THEMATIC BACKGROUND STUDY

The Contribution of Plant Genetic Resources to Health and Dietary Diversity

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EXECUTIVE SUMMARY

About 7 000 plant species have been cultivated or collected for food in the past, but today fewer than 150 species are under commercial cultivation and only 30 species provide 95 percent of human food energy needs. Wheat, rice and maize alone provide over 50 percent of the global human protein and dietary energy supply. Thousands of species are marginalized by both agriculture and nutrition researchers, yet some of these minor crops may be more nutritious than the major crops. A diversity of crops is the foundation of a balanced, nutritious diet.

But dietary diversity depends not only on a diversity of crops but also of diversity within crops. There is an increasing body of evidence of wide variation in nutrient contents within species, but data are lacking on nutrient composition and dietary intake for many underutilized species as well as for cultivars within species. Such information is needed both to enhance use of more nutritious cultivars in diets and to make them available for use in breeding programmes aimed at increasing the nutrient content of more commonly used varieties of the same species, eliminating the need for transgenic modifications.

Demographic changes, especially population growth and urbanization, are leading to rapid changes in diets. With higher disposable incomes and urbanization, people move away from diets based on indigenous staple grains or starchy roots, locally grown vegetables, other vegetables and fruits, and limited foods of animal origin, towards diets that include more preprocessed food, more foods of animal origin, more added sugar and fat. As a result, hunger and malnutrition coexist with obesity and obesity-related cardiovascular and degenerative diseases in developing countries.

The enhanced sustainable use of biodiversity for nutrition, such as growing locally adapted varieties and underutilized crops, would contribute to ecosystems conservation and counteract the simplification of agricultural systems, the simplification of diets and erosion of food systems and cultures.

This paper comprises four sections. The first lays out current knowledge about the state of edible plant genetic resources, including their conservation in gene banks, home gardens and botanic gardens and in forests. This is followed by a review of the role of biodiversity in food systems, focusing on recent dietary changes and diversity-based strategies for alleviating nutrition and health problems, including efforts to improve the nutritive value of crops through breeding and genetic engineering. The third section focuses on the state of knowledge of dietary composition and the nutritional value of food crops, especially underutilized species and at the intraspecific level. This highlights the lack of such information at present, linked to the lack of methods for obtaining, analysing, and using data on biodiversity in food consumption studies and nutritional programmes, and makes recommendations for actions to promote dietary diversification and use of biodiversity to improve nutrition and health. The final section of the report provides conclusions and recommendations for actions needed to support conservation and sustainable use of plant genetic resources to improve health and nutrition of both rural and urban populations.

The challenge of reducing malnutrition remains great and increasing our knowledge and use of existing diverse plant genetic resources can positively contribute to nutritional improvements.

1. EDIBLE PLANT GENETIC RESOURCES

1.1 State of crop diversity and edible plant genetic resources

There are estimated to be more than 300 000 higher plants (Groombridge and Jenkins, 2002; Ungricht, 2004), but only about 7 000 have been cultivated or collected for food (Khoshbakht and Hammer, 2008). Today, fewer than 150 species are under commercial cultivation and, of those, 30 species provide 95 percent of human food energy needs. Thousands of species are marginalized by both agriculture and nutrition researchers (GFU, 2007). Some 1 000 species of cultivated plants (excluding ornamentals) are thought to be threatened, of which roughly 200 species are listed by Hammer and Khoshbakht (2005).

Cereals play an important role in world agriculture, and they contribute significantly to food and nutrition security. Some cereals, particularly rice, wheat and maize, sorghum and millet are staple foods. Wheat, rice and maize are of prime importance – these three crops alone provide over 50 percent of the global human protein and dietary energy supply (Wood *et al*., 2005, FAOSTAT 2003, 2004). Maize has the potential for yielding more per unit of land area than other cereals.

A wide range of tuber crops are grown worldwide, but only five species account for the majority of the total world production: potato (*Solanum tuberosum*), cassava (*Manihot esculenta*), sweet potato (*Ipomea batatas*), yams (*Dioscorea* spp.) and taro (*Colocassia, Cytosperma, Xanthosoma* spp.) (O'Hair and Maynard, 2003; Maynard and O'Hair, 2003).

Although agriculture relies on relatively few crops, each comes in a vast range of different forms. They may vary, for example, in height, flower colour, branching pattern, fruiting time, seed size or flavour. The wild relatives of crops often offer a greater variety of traits than their domesticated relatives. However, this diversity is being rapidly eroded. Once, thousands of rice varieties were cultivated, but now there are fewer than 100 cultivars grown in any given country (Kennedy and Burlingame, 2003). The main crops are quite well represented in *ex situ* collections and gene banks, but crop wild relatives (CWR) are underrepresented in *ex situ* collections and are at risk in their native environments.

While genetic diversity within species is needed to supply useful traits for improving the nutritional value of specific crops, diversity of species provides a range of alternative crops that offer options for a more diverse and balanced diet. Minor crops are more important in some regions than in others. For example, in sub-Saharan Africa, sorghum and millets are as important as rice and wheat in contributions to the diet (FAOSTAT, 2003), and may be more nutritious (Table 1). But the diversity of these minor crops is less well understood than that of major crops, and much less is conserved either in *ex situ* gene banks or *in situ*. A large discrepancy exists between the potential role of minor crops in improving food security and nutrition and the small amount of attention they have received (GFU, 2007).

1.2 Edible plant genetic resources in gardens

1.2.1 Home and school gardens

The home garden is defined in this document as a supplementary food production system managed and controlled by household members. Home gardening provides a low-cost, sustainable strategy for increasing household food security by providing direct access to food (Marsh, 1998a, b). The garden may become the principal source of household food and income during periods of stress, e.g. the preharvest lean season, harvest failure.

TABLE 1

Major nutrients and mineral composition of the four important minor cereals in Africa, compared with wheat

Major Nutrients (g/100g)	Pearl millet	Finger millet	Teff	Fonio	Wheat
Protein	11	7.3	9.6	9.0	7.8
Carbohydrate	70	74	73	75	71
Fat	4.8	1.3	2.0	1.8	1.1
Crude fibre	2.3	3.6	3.0	3.3	2.0
Ash	1.9	2.6	2.9	3.4	1.6
Energy (KJ)	1 483	1 403	1 411	1 541	1 105
Mineral (mg/100g)					
Calcium	37	344	159	44	30
Copper	9.8	0.5	0.7		1.1
Iron	114	9.9	5.8	8.5	4.0
Manganese	190	140	170		120
Magnesium	0.8	1.9	6.4		3.6
Phosphorus	339	250	378	177	400
Potassium	418	314	401		330
Sodium	15	49	47		16
Zinc	2.0	1.5	20		3.5
Chloride	43	84	13		

Source: Obilana (2003)

Although a portion of the crop may be sold, some of the produce is consumed by the producers, and the functions and output of the home garden complement field agriculture by providing a diversity of fresh foods that improve the quantity and quality of nutrients available to the family. Households with gardens typically obtain from them more than 50 percent of their supply of vegetables and fruits (including such secondary staples as plantains, cassava, taro and sweet potato), medicinal plants and herbs.

Botanical surveys in more than 400 home gardens in south-western Bangladesh revealed 419 species (59 percent native, 51 percent trees and shrubs), six of which were on the IUCN Red List for Bangladesh (Kabir and Webb, 2008a; Kabir and Webb, 2008b; Webb and Kabir, 2009). Studies in other countries found 591 species in 36 home gardens across a large elevational transect in Venezuela (0–1500 m, Quiroz *et al*., 2004); 573 species in 30.5 ha surveyed in southern Vietnam (Hodel and Gessler, 1999); and 276 species in semi arid region and 414 in Alta Verapaz region of Guatemala (Leiva *et al*., 2002). Examples of other studies are given in Table 2.

Home gardening has received little quantitative research attention as a possible biodiversity conservation tool despite the prevalence of home gardens in the tropics and their importance for livelihood supplementation in urban and rural settings (Kumar and Nair, 2006).

School gardens also can be used to promote crops that are neglected and undervalued, and can be a powerful tool to improve the quality of nutrition and education of children and their families in rural and urban areas in developing countries, if they are integrated with national agricultural, nutrition and education programmes. Since 1997, over 150 school garden microprojects have been supported by FAO's TeleFood programme in more than 40 countries.

TABLE 2

Edible species in home gardens

Country, source	Aim	Results and number of species grown
South Africa, High and Shackleton (2000)	Evaluation of the wild plant resources harvested from home gardens and arable plots by inhabitants of a rural village in the Bushbuckridge lowveld (South Africa), and examines their importance relative to other domesticated crops.	Wild plants represented 31% of the value of all plants grown on residential plots relative to the 69% for domesticated crops (including fruit trees). On average each household made use of 4 to 5 species of wild plants growing on their residential plot. Approximately 72% of the total value of all plant products was consumed by the household and the remaining 28% was sold.
North East India, Barak Valley, Assam; Das and Das (2005)	Home gardens are important *in situ* conservation of plant diversity and can also serve as gene pools for the eroding indigenous tree species, and in accordance with the Convention of Biological Diversity Article 7, 8 and 10(c), making an inventory of such areas can help in the identification and conservation of biodiversity while assessing the sustainability of the system.	The home garden size falls within the range of 0.02–1.20 ha with an average of 0.30 ha. The total number of species encountered in the home gardens was 122, with indigenous fruit trees as the dominant use-component. Home gardens exhibit complex structure, both vertically and horizontally. The vertical structure of home gardens is composed of 3–4 canopy layers. The home gardens appear to be a haphazard mixture of trees, shrubs and herbs, but the locations of most plants were found to be deliberate. The species relative importance values show that the most dominant components in home gardens were *A. catechu* (52.7%), *Musa* sp. (22.2%), *A. heterophyllus* (9.4%) and *M. indica* (9.3%). Other important species of home gardens include *T. ciliata*, *Psidium guajava*, *Carica papaya*, *Citrus maxima* and *Cocos nucifera*.
5 countries: Ghana, Vietnam, Guatemala, Cuba, Venezuela; Eyzaguirre and Watson (2002); Trinh *et al.* (2003)	Strengthen the link between biodiversity conservation and development, 3 year research project on plant genetic resources of home gardens.	Vietnam: Pomelo (9–14 varieties), banana (*Musa* spp.) (9–12 var.), luffa (*Luffa cylindrical*) (6 var.), taro (*Colocasia esculenta*) (8–17 var.) Ghana: Yam (8 species, one wild), plantain (*Musa* spp.) (15 local var.), pearl millet (*Pennisetum glaucumi*) (3–4 var.) Guatemala: Zapote (*Pouteria sapota*), chillies (*Capsicum* spp.), huisquil (*Sechium edule*) Cuba: Lima bean (*Phaseolus lunatus*) (16 agro-morphological descriptors, 3 cultivated, 1 wild), zapote (*Pouteria sapota*), chilli (*Capsicum*) (3 species,) Venezuela: Papaya (*Carica papaya*) (5), avocado (*Persea americana*) (18), chilli (*Capsicum* sp.) (11), beans (*Phaseolus vulgaris*) (14).

Home gardens are not limited to rural areas, but can also benefit the poorest segments of the urban and peri-urban population. Urban home-, school-, community- and commercial-gardening contributes to an important percentage of total non-grain urban food supply in many developing countries, adding significantly to urban food self-sufficiency (UNDP, 1996).

1.2.2 Botanic gardens

There are over 2 500 botanic gardens worldwide. Botanic gardens play a key role in plant conservation, and are estimated to keep at least 100 000 species as living plants (nearly 30 percent of the world's plant diversity) and to maintain 250 000 seed bank accessions (Wyse Jackson, 1999).

Waylen (2006) summarises current work undertaken by botanic gardens that relates to human well-being, with a focus on nutrition, healthcare, poverty alleviation and community support. For example, Kisantu Botanic Garden in the Democratic Republic of the Congo has conducted trials on the popular fruit mangosteen, to enable local farmers to extend the shelf-life of the harvested fruit and so reach a larger market (Kibungu Kemelo, 2004).

1.3 Edible genetic resources in forests

The worldwide decline of forest habitat and the related loss of biodiversity are an urgent environmental issue. The best estimate is that over 8000 tree species, or 10 percent of the world's total, are facing extinction (Bioversity International, 2008).

Habitat decline contributes more than any other factor to the current extinction rate, which exceeds the natural rate by 100–1000 times (Baillie *et al*., 2004). The loss and fragmentation of forested ecosystems impairs critical ecosystem services.

Locally and sustainably managed forests enhance rural livelihoods, provide non-cash income (such as wild foods and fruits) and conserve biodiversity. They are important in helping to even out seasonal fluctuations in food availability, and in providing nutritious foods.

The most contentious aspects of plantation forestry are the widespread use of exotic species, and the fact that large areas have been converted into unnatural forest-types (Tucker *et al*., 1998). Plantation floras are typically impoverished compared with natural forests. However, plantations occur along a continuum from exotic monocultures with a very simple structure to heterogeneous stands of native species.

Methodologies are increasingly being developed to include nutrition and household food security in forestry planning (Egal *et al*., 2000). They need to be supported by more evidence and combined with documentation on the nutritional characteristics and patterns of use of forest foods.

2. NUTRITION, BIODIVERSITY AND HEALTH

2.1 State of food systems

A food system includes all processes involved in feeding a population: growing, harvesting, processing, packaging, transporting, marketing, consumption, and disposal of food. Globally, food systems are not providing enough balanced nutrient output to meet all the nutritional needs of every person, especially resource-poor women, infants and children in developing countries (Bouis *et al*., 1999). FAO calculated that there were 848 million undernourished people in 2005 (FAO, 2007–2008), yet there are billions with micronutrient deficiencies, more than half of whom have at least adequate energy intakes. Iron, vitamin A, zinc and iodine are deficiencies with the highest global prevalence (UNICEF, 2004), but other deficiencies such as several B vitamins, selenium, calcium, zinc, sulphur-containing amino acids and lysine, and fatty acids of the n-3 series are measured worldwide.

According to the UN *2006 Revision* (UN, 2007), the world population will likely increase to 9.2 billion by 2050. Moreover, virtually all population growth between 2000 and 2030 will be urban (FAO, 2003a). An important factor determining demand for food is urbanization. With higher disposable incomes and urbanization, people move away from diets based on indigenous staple grains or starchy roots, locally grown vegetables, other vegetables and fruits, and limited foods of animal origin, towards diets that include more preprocessed food, more foods of animal origin, more added sugar and fat (Wilkinson, 2004; Popkin, 2006a, b). For example, in China, between 1981 and 2001, human consumption of grains dropped by 7 percent in rural areas and 45 percent in urban areas. Meanwhile, meat and egg consumption increased by 85 percent and 278 percent respectively in rural areas and by 29 percent and 113 percent in urban areas (Zhou *et al*., 2003).

This transition leads to a rapid increase in global energy imbalances, and a rapid increase in diet-related chronic diseases, including heart disease, diabetes, hypertension and certain cancers (Kim *et al*., 2000, 2001; Lako and Nguyen, 2001; Matsumura, 2001; Khor, 2001; Galal, 2003; Lipoeto *et al*., 2004; Hawks *et al*., 2004). Rapid dietary change of indigenous peoples worldwide is also posing threats to use of traditional food from the local environment and the traditional knowledge required for traditional food system maintenance (Kuhnlein and Receveur, 1996; Raschke and Cheemaa, 2008; Welch *et al*., 2009).

2.2 Strategies to prevent and alleviate malnutrition

There are several broad categories of interventions that can alleviate malnutrition, and there are four categories of direct interventions believed to be successful in reducing micronutrient malnutrition: supplementation, disease reduction, fortification and dietary diversification (Bouis, 1996). Increasing food biodiversity can play an important role in dietary diversification (see Section 3 of this document).

2.2.1 Improving the nutritional value of crops

People in the developing countries, particularly in Asia, consume cereal grains as staple food and derive their energy and protein requirements from such cereals. Nutritional improvement in such cereals, such as changing the amino acid profile of cereal proteins and making them more balanced, would have an impact on hundreds of millions of people without altering their food habits. The basic information required to develop nutritionally improved cultivars is the range of intraspecies diversity, and nutrient composition data by species and variety (Burlingame *et al.*, 2009a).

The utilization of plant genetic resources to enhance the chemical composition of a few staple foods through biotechnology or conventional breeding has led to the development of varieties with enhanced levels of micronutrients, such as enhanced beta-carotene sweet potatoes, quality-protein maize (QPM) and beta-carotene-enriched rice (Johns and Eyzaguirre, 2007).

2.2.1.1 The traditional approach: breeding for nutritional improvement

Examples of conventional breeding efforts directed at improving the nutritional quality of crops include maize and rice. In maize, the genetic manipulation of protein quality began in 1964 with the discovery of high lysine mutants (Mertz *et al*., 1964). During the mid-1990s, 55 QPM inbred lines were made available to public and private sectors. In recent years at least 22 countries have released QPM materials, including China, India and Vietnam. From limited studies on humans and animals, QPM has been shown to have high biological value and high digestibility, but additional studies are needed to make nutritional and economic assessments (Vasal, 2002).

In rice, the International Rice Research Institute (IRRI) has been systematically documenting the iron and zinc content of hundreds of rice varieties (Graham *et al*., 1999). This work has led to the identification of varieties with high levels of iron and zinc content that can then be selected to produce improved varieties. The Africa Rice Center (WARDA) has combined the beneficial traits of both *Oryza glaberrima* and *Oryza sativa* using conventional and modern techniques. The new 'NERICA' (NEw RIce for AfriCA) varieties have higher protein content than the *Oryza sativa* varieties commonly grown in the region (WARDA, 1999).

2.2.1.2 The modern approach: genetic engineering for nutritional improvement

Scientific progress in the area of genetic mapping has made it possible to alter the biochemical structure of plants genetically by utilizing the genes of diverse plant species. 'Nutritional genomics' is a term used for the technologies used to manipulate the synthesis of nutritionally valuable plant compounds (Tian and DellaPenna, 2001a, b).

A different application of the technology is transgenetic manipulation, which introduces a completely new biosynthetic pathway into the plant. An example of this is the development of golden rice, in which an entire biosynthetic pathway for beta-carotene was introduced into a Japonica rice line through the use of a technique called agrobacterium-mediated transformation. This resulted in rice grains containing significant amounts of previously non-existent carotenoids, the precursors of vitamin A. The first experimental line contained 1.6 mcg/g carotenoid (Ye *et al*., 2000). In 2005 a new variety called Golden Rice 2 was announced which produces up to 37 mcg/g (Paine *et al*., 2005). In developing countries, where vitamin A deficiency prevails, golden rice is expected to reach the target populations, namely the urban poor and rural populations, particularly those living in remote areas, and provide this important micronutrient sustainably through agriculture and local trade (Zimmermann and Qaim, 2004; Al-Babili and Beyer, 2005).

The iron content of rice grains has also been doubled using a similar process, introducing a ferritin gene from *Phaseolus vulgaris* (Lucca *et al*., 2000). Additionally, a heat-tolerant phytase from *Aspergillus fumigatus* was introduced into the rice to boost absorption of the iron by humans.

Other important vitamins that could be enriched in plants using gene technology are folic acid and vitamin E. The accumulation of alpha-tocopherol has been suggested as a means of vitamin E fortification of plants (Hofius and Sonnewald, 2003), and has been experimented with in soybean (Sattler *et al.*, 2004). Similarly, folic acid accumulation has been enhanced in tomato and other crop plants (Diaz de la Garza *et al*., 2004; Hossain *et al*., 2004, DellaPenna, 2007).

Questions remain as to the degree to which micronutrient levels can be increased, the extent to which the increased levels of micronutrient in the grain will increase levels of bioavailability in humans.

2.3 The contribution of biodiversity to balanced diet and health

Attempts to reverse the trend of the problems of micronutrient deficiencies and coexisting obesity and related cardiovascular and degenerative diseases using single-nutrient intervention strategies have met with limited success, resulting in renewed calls for food-based approaches. The deployment of agricultural biodiversity is an approach that entails greater use of local biodiversity to ensure dietary diversity (Frison *et al*., 2006).

Links between food and health are increasingly found in terms of the functional benefits provided by phytochemicals, including numerous carotenoids and phenolics (Johns and Sthapit, 2004). Phytochemical are substances that typically occur in small quantities in plant foods and possess health-protective benefits: stimulants of immunity, antioxidants, glycaemic and lipidaemic agents can moderate non-communicable diseases such as diabetes, cancer and cardiovascular disease (see Table 3).

2.3.1 The example of antioxidants

Plants vary in their polyphenolic content and antioxidant activities, and fruits generally have higher antioxidant activity than vegetables (Issa *et al*., 2006). Many of the common fruits and vegetables contain bioactive compounds with antioxidant activities that may potentially be chemoprotective against cancers (Wargovich, 1997, 1999, 2001; Wargovich *et al*., 1996, 2001) (see Table 4). Polyphenols are of particular importance due to their wide availability in nature and the considerable antioxidant activity for many of them (Kris-Etherton *et al*., 2002). Over 4 000 flavonoids, a subcategory of phenolic compounds, have been identified in plants (Hollman, 1997). Flavonoids have extensive biological properties that promote human health and help reduce the risk of disease: they extend the activity of vitamin C, act as antioxidants, protect LDL cholesterol from oxidation, inhibit platelet aggregation, and act as anti-inflammatory and antitumor agents (Manach *et al*., 1996; Cook and Samman, 1996; Hertog *et al*., 1993).

2.4 Enhancing the contribution of biodiversity to nutrition

Numerous bioactive compounds appear to have beneficial health effects, but still much research needs to be conducted, as for example studies on specific community diets (Craig and Beck, 1999; Johnson, 2004). Systematic research is needed in screening traditional foods and diets for phytochemicals and assessing their potential in protecting against chronic diseases.

More food composition studies on biodiversity are needed to measure the nutrients, non-nutrients and bioactive compounds richness that can be found in cultivars and varieties of commonly consumed plants, as well as wild and underutilized plants.

3. BIODIVERSITY, FOOD CONSUMPTION AND COMPOSITION

Biodiversity is considered essential for food security and nutrition and can contribute to the achievement of the MDGs through improved dietary choices and positive health impacts. However, it is seldom included in nutrition programmes and interventions. This is due in large measure to insufficient data on scientific identification, the nutritional value of food biodiversity, and lack of methods for obtaining, analysing, and using data on biodiversity in food consumption studies and nutritional programmes.

FAO is thus building capacity in countries to generate, compile and disseminate varietally-differentiated nutrient data, by introducing more compositional data on biodiversity in national food composition databases and tables; developing and using dietary assessment instruments that capture food intake at the species and variety/cultivar/breed level; and allowing marketing and food labelling that encourage awareness of food plant varieties and food animal subspecies. This is aimed at increasing the use of nutrient-rich indigenous and traditional food crops to help the world's poor and malnourished to diversify and thus improve their diet.

3.1 Food composition

Nutrient composition and dietary intake data is lacking for many underutilized species as well as for varieties within species (Kuhnlein, 2003; Rodriguez-Amaya *et al*., 2008).

Studies that compare one variety with another commonly focus on a specific macro- or micronutrient and do not provide complete nutrient analysis. Many food composition tables and databases fail to capture individual foods by variety/strain/breed, preferring instead to group foods generically. Reasons for this include omissions on the part of both compilers of nutritional information on foods and persons who collect dietary intake data.

TABLE 3

Examples of functional properties of foods important in developing country food systems

Plant food	Bioactive compound	Function	Putative biological effect
Cereals			
Buckwheat	Proteins, phenolics	Heart disease and diabetes risk reduction	
Finger millet	Fibre	Diabetes risk reduction	
Amaranth	Fibre, protein, tocotrienols, squalene	Cholesterol-lowering	
Proso millet	Protein	Heart disease risk-reduction	
Rice	Amylase	Lower glycaemic index	
Legumes			
Soybean	Isoflavones; phytosterols	Heart disease; cancer	↓TC and LdL-C, LDL-C oxidation, TG, thrombosis, AOx, antimutagen, angiogenesis ↑HDL-C, apoptosis
Chickpea	Protein; saponins	Heart-disease risk reduction	
Fruits and vegetables			
Tomato	Lycopene	Anti-cancer; antioxidant	↓LDL-C and LDL-C oxidation, AOx, antimutagen
Garlic and onions	Organosulphur compounds, Allicin	Heart-disease risk reduction	↓TC and LDL-C, TG, cholesterol and FA synthesis, BP, thrombosis, AOx, carcinogen detoxification, tumour promotion
Cruciferous vegetables	Isothiocyanates, glucosinolates, indoles	Anti-cancer	↓tumour initiation/promotion, carcinogen activation, carcinogen detoxification
Leafy vegetables	Lutein	Prevent cataracts and	
Bitter gourd	Peptides, terpenoids	Macular degeneration	
Spices and condiments			
Fenugreek	Coumarins, steroids, alpha-tocopherol	Anti-diabetic	
Thyme	Polyphenols	Anti-diabetic	
Rosemary	Polyphenols	Antioxidant	

AOx=antioxidant activity; BP=blood pressure; CVD=cardiovascular disease; HDL-C=high-density lipoprotein cholesterol; HMGR=HMGCoA reductase; LDL-C=low-density lipoprotein cholesterol; TC= total cholesterol; TG= triglycerides.
Sources: Kris-Etherton et al. (2002); Johns and Eyzaguirre (2007).

TABLE 4
Phenolic antioxidants in dietary sources

Dietary source	Bioactive compound	Putative mechanism of action
Red grapes, red wine	Resveratrol	Modulation of cell signalling pathways, inhibition of angiogenesis, induction of apoptosis
Green tea	Catechins	Modulation of cell signalling pathways, inhibition of COX-2 and iNOS enzymes, anti-angiogenis, induction of apoptosis
Chilli peppers	Capsaicin	Modulation of cell signalling pathways, inhibition of phase I enzymes
Ginger	6-gingerol	Modulation of cell signalling pathways
Onions	Quercetin	Modulation of cell signalling pathways, inhibition of COX-2
Broccoli	Isothiocyanates	Induction of phase II enzymes, modulation of cell signalling pathways, induction of apoptosis

Adapted from Issa *et al*. (2006).

This has been addressed by development of the indicator for food composition for biodiversity and nutrition by the FAO-Bioversity International Expert Consultation as part of FAO/UNU International Network of Food Data Systems (INFOODS) (FAO, 2008a). This indicator helps in the generation, compilation and dissemination of food composition data in local ecosystems below the species level, i.e. at variety level for plants, and wild, neglected and underutilized foods at species level. The food composition indicator is defined as a count of the number of foods with a sufficiently detailed description to identify genus, species, subspecies and variety/cultivar/breed, and with at least one value for a nutrient or other bioactive component.

This indicator will help to improve the management of biodiversity and to increase the value of biodiversity's contribution to food security and nutrition in participating countries in determining which plants should be preferentially conserved and utilized.

3.1.1 Biodiversity and food composition

There is an increasing body of data showing that individual species or cultivars of the same species can have markedly different nutrient contents (Kennedy and Burlingame, 2003; Huang *et al*., 1999) (see Table 5), and recent studies show that rural people are capable of identifying the varieties or cultivars used in foods (Kennedy *et al*., 2005).

Food composition data at the taxonomic level below species can be used to explore the real and potential contribution of these foods to nutritional improvements. Such data are also important for the sectors of health, trade (absence of cultivar-specific food composition data can constitute a technical barrier, since most potential export markets for unique species and cultivars require nutrient composition data for food labels), environment and agriculture (information on cultivar-specific nutrient content can be used in breeding programmes to enhance the nutrient content of more commonly used varieties of the same species, eliminating the need for transgenic modifications).

TABLE 5

Examples of nutrient composition within varieties

	Protein (g)	Fibre (g)	Iron (mg)	Vitamin C (mg)	Beta-Carotenes (mcg)
Rice	5.6–14.6		0.7–6.4		
Cassava	0.7–6.4	0.9–1.5	0.9–2.5	25–34	<5–790
Sweet potato	1.3–2.1	0.7–3.9	0.6–14	2.4–35	100–23 100
Taro	1.1–3	2.1–3.8	0.6–3.6	0–15	5–2 040
Breadfruit	0.7–3.8	0.9	0.29–1.4	21–34.4	8–940 <5–317
Eggplant		9–19		50–129	
Mango	0.3–1.0	1.3–3.8	0.4–2.8	22–110	20–4320
GAC					6 180–13 720
Apricot	0.8–1.4	1.7–2.5	0.3–0.85	3.5–16.5	200–6 939 (beta carotene equivalent)
Pandanus			0.4	5–10	14–902
Banana			0.1–1.6	2.5–17.5	42–2 780 <1–8 500

Data expressed per 100 g edible portion.
Source: Burlingame ***et al***. (2009a).

Most national and international dietary guidelines set a recommendation on the consumption of foods, including for fruit or fruit and vegetables. However, in food- and nutrition-insecure populations, intake of one fruit or vegetable variety over another can be the difference between micronutrient deficiency and micronutrient adequacy. For example, a study in the Marshall Islands (Englberger *et al*., 2006a), where Pandanus fruits are commonly consumed and where the population suffers from vitamin A deficiencies, showed that only two of the three varieties usually consumed are rich in carotenoids.

Brazil provides a good example of harnessing biodiversity to improve and nutrition successfully through the nutrient data. In recent years, food producers have become more cognizant of the value of nutrients and bioactive compounds in their produce. As a result, for example, lycopene-rich guava varieties, acerola and pitanga, which used to be only garden fruits, are now commercially produced and processed. The leafy vegetable rucula is also now widely consumed.

Foods gathered from the wild, including vegetables and fruits, have been the mainstay of human diets for centuries. Many are a rich source of micronutrients (see Table 6) and could make an important contribution to combating micronutrient malnutrition as well as providing food security. For example, *Sclerocarya birrea* (marula) is an integral part of the diet of communities in southern Africa. Marula fruits are high in vitamin C, providing about four times more vitamin C than an orange. The fruit and the kernel are rich in protein and minerals and are consumed with sorghum, millet or maize porridge. In Botswana the species are preserved by local people in areas of natural occurrence (Wynberg *et al*., 2002).

Unfortunately, wild foods have been neglected by researchers and policy-makers. Their chemical, nutritional and toxicological properties, the bioavailability of micronutrients, and their modification by various processing techniques still need to be properly documented. Such information would be of fundamental importance in addressing dietary deficiencies in impoverished rural communities (Flyman and Afolayan, 2006).

TABLE 6

Some neotropical fruits in Brazil that are excellent sources of provitamin A

Fruits	Protein (g)	Fibre (g)	Iron (mg)	Vitamin C (mg)	Beta-Carotenes (mcg)
Mauritia vinifera	Pulp	80.5	360		γ-carotene, 37
Astrocaryum vulgare	Pulp		107	3.6	
Eugenia uniflora	Pulp		9.5		b-zeacarotene, 5.9
Acrocomia makayayba	Pulp		55		
Bactris gasipaes	Boiled Pulp	3.2	22		γ-carotene, 18
Malpighia glabra			26	3.6	

Fruits	Protein (g)	Fibre (g)	Iron (mg)	Vitamin C (mg)	Beta-Carotenes (mcg)
Mammea americana	Pulp		14		β-apo-10′-carotenal, 5 β-apo-8′-carotenol,11
Spondias lutea	Pulp & peel		1.4	17	
Cariocar villosum	Pulp		1.2	4.4	

Note: By comparison, mango (***Mangifera*** spp.) and papaya (***Carica papaya***) provide 38–257 and 25–150 retinol activity equivalents per 100 g, respectively.
Source: Adapted from Rodriguez-Amaya (1996).

3.2 Biodiversity and food consumption

3.2.1 Dietary diversity, health and biodiversity

Dietary diversity (DD) is usually measured using a simple count of foods or food groups over a given reference period (Torheim *et al*., 2004; FAO, 2008b). DD is now widely recognized as a key component of healthy diets (Tucker, 2001): there is now an increasing body of evidence that shows a high correlation between dietary diversity and nutritional adequacy and health outcomes among the rural poor, particularly women and children. In some populations, DD has also been shown to be positively associated with anthropometric indicators of nutritional status among young children (Arimond and Ruel, 2004; Hatloy *et al*., 2000; Kennedy *et al*., 2007; Onyango, 2003; Onyango *et al*., 1998; Roche *et al*., 2007, 2008; Ruel, 2003; Savy *et al*., 2005, 2006). All this suggests that one possible strategy for improving the health of poor people in developing countries is to promote dietary diversity.

Although many traditional subsistence systems depend on one or more staples such as cassava, rice or maize, such diets are kept diverse and balanced through small amounts of sauces, condiments, snacks and beverages obtained from plants (Johns and Maundu, 2006). In some parts of Africa, diets based on staple grains depend for their supply of vitamins on tree products, in the form of oil seeds, edible leaves and fruits (Odgen, 1990).

Dietary diversification is thus a fundamental principle of nutrition in order to ensure adequate nutrient intakes, and quantifying the consumption of food biodiversity can provide a deeper understanding of overall dietary diversity. There is an ongoing need to promote and maintain food diversity, and, with it, biodiversity, at the regional level and between communities.

3.2.2 Traditional diets and change in consumption of traditional foods

Rapid dietary change of indigenous peoples worldwide is causing decline in use of traditional wild food and in the traditional knowledge required for traditional food system maintenance (Kuhnlein and Receveur, 1996; Kuhnlein *et al*., 2003; Damman *et al*., 2008). Urbanization, particularly for those facing extreme poverty in the urban environment, is recognized as a significant force to dietary change and consequent poor nutrition, especially for children (Kuhnlein *et al*., 2003).

Use of traditional foods is declining because of several factors:

- a loss of knowledge about which local plants are edible (Ladio and Lozada, 2004; Reyes-García *et al*., 2005; Tabuti, 2006; Pardo-de-Santayana *et al*., 2007; Ali-Shtayeh *et al*., 2008, Rijal, 2008);
- change in consumption patterns from traditional food plants to introduced crops (Whiting and Mackenzie, 1998; Krahn, 2005; Tomlins *et al.*, 2005);
- changes in livelihood patterns that limit the amount of time spent gathering wild foods (Arnold and Ruiz Pérez, 1998; Brown and Lapuyade, 2001; Dounias *et al*., 2007) or processing and preparing it (traditional food-processing techniques can be time consuming) (Smith, 1995);
- the general shift from gathered to purchased foods as rural communities join the market economy and non-timber forest products lose ground to other food sources (Godoy *et al.*, 1995; Arnold and Ruiz Pérez, 1998; Byron and Arnold, 1999, Reyes-García *et al*., 2005).
- small local produce markets are being replaced by supermarkets in developing countries.

The rapid proliferation of supermarkets across East and Southern Africa, for example, is transforming food systems: changes to the supply and distribution of produce are having a direct impact on the lives of millions of small farmers (FAO, 2003b). In South Africa, for example, supermarkets already account for more than 55 percent of national food retail.

With increased market integration, farmers show a tendency towards replacement of traditional crops with introduced ones, as well as a reduction in the number of species or varieties grown (VanDusen *et al*., 2005).

3.2.3 Linking biodiversity and traditional diets to health

Given the considerable differences in nutrient composition found among varieties of a crop, consumption of different varieties and breeds within a species may have a significant impact on nutritional adequacy. Yet few studies have attempted to measure food biodiversity at the cultivar/variety level. Dietary assessment instruments scarcely attempt to collect intake information on species or varieties, because compositional data are not available for evaluation and because it was widely believed that survey participants were not able to recognize foods at species or subspecies level (Kennedy and Burlingame, 2003). However, recent research suggests that this is not the case. A survey in Bangladesh has shown that over 80 percent of households were able to identify rice by cultivar and 38 different cultivars were named (Kennedy *et al*., 2005).

Understanding how communities supplement the indigenous/ traditional diet is imperative to develop and evaluate specific nutrition interventions and future research protocols.

The traditional food systems of indigenous peoples contain numerous micronutrients that have been poorly described and reported in scientific literature. This lack of scientific coverage prevents the information from being included in health training programmes and public-health promotion programmes. It is therefore necessary to develop research on the analysis of the nutrient and non-nutrient properties of indigenous and traditional foods and to compile an easily accessible database on the diversity of nutrients and bioactive compounds in traditional foods within and between food crop species (Frison *et al*., 2006).

A procedure for documenting Indigenous Peoples' food systems was developed by researchers working with the Centre for Indigenous Peoples' Nutrition and Environment (CINE) at McGill University, Canada, and the FAO (Kuhnlein *et al*., 2006), in order to understand if the traditional food system could be used to improve micronutrient status of the community and to prevent or reverse the negative effects of the nutrition transition (obesity, poor quality diet).

Traditional knowledge and diverse food resources may be substantial enough to be used to improve indigenous people's micronutrient status. However, using traditional food resources for indigenous peoples in health promotion is most reasonably applied in rural areas where such food is most likely to be recognized by the group and readily available. In the case of traditional varieties of agricultural species, it is possible that urban agriculture and home gardens can be promoted to assist indigenous urban migrants.

3.2.4 Recommendations on dietary diversification and biodiversity

Diets in developing countries generally lack many nutrients, including energy, so that strategies need to also emphasize an increase in total food intake, in addition to a greater variety (Tontisirin *et al.*, 2002).

Promoting food crop diversity at both the species and subspecies levels is a key to improve nutrition. Promoting access to a wide diversity of food plants ensures the availability of a broad range of nutrients that combine to constitute a more balanced diet (Fassil *et al*., 2000).

Strategies to eliminate micronutrient deficiencies should include a food-based approach, such as the promotion of vitamin A-rich diets or the increase of iron intake through dietary biodiversity. The right food combinations of energy-rich staples, animal and/or fish as major sources of protein, and vitamin-, mineral- and phytonutrient-rich fruit and vegetables could constitute the types of diet promoted. Promotion of dietary biodiversity at the local, national and regional levels is a priority and should include the sharing of information and successful experiences in defending and enhancing the dietary use of plant diversity.

3.2.4.1 Priority actions

Successful interventions to support the use of biodiversity for health objectives should recognize both that dietary diversity is a fundamental way of resolving health problems related to malnutrition and that diversity-based approaches depend on the conservation and sustainable use of biodiversity.

Dietary diversity interventions

Dietary-diversity interventions can be adapted to the single-nutrient approach commonly adopted interventions in developing countries. For example, in recent years, a limited number of successful dietary diversification interventions against vitamin A deficiency have been reported, including in Bangladesh (Talukder *et al*., 2000), India (Chakravarty, 2000) and Tanzania (Kidala *et al*., 2000).

Promoting availability of diverse foods

Supermarkets and other commercial entities should be encouraged to participate in efforts to promote the use of biodiversity in food. For example, in Kenya, a local non-governmental organization called Family Concerns successfully promoted African leafy vegetables by linking small-scale producers with a supermarket chain (Johns *et al*., 2005).

Simple appropriate technology for the preservation of micronutrient-rich foods will need further development and promotion to ensure the foods are available year-round. Seed supplies and production technology will need to be developed to help farmers to meet growing demand for diverse crops.

Policies and regulations

International policies and regulations related to trade and to human rights, including cultural and food rights, must be developed to ensure the viability of food systems that guarantee the sustainability of local ecosystems and respect cultural traditions. For example, the international voluntary guidelines on the right to food (FAO, 2005) explicitly recognize the importance of customs and traditions on matters related to food.

Local policies should be developed that support dietary diversity. For example, agricultural and food policies should be formulated to promote and support home gardening for the explicit purpose of increasing household consumption of micronutrient-rich foods. 'Desirable' dietary patterns that meet micronutrient needs should be used in the formulation of agricultural policies and programmes.

Research

Research on indigenous food plants requires correct taxonomic identification, chemical analysis, and nutritional data. Research should focus on:

- **Enhancing the knowledge base on traditional foods:** knowledge of the foods that are part of the traditional food systems is imperative. There is a dearth of taxonomic and nutritional information on indigenous and traditional foods, and therefore they are largely ignored by international agencies in global food and nutrition initiatives. Surveys of traditional knowledge of food diversity and its use should be promoted. Methods should be developed for measuring dietary diversity and its association with nutritional and health status. Factors, including seasonality, that contribute to food choices of rural and urban dwellers should be studied.
- **Making use of indigenous knowledge:** there is evidence that indigenous communities recognize the health benefits of some of these food crops that are part of their traditional food systems. They are well aware of cultivar-specific differences in agronomic and dietary attributes (Kennedy et al., 2005), and they often describe certain cultivars or indigenous varieties as having particular nutritional or therapeutic value. This knowledge must be captured and documented and made accessible to those developing nutrition interventions and policies.
- **Enhancing laboratory analyses** and compilation of data on the nutrient and phytochemical composition of underutilized plant products, including consideration of seasonal variability.

4. CONCLUSIONS AND RECOMMENDATIONS TO BETTER SUPPORT THE CONSERVATION AND SUSTAINABLE USE OF PLANT GENETIC RESOURCES FOR NUTRITION

With the population explosion expected in the future, new food systems need to be developed to deliver enough nutrient rich food to deliver the required nutrients and micronutrients for a healthy diet. The challenge will be to support an agriculture which aims not only for productivity and sustainability, but also for balanced nutrition, or what has been called the *productive, sustainable, nutritious food systems paradigm* (Graham *et al*., 2001). The new food systems will need to be based on a more sustainable agriculture that will to conserve and use biodiversity to provide nutrition security and eliminate micronutrient malnutrition (Underwood, 2000).

Promoting food biodiversity at the local, national and regional levels is a key to improve nutrition, by ensuring the availability of a broad range of nutrients, micronutrients and bioactive compounds. Food systems that promote the consumption of a wide diversity of food plants at both the species and subspecies levels will help populations to better balance their diet. Combinations of energy-rich crops, animal and/or fish as major sources of protein, and vitamin-, mineral- and phytonutrient-rich fruit and vegetables could constitute the types of diet promoted.

Tools and indicators are needed to measure the nutritional values of food plants at the species and intraspecific levels and to determine the contribution of biodiversity to human nutrition and diets. The information gathered using these tools and indicators should be compiled into inventories of nutrient composition and consumption of foods at the species and intraspecific levels, and within specific agro-ecological zones. This will include introducing more nutrient composition data on biodiversity in food composition databases and tables; developing and using dietary assessment instruments that capture food intake at the species and variety level; and allowing food labelling that encourages awareness of the often unique composition of these neglected, nutritionally-rich foods.

Improved knowledge of the nutritional quality of traditional, wild and underutilized crops and varieties of these can help in promoting their production and consumption, including through policies and dietary guidelines. It can also be used to encourage the most vulnerable groups to use local food resources and avoid the transition to the use of imported foods that are of inferior nutrient density compared to local species. Education programmes should make the local populations aware of the nutritional benefit of consuming a traditional food, and market chains of local crops should be improved.

Studies are also needed into trends in consumption, comparing past and current food consumption behaviour. This information will help identify policies to promote the conservation of traditional food systems as a means of addressing nutritional and health issues, and can be used to promote public initiatives to influence food consumption behaviour and to maintain or increase the use of food biodiversity.

Public awareness campaigns will be needed to influence food consumption behaviour and win back people's attention to resources that have disappeared from the markets and diets of local populations. A successful example is the action undertaken by Bioversity International to promote the production and maintenance of diversity in the undervalued African leafy vegetables that have been found beneficial for the nutritional status and the incomes of women farmers (Chweya and Eyzaguirre, 1999).

The challenge of reducing malnutrition remains great and increasing our knowledge and use of existing diverse plant genetic resources can positively contribute to nutritional improvements.

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