May work best for promoting relatively modest increases in use in a wide range of species, in a manner that balances diversity in farming systems (no one crop comes to dominate through displacement).	•May work best for those crops that have some history of use at a national level and are not yet internationally traded. Probably effective for only a relatively small number of species, though more than for international markets.	•May currently work best for a relatively limited number of high value species, especially when promoting varieties of products that are already exposed to the international market. 'Major' crop examples are cocoa and coffee (e.g. DO, Fair Trade).

interventions to support diversification are possible in a given situation and how fragile the wider biodiversity within current farm ecosystems may be to displacement by newly marketed crops (Shackleton et al. 2009).

Nill and Böhnert (2006) and Giuliani (2007) assessed the development opportunities and biodiversity implications of several different value chains. They showed that the way in which product value chains can support diversity depends on the level of operation of various markets, and the access of communities to these markets. Markets locally, nationally and globally will generally only be effective in supporting diversity if emphasis is placed on educating consumers about diversity, enough consumers are willing to pay premium prices for products that support diversity and attention is given to higher-value niche market development. Product markets at all scales often lack transparency, with premiums paid for particular crops, varieties and products frequently not filtering down to farmers. Farmers could diversify to produce higher value crops if market opportunities were evident to them. Increasing transparency and awareness are thus important considerations at all levels.

Some of the issues that are particularly important for promoting diversity in different types of markets are summarised in Table 3. Whilst many interventions are of general importance, at a local level, particular emphasis may be placed on supporting collective action that facilitates exchange of community knowledge and innovations. At a national level, there may be a particular focus on the promotion of a more diverse range of attractively presented and/or processed products through radio and other media, and through strategic placements in large commercial outlets, such as supermarkets catering to urban populations and the developing middle classes (Moustier et al. 2010). Training in value chain development appears to be important as is increasing the availability of credit to small producers and micro-processors and training in areas such as processing, packaging, book keeping, reaching economies of scale, accessing market information (e.g. through channels such as text messaging on mobile phones) and negotiating with different actors and on how to respond to market changes. Such capacity building efforts have been undertaken (see Fig. 6) such as the ACP-European Union-funded project led by RUFORUM[2] which trains young African scientists specifically on interdisciplinary research on DOCs (see http://www.acp-st.eu/content/building-human-and-institutional-capacity-enhancing-conservation-and-use-neglected-and-under).

Internationally, there is rising interest in new foods and other products that can contribute in novel ways to improving human health and nutrition. This interest can be exploited to develop markets for non-staple crops from which poor communities can benefit if the right approaches to promotion are applied. Particular emphasis may be placed on promoting niche market arrangements through Denomination of Origin, Eco-labelling, Fair Trade, Organic and Slow Food initiatives. Van de Kop et al. (2006) provide several examples for existing value chains using Denomination of Origin, Trademark or Fair Trade labelling in Latin America, Europe and Africa. In different ways, all of these initiatives can support agrobiodiversity

Fig. 6 Training session in a rural village of India to make people aware of the plant diversity surrounding them, let recognize the species and share knowledge about their requirements and uses (Photo FAO)

and provide livelihood opportunities for smallholder producers. The key is to have consumers become more interested in the plants, land, supply chains and farming communities that produce and deliver what they eat.

Equally important is to reduce constraints to market entry, for example by lowering the costs involved in 'process' and 'product' certification. Buckingham et al. (2009), for example, describe how at present certification of bamboo may not be attractive for smallholder farmers and local forest managers due to its high costs, which are not translated into higher prices at the farm gate. Also needed is modifying restrictive tariff and non-tariff barriers such as the European Union 'Novel Food Regulation', which restricts the access of 'new' foods into member states (Hermann 2009). This regulation results in high premiums paid for niche products by consumers in order to cover the technically complex, time-consuming and financially burdensome nature of certification procedures. Less costly schemes are required if major benefits through DO and other niche market initiatives are to be realised for livelihoods and biodiversity. One option is to more directly link farm communities with consumers in order to guarantee product quality and origin; another is joint certification serving more than one market niche. Other regulations, such as phytosanitary control measures and the FAO/WHO Codex Alimentarius (http://www.codexalimentarius.net/web/index_en.jsp), aim at protecting consumers but may have unwanted side effects through restricting market access for minor crops.

6 An initiative for coordinating advocacy of development opportunity crops

DOCs must be recognized as an essential resource for sustainable global development. However, without increased research to support the development of integrated and diversified systems for the local production of locally consumed products, the

[2] Regional Universities Forum for Capacity Building in Agriculture (http://www.ruforum.org/)

target of an adequate and sustainable global supply of safe and nutritious food in 2050 will be unreachable. Given the situation of diverse and insufficiently connected research and development projects, widely dispersed publications and a relative isolation of the actors—even those working on the same species or production systems, greater synergy and more collective actions are required. This is not the first time that programmes and strategies for collective action have been formulated (e.g. Jaenicke and Höschle-Zeledon 2006; Jaenicke 2010; APAARI 2010), and there are numerous ongoing activities, for example the Platform for Agrobiodiversity Research (PAR),[3] the Agricultural Biodiversity Initiative for Africa (ABIA),[4] the NTFP Global Partnership Programme,[5] agroBIODIVERSITY,[6] the IFAD-CCAFS-UE-supported Project on Neglected and Underutilized Species,[7] etc.

Regional initiatives and multi-partner international actions, recently those related to the International Year of Biodiversity 2010, have highlighted the links between sustainable development and the use of agricultural diversity, especially the need to broaden the genetic base and to capture the traditional knowledge for crop productivity. FAO and Bioversity International organized in 2010 a joint scientific symposium to raise awareness of policy makers and research donors on the strong linkages between biodiversity, nutrition and environmental sustainability (Burlingame and Dernini 2012). The top management of FAO gave a significant contribution to the agrobiodiversity discussion during the high level policy makers and multi-stakeholders international conference on neglected and underutilized species in Cordoba, Spain 2012 (http://www.cultivosparaelsigloxxi.com/en/inicio.html). But it seems that the turnover of staff in the organisations partnering in these and other initiatives and their often relatively short-term 'project' approach is counterproductive to sustainable, long-term collaborative efforts. The other characteristic of most of these initiatives, including the latest one, is that most of the partners are coming from the 'advocacy' sector with very few actually contributing to enhancing the current knowledge base—although it is appreciated that successful advocacy requires a solid foundation based on evidence coming from research.

The multiple stakeholders of the Global Forum on Agricultural Research (GFAR) have prioritized the issue of sustaining a rich agrobiodiversity as one of prime global importance. This position is supported by the Council of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) that also champions the importance of agricultural research on crop diversity and contains special provisions for the exchange of information, transfer of technology and capacity building related to plant genetic resources. Both organisations have identified as priorities the need to expand varietal conservation, exchange and use, and the fair sharing of benefits derived from commercial exploitation of plant agricultural biodiversity, to include a wide range of species that have huge local significance and in many cases global market potential. Furthermore, both organizations have used the term 'development opportunity crops' when referring to this valuable pool of undervalorised plant genetic resources.

An overview of the policy frameworks already in place for the preservation of DOCs is available since 2008. It clearly shows that broad-based recommendations, including ways to enlarge Annex I of the International Treaty to include many of these crops and species, are not sufficient to influence decision makers in agriculture, biodiversity, education, health or trade sectors (Chishakwe 2008). Therefore, both GFAR and ITPGRFA wish to facilitate greater collaboration[8] and synergies among the many programmes and initiatives addressing this need. This view has been put forward in discussion with many other organizations concerned about food security and sustainable agriculture in the future, and embedded in the final Cordoba Declaration[9] on promising crops for the XXI Century, to be presented at the United Nations' Assembly in June 2013 as a key message behind the international year of quinoa. The key priorities of this Declaration, all focussing on neglected and underutilized species but apply equally to DOCs, are as follows:

- Raising awareness of these crops and their strategic roles
- Conserving genetic and cultural diversity
- Promoting their use in small–scale family farming to improve rural livelihoods

[3] www.agrobiodiversityplatform.org. PAR's goal is: "to enhance the sustainable management and use of agrobiodiversity by improving knowledge of all its different aspects. It seeks to promote research and integrate, mobilize and share research findings on the sustainable management of agrobiodiversity"

[4] This is an initiative by FARA, launched on 20 July 2010. ABIA supports efforts of SROs, NARS and Partners in R&D on agricultural biodiversity in Africa; it will build partnerships for action, seek resources and commission research; it will engage in advocacy for right policies and for R&D in agricultural biodiversity

[5] A global partnership programme supported by GFAR: http://ntfp.inbar.int/wiki/index.php/Main_Page

[6] www.agrobiodiversity-diversitas.org. The agrobiodiversity cross-cutting network of DIVERSITAS (www.diversitas-international.org) aims to inspire and facilitate interdisciplinary research for understanding the role of biological diversity in agricultural landscapes. The activities span the continuum from basic to applied research across eight benchmark sites worldwide and include adaptive land management in collaboration with local stakeholders

[7] http://bit.ly/QBvmuI

[8] http://www.egfar.org/content/itpgrfa-gfar-collaboration

[9] http://www.planttreaty.org/sites/default/files/Cordoba%20NUS%20Declaration%202012%20FINAL.pdf

- Developing value chains from production to consumption and to gastronomy
- Changing incorrect perceptions and developing the evidence base
- Enhancing research and capacities for promotion
- Building inter-sectoral and interdisciplinary collaboration
- Creating a conducive policy environment
- Establishing an Ombudsman for the future generations

To promote greater international synergy around this crucial agenda, the secretariats of GFAR and ITPGRFA are spearheading the Diversity for Development (DforD) Alliance with the goal of "collaborative action to strengthen the role and value of agro-biodiversity and its sustainable use in contributing to development aims". The applied objective of this action is advocacy for research on the contribution that DOC-based agrobiodiversity can play towards environment smart and small-scale adapted global food production, and in particular on how to mobilize the contribution of minor and local crops or species to sustainable development. The DforD Alliance brings together United Nations' organizations, international research networks and institutions as well as civil society, all concerned with generating, accessing and using knowledge of these crops and with promoting their sustainable use and their value in development. This Alliance targets three key development objectives:

1. Improving food security, nutrition and health—through production of crops that provide household/community food security and a diverse diet naturally rich in micronutrients;
2. Enhancing resilience of farming systems and environmental services at field or landscape level (e.g. to manage pests and diseases or maintain soil fertility); and
3. Improving incomes for resource-poor smallholders by offering new marketing and value-added opportunities.

The initial focus of this initiative is on the opportunities for development that can be provided by recognizing and exploiting a much wider array of plants and crops in the environmentally smart and economically sustainable farming and sustainable forest management systems that will be needed for the future. Too little attention is given to the mostly marginal populations to whom these opportunity crops contribute, both in terms of food security and occasionally cash (Bourgeois 2006). Key to the approach of the Alliance is raising the awareness and commitment of scientists and policy makers on the importance of increasing agrobiodiversity in the food systems of the future. The potential benefits of the DOCs within the context of sustainable and productive development have now been scientifically documented and shall be used for policy, research and development proposals at a global scale.

7 Conclusions

It is well documented that the present world food supply is highly dependent on a few key staple crops. In industrialized countries, these crops are grown on large farms using sophisticated equipment and high inputs of fertilizer and pest control chemicals; a very small proportion of the population is engaged directly with agriculture, yet food is plentiful and relatively affordable. Across much of the developing world, there is a comparable dependence on a limited number of staple crops, but they are produced by smallholders who consume much of what they produce. Here, a large proportion of the population is engaged directly or indirectly with agriculture, yet hunger and malnutrition are commonplace. Within both global realms, there is great potential to achieve productivity and long-term sustainability gains through crop diversification to include a much broader array of crops and species.

Through the four sections of this presentation, agricultural farming systems, health and nutrition, environmental sustainability and prosperity of the populations, the development opportunity crops bring benefits and services when well integrated in the food systems. All reported studies emphasizing the roles of these crops also acknowledge the strategic synergy with major staple crops in feeding humankind sustainably. There are thousands of minor crops, many of which have yet to be improved by breeding or otherwise studied in depth, with demonstrated potential to improve the livelihoods of farmers while also providing options for both enterprise and diet diversification. Greater use of these development opportunity crops can contribute importantly to the enhancement of global agrobiodiversity with all of its biological, ecological, economic and societal benefits. Prominent amongst these crops are a host of minor grains and pulses, edible roots and tubers, leafy vegetables, vegetable fruits, and perennial trees and bushes producing edible fruits. There are little known forage species, medicinal plants, beverage crops and many minor herbs and spices. All have the potential to contribute important traits through hybridization or molecular genetics. None should be lost before they can be studied and safely conserved. Incorporating them into profitable and sustainable farming systems is one way to ensure their preservation.

Increasing agrobiodiversity must be recognized as a pillar for building the robust, resilient and sustainable food production capacity the world will need to feed 9 billion people in 2050. This goal can be achieved by devoting a much greater portion of the global agricultural research effort to discovering and developing crops that are richer in essential nutrients, offer resilience to the host of production hazards that will come with climate change and are ultimately deemed attractive to both producers and consumers. Fortunately, the plant genetic resources and the indigenous knowledge needed to kick-start this research can be found throughout the developing world.

However, the ultimate food and agriculture development challenge for coming decades will be to devise and achieve adoption of farming and food distribution systems that contribute less to climate change, are less exploitive of natural resources, provide a high degree of local food and nutrition security and can sustain the small farms and farmers that will continue to produce the bulk of the world's food. Achieving this end will require challenging deeply entrenched socioeconomic norms and will require great resolve by governments everywhere. The Diversity for Development Alliance brings together many of the organizations that can credibly inform the inevitable and quite necessary debates.

Acknowledgments The Secretariat of the Global Forum on Agricultural Research (GFAR) is gratefully acknowledged for enabling collective efforts to highlight the value of agrobiodiversity in a range of development contexts, by fostering and supporting the Diversity for Development Alliance among all those involved here. A grant from GFAR to GlobalHort Secretariat enabled the engagement of Dr. Hannah Jaenicke to conduct the literature review on which this present paper is constructed. The authors wish to express their deep appreciation to Mark Holderness and Harry Palmier, GFAR Secretariat, for their leadership and much needed support. The contribution of Ms. Anne Vogelsang in the literature review has been very much appreciated. Peter Andersen, Paul Bordoni, Emile Frison, Luigi Guarino, Phil Hollington, Bhag Mal and Lim Eng Siang provided valuable input to an earlier version of the document.

References

ACC/SCN (1997) 3rd Report on the World Nutrition Situation. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition, Geneva

Adebooye OC, Ajayi SA, Baidu-Forson JJ, Opabode JT (2005) Seed constraint to cultivation and productivity of African indigenous leaf vegetables. Afr J Biotechnol 4(13):1480–1484

Adoukonou-Sagbadja H, Dansi A, Vodouhè R, Akpagana K (2006) Indigenous knowledge and traditional conservation of fonio millet (*Digitaria exilis*, *Digitaria iburua*) in Togo. Biodiversity and Conservation 15(8):2379–2395

Akroyd WR, Doughty J (1982) Legumes in human nutrition. FAO, Rome, (revised by Joyce Doughty and Ann Walker). FAO Food and Nutrition Paper No 20

Akubugwo IE, Obasi NA, Chinyere GC, Ugbogu AE (2007) Nutritional and chemical value of *Amaranthus hybridus* L. leaves from Afikpo, Nigeria. African Journal of Biotechnology 6(24):2833–2839

Aletor VA, Oshodi AA, Ipinmoroti K (2002) Chemical composition of common leafy vegetables and functional properties of their leaf protein concentrates. Food Chemistry 78(1):63–68. doi:10.1016/S0308-8146(01)00374

Altieri MA (2002) Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems and Environment 93:1–24. doi:10.1016/S0167-8809(02)00085-3

Altieri MA (2004) Linking ecologists and traditional farmers in the search for sustainable agriculture. Frontiers in Ecology and the Environment. doi:10.1890/1540-9295(2004)002[0035:LEATFI]2.0.CO;2

APAARI (2010) The Suwon Agrobiodiversity Framework. The way forward for managing agrobiodiversity for sustainable agriculture in the Asia-Pacific region. Rural Development Administration, Republic of Korea, 13–15 October 2010. Asia Pacific Association of Agricultural Research Institutes, Korea

Azam-Ali SN (2003) Multicropping. Encyclopedia of applied plant science. Elsevier Ltd, London, pp 978–984

Azam-Ali SN, Squire GR (2002) Principles of tropical agronomy. CAB International, Wallingford, p 236

Bala Ravi S, Hrideek TK, Kishore Kumar AT, Prabhakaran AT, Mal B, Padulosi S (2010) Mobilizing neglected and underutilized crops to strengthen food security and alleviate poverty in India. Indian Journal of Plant Genetic Resources 23(1):110–116

Baumgärtner S, Quaas MF (2010) Managing increasing environmental risks through agrobiodiversity and agrienvironmental policies. Agricultural Economics 41(5):483–496. doi:10.1111/j.1574-0862.2010.00460.x

Beaglehole R, Yach D (2003) Globalisation and the prevention and control of non-communicable disease: the neglected chronic diseases of adults. The Lancet 362:903–908

Bhag M (1994) Underutilized grain legumes and pseudocereals: their potentials in Asia. FAO, Bangkok, RAPA Publication 1994/14

Bharucha Z, Pretty J (2010) The roles and values of wild foods in agricultural systems. Philosophical Transactions of the Royal Society, series B 365:2913–2926. doi:10.1098/rstb.2010.0123

Bioversity International (2011) Nutrition strategy 2011–2012. Resilient food and nutrition systems: analyzing the role of agricultural biodiversity in enhancing human nutrition and health. Bioversity International, Maccarese

Block G, Patterson B, Subar A (1992) Fruit, vegetables, and cancer prevention: a review of the epidemiological evidence. Nutrition and Cancer 18(1):1–29. doi:10.1080/01635589209514201

Bourgeois R (2006) Secondary crops, rural poverty and policy bias. In: Bourgeois R, Svensson L, Burrows ML (eds) Farming a way out of poverty—forgotten crops and marginal populations in Asia and the Pacific. Proceedings of the regional workshop on "Rural prosperity and secondary crops: Towards applied pro-poor research and policies in Asia and the Pacific", Bogor, Indonesia, 6–9 December 2005. CAPSA Monograph No 48, pp. 3–14

Brondizio ES (2004) From staple to fashion food: shifting cycles and shifting opportunities in the development of the acai fruit palm economy in the Amazonian estuary. In: Zarin DJ, Alavalapati JRR, Putz FE, Schmink M (eds) Working forest in the neotropics. Columbia University Press, New York, pp 339–365

Brondizio ES, Safar CAM, Siqueira AD (2002) The urban market of açaí fruit (*Euterpe oleracea* Mart.) and rural land use change: ethnographic insights into the role of price and land tenure constraining agricultural choices in the Amazon estuary. Urban Ecosystems 6(1–2):67–97

Brush S, Meng E (1996) Farmers' valuation and conservation of crop genetic resources. Paper prepared for the Symposium on the economics of valuation and conservation of genetic resources for agriculture, 13–15 May 1996, Centre for International Studies on Economic Growth, Tor Vergata University, Rome

Buckingham KC, Lou YP, Hoogendoorn J (2009) How can bamboo certification contribute to sustainable bamboo management. In: Buckingham KC, Henley G, Lou YP (eds) Certification of commodities: opportunities and challenges for the rural poor. Proceedings of the ICB-CFC International Certification Workshop, April 2009, Beijing pp 74–88

Burlingham B, Dernini S (eds) (2012) Sustainable diets and biodiversity: directions and solutions for policy, research and action. Proceedings of the International Scientific Symposium Biodiversity and sustainable Diets United against Hunger, 3–5 November 2010, FAO, Rome, Italy. http://www.fao.org/docrep/016/i3004e/i3004e.pdf. Accessed 15 Jan 2013

Chadha ML (2010) Short-duration mungbean. A new success in South Asia. Association of Asia Pacific Agricultural Research Institutions, Bangkok

Chadha ML, Hasan Mndiga H (2007) African eggplant—from underutilized to a commercially profitable venture. Acta Horticulturae (ISHS) 752:521–523

Chadha ML, Guo G, Gowda CLL (2007) Proceedings of the first international conference on indigenous vegetables and legumes—prospects for fighting poverty, hunger and malnutrition. Acta Horticulturae (ISHS) 752 623 p

Chishakwe NE (2008) An overview of the international regulatory frameworks that influence the conservation and use of underutilized plant species. Global Facilitation Unit for Underutilized Species, Rome, Italy, and The Genetic Resources Policy Initiative, Nairobi, Kenya, 31 p. http://www.underutilized-species.org/Documents/PUBLICATIONS/international_policy_analysis.pdf. Accessed 15 Feb 2013

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

Clough Y, Barkmann J, Juhrbandt J et al (2011) Combining high biodiversity with high yields in tropical agroforests. Proceedings of the National Academy of Sciences 108(20):8311–8316. doi:10.1073/pnas.1016799108

Condori B, Hijmans RJ, Quiroz R, Ledent FJ (2010) Quantifying the expression of potato genetic diversity in the high Andes: growth analysis and modelling. Field Crops Research 119:135–144. doi:10.1016/j.fcr.2010.07.003

Das M, Das R (2012) Need of education and awareness towards zinc supplementation: a review. International Journal of Nutrition and Metabolism 4(3):45–50. doi:10.5897/ijnam11.043

Dawson IK, Guarino L, Jaenicke H (2007) Underutilised plant species: impacts of promotion on biodiversity. Position Paper No 2. International Centre for Underutilised Crops, Colombo

De Bon H, Parrot L, Moustier P (2009) Sustainable urban agriculture in developing countries: a review. Agronomy for Sustainable Agriculture 6:619–633. doi:10.1051/agro:2008062

De Foresta H, Michon G, Kusworo A, Levang P (2004) Damar agroforests in Sumatra, Indonesia: domestication of a forest ecosystem through domestication of dipterocarps for resin production. In: Kuster K, Belcher B (eds) Forest products, livelihoods and conservation: case studies of non-timber forest product systems, volume 1—Asia. CIFOR, Bogor

De Pee S, West CE (1996) Dietary carotenoids and their role in combating vitamin A deficiency: a review of the literature. European Journal of Clinical Nutrition 50(3):38–53

De Schutter O (2010) Agroecology and the right to food. Report presented to the Human Rights Council of the United Nations, 16th Session (UN Doc. A/HRC/16/49) http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G10/178/49/PDF/G1017849.pdf?OpenElement

Desjardins Y (2007) First international symposium on human health effects of fruits and vegetables. Acta Horticulturae (ISHS) 744 470 p

Di Falco S, Chavas JP (2008) Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. Land Economics 84(1):83–96. doi:10.3368/le.84.1.83

Di Falco S, Perrings C (2005) Crop biodiversity, risk management and the implications of agricultural assistance. Ecological Economics 55(4):459–466. doi:10.1016/j.ecolecon.2004.12.005

Donald CM (1968) The breeding of crop ideotypes. Euphytica 17:385–403. doi:10.1007/BF00056241

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

Ekpa OD (1996) Nutrient composition of three Nigerian medicinal plants. Food Chemistry 57(2):229–232

Engel S, Pagiola S, Wunder S (2008) Designing payments for environmental services in theory and practice: an overview of the issues. Ecological Economics 65(4):663–674. doi:10.1016/j.ecolecon.2008.03.011

Englberger L, Lorens A (2009) Let's go local initiative in Pohnpei, Micronesia for promoting underutilized crops. Acta Horticulturae (ISHS) 806:229–234

Englberger L, Schierle J, Aalbersberg W et al (2006) Carotenoid and vitamin content of Karat and other Micronesian banana cultivars. International Journal of Food Science and Nutrition 57:399–418. doi:10.1080/09637480600872010

Englberger L, Schierle J, Kraemer K et al (2008) Carotenoid and mineral content of Micronesian giant swamp taro (*Cyrtosperma*) cultivars. Journal of Food Composition and Analysis 21:93–106. doi:10.1016/j.jfca.2007.09.007

Englberger L, Lorens A, Levendusky A et al (2009) Documentation of the indigenous food system of Pohnpei. In: Kuhnlein H, Erasmus B, Spigelski D (eds) Indigenous peoples' food systems. FAO, Rome

FAO (2001) The spectrum of malnutrition. Fact sheet, July 2001, FAO, Rome, Italy. http://www.fao.org/worldfoodsummit/english/fsheets/malnutrition.pdf. Accessed 15 Jun 2012

FAO (2010a) The State of the Food Insecurity in the World. Addressing food insecurity in protracted crises. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/docrep/013/i1683e/i1683e.pdf. Accessed 15 Jun 2012

FAO (2010b) The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture. Commission on Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/docrep/013/i1500e/i1500e00.pdf. Accessed 15 Jun 2012

FAO (2011a) Food, agriculture and cities. Challenges of food and nutrition security, agriculture and ecosystem management in a urbanizing world. Food for the Cities multidisciplinary initiative position paper, Food and Agriculture Organization of the United Nations, Rome, Italy http://www.fao.org/fileadmin/templates/FCIT/PDF/FoodAgriCities_Oct2011.pdf. Accessed 23 May 2012

FAO (2011b) Food, agriculture and cities. Save and grow: a new paradigm of agriculture. A policymaker's guide to the sustainable intensification of smallholder crop production. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/ag/save-and-grow/. Accessed 13 Jun 2012

FAO/PAR (2010) Biodiversity for food and agriculture: contributing to food security and sustainability in a changing world. FAO and the Platform for Agrobiodiversity Research, Rome, p 66

Flyman MV, Afolayan AJ (2006) The suitability of wild vegetables for alleviating human dietary deficiencies. South African Journal of Botany 72(4):492–497. doi:10.1016/j.sajb.2006.02.003

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

Gibson RS, Bailey KB, Gibbs M, Ferguson EL (2010) A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. Food and Nutrition Bulletin 31(2 Suppl):134–46

Giuliani A (2007) Developing markets for agrobiodiversity: securing livelihoods in dryland areas. Earthscan Research Editions, London

Gopalan C (1996) Current food and nutrition situation in south Asian and south-east Asian countries. Biomedical and Environmental Science 9(2–3):102–116

Graefe S, Dufour D, van Zonneveld M, Rodriguez F, Gonzalez A (2012) Peach palm (*Bactris gasipaes*) in tropical Latin America: implications for biodiversity conservation, natural resource management and human nutrition. Biodiversity and Conservation. doi:10.1007/s10531-012-0402-3

Grivetti LE, Ogle BM (2000) Value of traditional foods in meeting macro- and micronutrient needs: the wild plant connection. Nutrition Research Reviews 13(1):31–46. doi:10.1079/095442200108728990

Guarino L, Lobell DB (2011) A walk on the wild side. Nature Climate Change 1: 374–375. http://issuu.com/croptrust/docs/nclimate1272_2_/1. Accessed 15 Jun 2012. doi:10.1038/nclimate1272

Gupta S, Lakshmi AJ, Manjunath MN, Prakash J (2005) Analysis of nutrient and antinutrient content of underutilized green leafy vegetables. LWT–Food Science and Technology. doi:10.1016/j.lwt.2004.06.012

Hammer K (1998) Agrarbiodiversität und pflanzengenetische Ressourcen. Schriften zu Genetischen Ressourcen, Band 10, ZADI, Bonn, Germany, 98 p http://www.genres.de/fileadmin/SITE_GENRES/downloads/schriftenreihe/Band10_Gesamt.pdf. Accessed 14 Nov 2011

Harlan J (1975) Crops and man. American Society for Agricultural Sciences, Madison

Harvey M (2006) Cultivating resilience: recovery of homestead gardens in Sri Lanka after the 2004 Tsunami. Coventry University and HDRA, Coventry

Hatløy A, Hallund J, Diarra MM, Oshaug A (2000) Relationship between food variety scores, socio-economic status and nutritional status. A case study from Mali. Public Health and Nutrition 3(1):57–65

Hellin J, Higman S (2005) Crop diversity and livelihood security in the Andes. Development in Practice 15:165–174. doi:10.1080/09614520500041344

Hermann M (2009) The impact of the European Novel Food Regulation on trade and food innovation based on traditional plant foods from developing countries. Food Policy 34:499–507. doi:10.1016/j.foodpol.2009.08.005

Hermann M, Bernet T (2009) The transition of maca from neglect to market prominence. Lessons for improving use strategies and market chains of minor crops. Bioversity International, Rome, Agricultural Biodiversity and Livelihoods, Discussion Papers 1

Hermann M, Quynh NK, Peters D (1999) Reappraisal of edible canna as a high-value starch crop in Vietnam. In: Impact on a changing world, Program Report 1997–1998, The International Potato Center (CIP), Lima, Peru, pp 415–424

Herren H, Löhr B (2001) The international center of insect physiology and ecology. Pesticide Outlook. doi:10.1039/b108608c

Hoddinott J, Yohannes Y (2002) Dietary diversity as a household food security indicator. IFPRI, Washington, DC, Food Consumption and Nutrition Division, Discussion Paper No 136

Hollington PA, Andersen P, Bajracharya J, Gautam R, Joshi KD, Khanal A, Kumar N, Mueller RAE, Neog SB, Yadavendra JP (2010) Food security through ricebean research in India and Nepal (FOSRIN). Final Technical Report, Bangor, UK: Centre for Advanced Research in International Agricultural Development (CARIAD) 154 p. http://www.ricebean.org/deliverables/032055%20FOSRIN%20final%20report.pdf. Accessed 14 Nov 2011

Holt-Gimenez E, Altieri MA, Rosset P (2006) Food First Policy Brief No12: Ten reasons why the Rockefeller and Bill and Melinda Gates Foundations' alliance for Another Green Revolution will not solve the problem of poverty and hunger in sub-Saharan Africa. http://www.foodfirst.org/en/node/1527. Accessed 13 Jun 2012

Hongo T, Suzuki T, Ohtsuka R, Kawabe T, Inaoka T, Akimichi T (1989) Element intake of the Gidra in lowland Papua: inter-village variation and the comparison with contemporary levels in developed countries. Ecology of Food and Nutrition 23(4):293–309. doi:10.1080/03670244.1989.9991112

Hughes J (2009) Just famine foods? What contributions can underutilized plants make to food security? Acta Horticulturae (ISHS) 806:39–47

IAASTD (2008) International assessment of agricultural knowledge, science and technology for development. Global Report. http://ww.agassessment.org. Accessed 6 Aug 2011

IAEA (2004) Genetic improvement of under-utilized and neglected crops in low income food deficit countries through irradiation and related techniques. Proceedings of a final Research Coordination Meeting organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Pretoria, South Africa, 19–23 May 2003. International Atomic Energy Agency. Vienna, Austria, p. 219

Jackson LE, Pascual U, Hodgkin T (2007) Utilizing and conserving agrobiodiversity in agricultural landscapes. Agriculture, Ecosystems and Environment 121(3):196–210. doi:10.1016/j.agee.2006.12.017

Jackson L, van Noordwijk M, Bengtsson J, Foster W, Lipper L, Pulleman M, Said M, Snaddon J, Vodouhe R (2010) Biodiversity and agricultural sustainagility: from assessment to adaptive management. Current Opinion in Environmental Sustainability 2:80–87. doi:10.1016/j.cosust.2010.02.007

Jaenicke H (2009) Nutzung vernachlässigter Pflanzenarten und ihres genetischen Potentials zur Verbesserung der Welternährungslage–Status und Aussichten eines nachhaltigen Beitrags deutscher Wissenschaftseinrichtungen. Gutachten an den Deutschen Bundestag vorgelegt dem Büro für Technikfolgen Abschätzung beim Deutschen Bundestag (TAB)

Jaenicke H (2010) Optimising the CGIAR's contribution to global efforts on the conservation and sustainable use of underutilized plant genetic resources—some thoughts about strategic priorities. Report prepared for the Global Public Goods Programme Phase 2 of the System-wide Genetic Resources Programme

Jaenicke H, Höschle-Zeledon I (eds) (2006) Strategic framework for research and development of underutilised plant species with special reference to Asia, the Pacific and Sub-Saharan Africa. International Centre for Underutilised Crops, Colombo, 33 p

Jarvis DI, Hodgkin T, Sthapit BR, FaddaC L-NI (2011) An heuristic framework for identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system. Critical Reviews in Plant Science 30:125–176. doi:10.1080/07352689.2011.554358

Jat ML, Gupta K, Erenstein O, Ortiz R (2006) Diversifying the intensive cereal cropping systems of the Indo-Ganges through horticulture. Chronica Horticulturae 46(3):27–31

Kang J, Xie C, Li Z, Nagarajan S, Schauss AG, Wu T, Wu X (2011) Flavonoids from acai (*Euterpe oleracea* Mart.) pulp and their antioxidant and anti-inflammatory activities. Food Chemistry 128(1):152–157

Keatinge JDH, Ledesma D, Hughes D'A J, de la Peña R (2009) A strategic look to the future for vegetable research: The World Vegetable Centre and its partners, pp 113–118. In: Iiyama K (ed) global climate change: imperatives for agricultural research in Asia-Pacific, JIRCAS, Tsukuba City, Japan

Keatinge JDH, Waliyar F, Jamnadass RH, Moustafa A, Andrade M, Drechsel P, Hughes D'A J, Palchamy K, Luther K (2010) Re-learning old lessons for the future of food: by bread alone no longer diversifying diets with fruit and vegetables. Crop Science 50:51–62. doi:10.2135/cropsci2009.09.0528

Keatinge JDH, Yang R-Y, Hughes D'A J, Easdown WJ, Holmer R (2011) The importance of vegetables in ensuring both food and nutritional security in attainment of the Millennium Development Goals. Food Security 3:491–501. doi:10.1007/s12571-011-0150-3

Keding GB (2010) Linking nutrition security and agrobiodiversity: the importance of traditional vegetables for nutritional health of women in rural Tanzania. PhD Thesis, Institute of Nutritional Sciences, Justus-Liebig-University Giessen. University of Göttingen, Cuvillier Verlag, Germany

Khan ZR, Pickett JA (2004) The 'push–pull' strategy for stem borer management: a case study in exploiting biodiversity and chemical ecology. In: Gurr GM, Wratten SD, Altieri MA (eds) Ecological engineering for pest management: advances in habitat manipulation for arthropods. CSIRO Publishing, Australia, pp 155–164

Khanal AR, Khadka K, Poudel I, Joshi KD, Hollington PA (2007) Food security through ricebean research in India and Nepal (FOSRIN).

Report 3. Farmers' local knowledge associated with the production, utilization and diversity of ricebean (*Vigna umbellata*) in Nepal, Pokhara, Nepal. Local Initiatives for Biodiversity, Research and Development (LIBIRD), Rampur, Chitwan, Nepal, Institute of Agriculture and Animal Sciences, and Bangor, Wales, UK, CAZS Natural Resources, College of Natural Sciences, Bangor University. http://www.ricebean.org/deliverables/deliverable%204%20-%20indigenous%20knowledge.pdf. Accessed 4 Nov 2011

Krupinsky JM, Bailey KL, McMullen MP, Gossen BD, Turkington TK (2002) Managing plant disease risk in diversified cropping systems. Agronomy Journal 94:198–209. doi:10.2134/agronj2002.1980

Kumaraswamy S (2012) Sustainability issues in agroecology: socio-ecological perspective. Agricultural Sciences 3:153–169. doi:10.4236/as.2012.32018

Kunkel G (1984) Plants for human consumption: an annotated check-list of the edible phanerogams and ferns. Koeltz Scientific Books, Koenigstein, p 393

Leakey RRB, Temu AB, Melnyk M, Vantomme P (eds) (1996) Domestication and commercialization of non-timber forest products in agroforestry systems. Proceedings of an international conference held in Nairobi, Kenya, 19–23 February 1996. FAO Non-Wood Forest Products 9. FAO, Rome, Italy

Leakey RRB, Greenwell P, Hall MN, Atangana AR, Usoro C, Anegbeh PO, Fondoun J-M, Tchoundjeu Z (2005a) Domestication of *Irvingia gabonensis*: 4. Tree-to-tree variation in food-thickening properties and in fat and protein contents of Dika Nut. Food Chemistry 90:365–378

Leakey R, Pate K, Lombard C (2005b) Domestication potential of Marula (*Sclerocarya birrea* subsp *caffra*) in South Africa and Namibia: 2. Phenotypic variation in nut and kernel traits. Agroforestry Systems 64:37–49. doi:10.1007/s10457-005-2420-6

Leakey RRB, Tchoundjeu Z, Schreckenberg K, Shackleton SE, Shackleton CM (2005c) Agroforestry tree products (AFTPs): targeting poverty reduction and enhanced livelihoods. International Journal of Agricultural Sustainability 3:1–23

Leakey RRB, Fuller S, Treloar T, Stevenson L, Hunter D, Nevenimo T, Binifa J, Moxon J (2008) Characterization of tree-to-tree variation in morphological, nutritional and chemical properties of *Canarium indicum* nuts. Agroforestry Systems 73:77–87. doi:10.1007/s10457-007-9103-4

Lebot V, Someoni P, Jackson G (2001) Networking with food crops: a new approach in the Pacific. In: Wells KF, Eldridge KG (eds) Plant genetic resources in the Pacific: towards regional cooperation in conservation and management. ACIAR, Canberra, pp 82–85, ACIAR Monograph 76

Legwaila GM, Mojeremane W, Madisa ME, Mmolotsi RM, Rampart M (2011) Potential of traditional food plants in rural household food security in Botswana. Journal of Horticulture and Forestry 3(6):171–177

Lenné JM, Wood D (2011) Agricultural revolutions and their enemies: lessons for policy makers. In: Lenné j, Wood D (eds) Agrobiodiversity management for food security: a critical review. CABI, Wallingford, pp 212–227, 235 p

Li LY, Xu XY (2009) Exploring the comparative advantage of non-timber forest products – The case of Zhejiang province, China. In: Siry J, Izlar B, Bettinger P, Harris T, Tye T, Baldwin S, Merry K (eds.) Proceedings of the 2008 Southern Forest Economics Workers Annual Meeting, 9–11 March 2008, Savannah, Athens (GA) Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia. Center for Forest Business Publication No 30: 163–173

Lutaladio N, Burlingame B, Crews J (2010) Horticulture, biodiversity and nutrition. Journal of Food Composition and Analysis 23:481–485. doi:10.1016/j.jfca.2010.08.001

Maikhuri RK, Rao KS, Saxena KG (1996) Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. International Journal of Sustainable Development and World Ecology 3(3):8–31. doi:10.1080/13504509609469926

Makobo ND, Shoko MD, Mtaita TA (2010) Nutrient content of vegetable amaranth (*Amaranths cruentus* L.) at different harvesting stages. World Journal of Agricultural Sciences 6(3):285–289

Mal B (2007) Neglected and underutilized crop genetic resources for sustainable agriculture. Indian Journal of Plant Genetic Resources 20(1):1–14

Markelova H, Meinzen-Dick R, Hellin J, Dohrn S (2009) Collective action for smallholder market access. Food Policy 34:1–7. doi:10.1016/j.foodpol.2008.10.001

Marshall E, Newton AC, Schreckenberg K (2003) Commercialisation of non-timber forest products: first steps in analysing the factors influencing success. International Forestry Review 5(2):128–137. doi:10.1505/IFOR.5.2.128.17410

Marshall E, Schreckenberg K, Newton AC (2006) Commercialization of non-timber forest products: factors influencing success. lessons learned from Mexico and Bolivia and policy implications for decision-makers. UNEP World Conservation Monitoring Centre, Cambridge

Matson PA, Parton WJ, Power AG, Swift MJ (1997) Agricultural intensification and ecosystem properties. Science 277(5325):504–509. doi:10.1126/science.277.5325.504

McKay J (2009) Food and health considerations in Asia-Pacific regional security. Asia Pacific Journal of Clinical Nutrition 18:654–663

Millenium Ecosystem Assessment (2005) Ecosystems and human well-being: synthesis. MA, Island Press, Washington DC, USA. http://www.maweb.org/documents/document.356.aspx.pdf. Accessed 15 Jun 2012

Mogina J (1999) Maintenance of crop diversity and food security in rural Papua New Guinea: case studies from Cape Vogel and Goodenough Island. Australian National University Development Bulletin 50:32–36

Mora-Urpí J, Weber JC, Clement CR (1997) Peach palm. *Bactris gasipaes* Kunth. Promoting the conservation and use of underutilized and neglected crops, No 20. Institute of Plant Genetics and Crop Plant Research, Gatersleben

Moustier P, Tam PTG, Anh DT, Binh VT, Loc NTT (2010) The role of farmer organizations in supplying supermarkets with quality food in Vietnam. Food Policy 35:69–78. doi:10.1016/j.foodpol.2009.08.003

Msuya JM, Mamiro P, Weinberger K (2009) Iron, zinc and β-carotene nutrient potential of non-cultivated indigenous vegetables in Tanzania. Acta Horticulturae (ISHS) 806:217–222

Nagpal A, Karki M (2004) A study on marketing opportunities for medicinal aromatic and dye plants in South Asia. IDRC-Medicinal and Aromatic Plants Program in Asia (MAPPA) 114 p

Neumann RP, Hirsch E (2000) Commercialisation of non-timber forest products: review and analysis of research. Center for International Forestry Research, Bogor, p 187

Nill D, Böhnert E (2006) Value chains for the conservation of biological diversity for food and agriculture. Potatoes in the Andes, Ethiopian coffee, argan oil from Morocco and grasscutters in West Africa. Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn, Germany and the Global Facilitation Unit for Underutilized Species, Rome, Italy, 78 p

Odhav B, Beekrum S, Akula U, Baijnath H (2007) Preliminary assessment of nutritional value of traditional leafy vegetables in KwaZulu-Natal, South Africa. Journal of Food Composition and Analysis 5:430–435. doi:10.1016/j.jfca.2006.04.015

Ortiz R (2011a) Agrobiodiversity management for climate change. In: Lenné JM, Wood D (eds) Agrobiodiversity management for food security. A critical review. CAB International, Wallingford, pp 189–211

Ortiz R (2011b) The way ahead: from science to policy—coordinating efforts in a global world. In: Araus JL, Slater GA (eds) Crop stress management and global climate change. CAB International, Wallingford

Pacheco-Palencia LA, Mertens-Talcott S, Talcott ST (2008) Chemical composition, antioxidant properties, and thermal stability of a phytochemical enriched oil from açai (*Euterpe oleracea* Mart.). Journal of Agricultural Food Chemistry 56(12):4631–4636. doi:10.1021/jf800161u

Padulosi S (2011) Unlocking the potential of minor millets. Appropriate Technology 38(1):21–23

Padulosi S, Hodgkin T, Williams JT, Haq N (2002) Underutilized crops: trends, challenges and opportunities in the 21st century. In: Engels JMM, Ramanatha Rao V, Brown AHD, Jackson MT (eds) Managing plant genetic resources. CAB International, Wallingford, pp 323–338

Padulosi S, Mal B, Bala Ravi S, Gowda J, Gowda KTK, Shanthakumar G, Yenagi N, Dutta M (2009) Food security and climate change: role of plant genetic resources of minor millets. Indian Journal of Plant Genetic Resources 22(1):1–16

Padulosi S, Heywood V, Hunter D, Jarvis A (2011) Underutilized species and climate change: current status and outlook. In: Yadav SS, Redden RJ, Hatfield JL, Lotze-Campen H, Hall AE (eds) Crop adaptation to climate change. Wiley-Blackwell, Oxford, pp 507–521. doi:10.1002/9780470960929.ch35

Padulosi S, Bergamini N, Lawrence T (Eds) (2012) On farm conservation of neglected and underutilized species: trends and novel approaches to cope with climate change. Proceedings of the International Conference, Friedrichsdorf, Frankfurt, 14–16 June 2011. Bioversity International, Rome, Italy. http://www.bioversityinternational.org/fileadmin/bioversity/publications/pdfs/1512_On_farm_conservation_of_neglected_and_underutilized_species_status_trends_and_novel_approaches_to_cope_with.pdf . Accessed 15 Feb 2013

Pardey PG, Pingali PL (2010) Reassessing international agricultural research for food and agriculture. Report prepared for GCARD, Montpellier, France, March 2010. http://www.ciat.cgiar.org/cgiar/Documents/4.%20Phil%20Pardey%20Paper.pdf. Accessed 15 Jun 2012

Parr JF, Stewart BA, Hornick SB, Singh RP (1990) Improving the sustainability of dryland farming systems: a global perspective. In: Singh RP, Parr JF, Stewart BA (eds) Advances in soil science, vol 13. Dryland Agriculture Strategies for Sustainability, New York, pp 1–8

Perrings C, Jackson L, Bawa K, Brussard L, Brush S, Gavin T, Pap R, Pascual U, de Ruiter P (2006) Biodiversity in agricultural landscapes: saving natural capital without losing interest. Conservation Biology 20(2):263–264. doi:10.1111/j.1523-1739.2006.00390.x

Popkin BM (2003) The nutrition transition in the developing world. Development Policy Review 21(5–6):581–97

Prescott-Allen R, Prescott-Allen C (1990) How many plants feed the world? Conservation Biology 4(4):365–374. doi:10.1111/j.1523-1739.1990.tb00310.x

Ramadani T (2002) Marketing of indigenous fruits in Zimbabwe. Socio-economic studies on rural development, vol 129. Wissenschaftsverlag Vauk Kiel KG, Kiel, Germany, p 212

Ratnadass A, Fernandes P, Avelino J, Habib R (2011) Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. Agronomy for Sustainable Development. doi:10.1007/s13593-011-0022-4

Reardon T, Neven D (2004) The rise of Kenyan supermarkets and the evolution of their horticulture product procurement systems. Development Policy Review 22(6):669–699

Renkow M, Byerlee D (2010) The impacts of CGIAR research: a review of recent evidence. Food Policy 35(5):391–402. doi:10.1016/j.foodpol.2010.04.006

Richards P, Ruivenkamp G (1997) Seeds and survival. Crop genetic resources in war and reconstruction in Africa. IPGRI, Rome, 64 p

Robson JRK (1976) Commentary: changing food habits in developing countries. Ecology of Nutrition 4(4):251–256. doi:10.1080/03670244.1976.9990436

Rockström J, Steffen W, Noone K, Persson Å, Chapin FS 3rd, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA (2009) A safe operating space for humanity. Nature 461:472–475. doi:10.1038/461472a

Rojas W, Valdivia R, Padulosi S, Pinto M, Soto JL, Alcocer E, Guzman L, Estrada R, Apaza V, Bravo R (2009) From neglect to limelight: issues, methods and approaches in enhancing sustainable conservation and use of Andean grains in Bolivia and Peru. In: Buerkert A and Gebauer J (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. pp 87–117. http://www.upress.uni-kassel.de/online/frei/978-3-89958-680-0.volltext.frei.pdf. Accessed 6 Aug 2011

Royal Society (2009) Reaping the benefits: science and the sustainable intensification of global agriculture. The Royal Society, London, UK, 72 p http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/4294967719.pdf. Accessed 15 Jun 2012

Ruel MT, Minot N, Smith L (2005) Patterns and determinants of fruit and vegetable consumption in sub-Saharan Africa. Background paper for the Joint FAO/WHO Workshop on Fruits and Vegetables for Health, 1–3 September 2004, Kobe, Japan. WHO, 45 p. http://www.who.int/dietphysicalactivity/publications/f&v_africa_economics.pdf. Accessed 15 Jun 2012

Sandberg AS (2002) Bioavailability of minerals in legumes. British Journal of Nutrition 88(Suppl 3):281–285. doi:10.1079/BJN/2002718

Schroth G, D'Angelo SA, Teixeira WG, Haag D, Lieberei R (2002) Conversion of secondary forest into agroforestry and monoculture plantations in Amazonia: consequences for biomass, litter and soil carbon stocks after 7 years. Forest Ecology and Management 163:131–150

Schulz S, Keatinge JDH, Wells GJ, Shrestha R (2001) Effect of legume management on forage production and residual effects on upland rice. Journal of Agronomy and Crop Science 184:173–180. doi:10.1046/j.1439-037x.2000.00398.x

Shackleton CM, Pasquini MW, Drescher AW (eds) (2009) African indigenous vegetables in urban agriculture. Earthscan, London. doi:10.1002/ldr.967, 298 p

Shanley P, Luz L, Swingland IR (2002) The faint promise of a distant market: a survey of Belém's trade in non-timber forest products. Biodiversity and Conservation 11:615–636

Sheil D, Wunder S (2002) The value of tropical forest to local communities: complications, caveats, and cautions. Conservation Ecology 6(2):9

Simitu P, Jamnadass R, Kindt R, Kimiywe J, Kungu J (2009) Consumption of dryland indigenous fruits to improve livelihoods in Kenya: the case of Mwingi District. Acta Horticulturae (ISHS) 806:93–98

Singh KP, Kumar A, Saharan RP, Kumar R (2006) A new boldseeded genotype of mungbean-MRH-5. National Journal of Plant Improvement 8(1):92–93

Smale M (ed) (2006) Valuing crop biodiversity: on-farm genetic resources and genetic change. CAB International Publishing, Wallingford, p 323

Smale M, Hartell J, Heisey PW, Senauer B (1998) The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan. American Journal of Agricultural Economics 80(3):482–493

Smale M, Mar I, Jarvis DI (eds) (2002) The economics of conserving agricultural biodiversity on-farm: research methods developed from

IPGRI's global project 'Strengthening the scientific basis of in situ conservation of agricultural biodiversity'. International Plant Genetic Resources Institute (Bioversity International), Rome, Italy, 79 p. ftp://www.bgbd.net/ipgri/MAARTEN_VAN_ZONNEVELD/Manual%20y%20datos%20curso%20SIG/Literatura%20adicional/Publicaciones%20Bioversity/Conservacion%20In%20situ/The%20economics%20of%20conserving%20agricultural%20biodiversity%20on-farm.pdf. Accessed 15 Jun 2012

Smale M, Hazell P, Hodgkin T, Fowler C (2009) Do we have an adequate global strategy for securing the biodiversity of major food crops? In: Kontoleon A, Pascual U, Smale M (eds) Agrobiodiversity conservation and economic development. Routledge, Abingdon, pp 40–50

Steele KA, Gyawali S, Joshi KD, Shrestha P, Sthapit BR, Witcombe JR (2009) Has the introduction of modern rice varieties changed rice genetic diversity in a high-altitude region of Nepal? Field Crops Research 113(1):24–30. doi:10.1016/j.fcr.2009.04.002

Termote C, Bwama Meyi M, Dhed'a Djailo B, Huybregts L, Lachat C, Kolsteren P, Van Damme P (2012) A biodiverse rich environment does not contribute to a better diet: a case study from DR Congo. PLoS ONE. doi:10.1371/journal.pone.0030533

Tester M, Langridge P (2010) Breeding technologies to increase crop production in a changing world. Science 327:818–822. doi:10.1126/science.1183700

Thrupp LA (1998) Cultivating diversity. Agrobiodiversity and food security. World Resources Institute, Washington DC, 80 p. http://pdf.wri.org/cultivatingdiversity_bw.pdf. Accessed 13 Jul 2012

Toledo A, Burlingame B (2006) Biodiversity and nutrition: a common path toward global food security and sustainable development. Journal of Food Composition and Analysis 19:477–483. doi:10.1016/j.jfca.2006.05.001

Tomooka N, Kashiwaba K, Vaughan DA, Ishimoto M, Egawa Y (2000) The effectiveness of evaluating wild species: searching for sources of resistance to bruchid beetles in the genus *Vigna* subgenus *Ceratotropis*. Euphytica 115(1):27–41

UNSCN (2010) Progress on nutrition. 6th Report on the World Nutrition Situation of the United Nations Standing Committee on Nutrition. Geneva, Switzerland. http://www.unscn.org/files/Publications/RWNS6/report/SCN_report.pdf. Accessed 15 Jun 2012

van de Kop P, Sautier D, Gerz A (2006) Origin-based products. Lessons learnt for pro-poor market development. Bulletin No 372. Royal Tropical Institute (KIT), Amsterdam and French Agricultural Research Centre for International Development (CIRAD), Montpellier. http://www.kit.nl/net/KIT_Publicaties_output/ShowFile2.aspx?e=921 Accessed 15 Jun 2012

Van Noordwijk M (2010) Climate change, biodiversity, livelihoods and sustainagility in Southeast Asia. In: Sajise PE, Ticsay MV, Saguiguit GC (eds) Moving forward: Southeast Asia perspectives on climate change and biodiversity. Southeast Asia Regional Centre for Graduate Study and Research in Agriculture and Institute of Southeast Asian Studies, Laguna, pp 55–83

Van Rensburg WSJ, de Ronde JA, Venter SL, Netshiluvhi TR, van den Heever E, Vorster HJ (2004) Role of indigenous leafy vegetables in combating hunger and malnutrition. South African Journal of Botany 70(1):52–59

Van't Veer P, Jansen MCJF, Klerk M, Kok FJ (1999) Fruits and vegetables in the prevention of cancer and cardiovascular disease. Public Health Nutrition 3(1):103–107

Vijayalakshmi D, Geetha K, Gowda J, Bala Ravi S, Padulosi S, Mal B (2010) Empowerment of women farmers through value addition on minor millets genetic resources: a case study in Karnataka. Indian Journal of Plant Genetic Resources 23(1):132–135

Virk DS, Chakraborty M, Ghosh J, Harris D (2006) Participatory evaluation of horsegram (*Macrotyloma uniflorum*) varieties and their on-station responses to on-farm seed priming in Eastern India. Experimental Agriculture 42(4):411–425. doi:10.1017/S0014479706003838

Waruhiu AN, Kengue J, Atangana AR, Tchoundjeu Z, Leakey RRB (2004) Domestication of *Dacryodes edulis*: 2. Phenotypic variation of fruit traits in 200 trees from four populations in the humid lowlands of Cameroon. Food, Agriculture & Environment 2:340–346

WBCSD (2008) Sustainable consumption facts and trends from a business perspective. World Business Council for Sustainable Development, USA, Belgium, Switzerland, 38 p http://www.sbc.org.nz/_attachments/WBCSD_sustainable_consumption_research_Dec_08.pdf. Accessed 12 Jul 2012

Weinberger L, Lumpkin TA (2007) Diversification into horticulture and poverty reduction: a research agenda. World Development 35(8):1464–1480. doi:10.1016/j.worlddev.2007.05.002

Weinberger K, Msuya J (2004) Indigenous vegetables in Tanzania: significance and prospects. Technical Bulletin No 31. AVRDC Publication, Shanhua, p 70

WHO (2008) Worldwide prevalence of anaemia 1993–2005: WHO global database on anaemia. de Benoist B, McLean E, Egli I, Cogswell M (eds). WHO, Geneva, Switzerland

WHO (2009) Global prevalence of vitamin A deficiency in populations at risk 1995–2005. WHO global database on vitamin A deficiency. WHO, Geneva, Switzerland

Wickens GE (1991) Management issues for development of non-timber forest products. Unasylva 42:3–8

Will M (2008) Promoting value chains of neglected and underutilized species for pro-poor growth and biodiversity conservation. Global Facilitation Unit for Underutilized Species, Rome, Italy. http://www.underutilized-species.org/documents/PUBLICATIONS/promoting_vc.pdf. Accessed 15 Jun 2012

Witcombe JR, Joshi A, Joshi KD, Sthapit BR (1996) Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity. Experimental Agriculture 32(4):445–460. doi:10.1017/S0014479700001526

Witcombe JR, Joshi KD, Gyawali S, Musa AM, Johansen C, Virk DS, Sthapit BR (2005) Participatory plant breeding is better described as highly client-oriented plant breeding. I. Four indicators of client-orientation in plant breeding. Experimental Agriculture 41(3):299–319. doi:10.1017/S0014479705002656

Witcombe JR, Devkota KP, Joshi KD (2010) Linking community-based seed producers to markets for a sustainable seed supply system. Experimental Agriculture 46(4):425–437. doi:10.1017/S001447971000061X

Wojtkowski P (2008) Agroecological economics. Sustainability and biodiversity. Academic Press, Amsterdam, p 293

Wollenberg E, Belcher B (2001) NTFPs—income for rural populations or not? ETFRN News http://hdl.handle.net/10568/18522. Accessed 12 Jul 2012

Wood D, Lenné JM (1999) Agrobiodiversity: characterization, utilization and management. CABI Publishing, Wallingford, pp 1–13

Wunder S, Engel S, Pagiola S (2008) Taking stock: a comparative analysis of payments for environmental services programs in developed and developing countries. Ecological Economics 65(4):843–852. doi:10.1016/j.ecolecon.2008.03.010

Yadav M, Singh DB, Chaudary R (2009) Genetic analysis and powdery mildew resistance in bitter gourd (*Momordica charantia* L.). Acta Horticulturae (ISHS) 806:331–338

Yalu A, Singh D, Yadav SS (2009) Taro improvement and development in Papua New Guinea—a success story. Association for the Promotion of Agricultural Research Institutions (APAARI), Bangkok, p 35

Yenagi NB, Handigol JA, Bala Ravi S, Mal B, Padulosi S (2010) Nutritional and technological advancements in the promotion of ethnic and novel foods using the genetic diversity of minor millets in India. Indian Journal of Plant Genetic Resources 23(1):82–86