EcoHealth 8, 381–399, 2011
DOI: 10.1007/s10393-011-0700-3

ECOHEALTH

Review

A Systematic Review on the Contributions of Edible Plant and Animal Biodiversity to Human Diets

Daniela Penafiel,[1,2,3] Carl Lachat,[2,4] Ramon Espinel,[3] Patrick Van Damme,[1] and Patrick Kolsteren[2,4]

[1]*Faculty of Bioscience Engineering, Department of Plant Production, Universiteit Gent, Coupure Links 653, 9000 Ghent, Belgium*
[2]*Faculty of Bioscience Engineering, Department of Food Safety and Food Quality, Universiteit Gent, Coupure Links 653, 9000 Ghent, Belgium*
[3]*Faculty of Mechanical Engineering and Production Sciences, Rural Research Center, Escuela Superior Politécnica del Litoral, km 30.5 vía perimetral, Guayaquil, Ecuador*
[4]*Nutrition and Child Health Unit, Institute of Tropical Medicine, Nationalestraat 155, 2000 Antwerpen, Belgium*

Abstract: The sustainable use of natural and agricultural biodiversity in the diet can be instrumental to preserve existing food biodiversity, address malnutrition, and mitigate adverse effects of dietary changes worldwide. This systematic review of literature summarizes the current evidence on the contribution of plant and animal biodiversity to human diets in terms of energy intake, micronutrient intake, and dietary diversification. Peer-reviewed studies were searched in ten databases using pre-defined search terms. Only original studies assessing food biodiversity and dietary intake were included, resulting in a total of 34 studies. 7, 14, and 17 studies reported information in relation to energy intake, micronutrient intake, and dietary diversification, respectively. In general, locally available foods were found to be important sources of energy, micronutrients, and dietary diversification in the diet of particularly rural and forest communities of highly biodiverse ecosystems. The current evidence shows local food biodiversity as important contributor of nutritious diets. Findings are, however, limited to populations living in highly biodiverse areas. Research on the contribution of biodiversity in diets of industrialized and urban settings needs more attention. Instruments are needed that would more appropriately measure the dietary contribution of local biodiversity.

Keywords: nutrition, diet, food, diversity, energy, micronutrient

Introduction

Biodiversity or biological diversity refers to the variety and variability amongst all living organisms on earth. Therefore, the preservation of biodiversity is the basis for sustaining life. Biodiversity supplies a variety of genetic material that not only serves as food, but its sustainable use contributes to food and nutrition security (Frison et al. 2011), poverty reduction (Frison et al. 2005; Johns and Eyzaguirre 2007) and it is part of cultural heritage (Wahlqvist 2005). Worldwide, however, biological diversity from wild and agricultural ecosystems is declining. This trend negatively affects livelihoods, particularly of rural people who subsist from the foods supplied by the local biodiversity.

Today, about one billion people suffer from hunger and even more are deficient in micronutrients (FAO 2010c). In addition, one hundred million of disability adjusted life years are attributed to diet-related chronic

Published online: September 23, 2011

Correspondence to: Patrick Kolsteren, e-mail: Patrick.Kolsteren@ugent.be

diseases such as cardiovascular diseases and diabetes (Abegunde et al. 2007). This double burden of over- and under-nutrition-related diseases is rapidly increasing and particularly affects low and middle-income countries (Monteiro et al. 2004). For these countries, which highly depend on own food supply, food-based strategies rooted in the sustainable use of biological resources are needed to improve local diets. Unfortunately, the diet of most populations around the world nowadays are based on few crops (~30) which supply about 95% of the total energy (FAO 1997) and only few traditional societies still base their diets on about 200 species (Kuhnlein et al. 2009).

Several researchers consider that the promotion of biodiverse diets (diets with a high number of species) can be an effective and sustainable way to address the current dietary challenges by increasing the number of foods in the diet, and eradicating energy and micronutrient deficiencies (Burlingame et al. 2006; Flyman and Afolayan 2006; Johns and Eyzaguirre 2006; Englberger et al. 2010a; FAO 2010b). Diversified diets have been shown to contribute to food security (Hoddinott and Yohannes 2002), to be adequate in nutrients (Ruel 2003; Torheim et al. 2004; Steyn et al. 2006; Kennedy et al. 2007), and to be associated with improved nutritional status (Arimond and Ruel 2004; Savy et al. 2005).

Several traditional varieties of plants are known to have a higher micronutrient content compared with the intensively cultivated ones (Burlingame et al. 2009; Mouillé et al. 2010). The use of local plant and animal varieties in the human diet can thus be instrumental to enhance public health since the regular intake of bioactive compounds has been associated with positive health outcomes such as the reduction of serum cholesterol and carcinogen detoxification (Kris-Etherton et al. 2002). At the same time, it is imperative to conserve natural biodiversity as a way to meet present and future global food demand (Godfray et al. 2010), which can be achieved by integrating environmental and public health policies (Lang et al. 2001).

Against a background of biodiversity loss and dietary changes, the cross-cutting initiative on biodiversity and human nutrition has been launched to main stream the sustainable use of biological diversity to increase the diversity in the diets and to tackle both under- and over-nutrition (CBD 2006). The general aim of the initiative is to contribute to reach millennium development goal (MDG) 1 of reducing hunger and poverty, and at the same time to ensure environmental sustainability (MDG 7). This initiative acknowledges the urgent need to review current knowledge on the links between biodiversity and human nutrition. To monitor progress towards the targets set for biodiversity preservation, indicators for food composition (FAO 2008) and for consumption of food biodiversity (FAO 2010a) have been proposed by the Food and Agriculture Organization of the United Nations (FAO). The latter contains a list of dietary assessment methodologies which are recommended to record the diversity of plants, animals, and other organisms used for food.

To date, however, no systematic literature review on the contribution of biodiversity in human diets is available. Lack of such compiled evidence impairs biodiversity preservation strategies to set benchmarks that include dietary diversification as a key principle. In addition, it is unclear which methodologies are currently applied to measure and document biodiversity in diets. Because of the multidisciplinary of the topic the use of various biodiversity and nutrition terms have made the consensus difficult.

This article summarizes the current knowledge on the contribution of plant and animal biodiversity in human diets. During the review, we conceptualized biodiversity as both wild and agricultural products, with the latter also written as agro-biodiversity or agricultural biodiversity which is the variety and variability of animals, plants, and micro-organisms, at the genetic, species, and ecosystem levels, relevant to food and agriculture. In addition, we use the word "food biodiversity" when referring to the diversity of plants, animals, and other organisms used for food. We used the term "local foods" referring to those wild or agricultural food products, and "traditional foods" to foods with cultural significance.

We systematically reviewed all available information on the dietary contribution of biodiversity in terms of:

(i) energy intake, as overall indicator of healthy diets (FAO 1995); and due to its potential importance to contribute to reduce energy malnutrition;
(ii) micronutrient intake, as a proxy for the prevention of micronutrient deficiencies (FAO 1998);
(iii) dietary diversity; as a reflection of overall dietary quality and nutrient adequacy (Ruel 2003).

METHODOLOGY

Peer-reviewed articles for this review were searched in May 2010 in ten scientific literature data bases, i.e., Ingenta-

Connect, ISI web of Knowledge, Science Direct, Worldcat (multidisciplinary databases); Cochrane library, EMBASE, and PubMed (life science, biomedical databases); Bioline International (bioscience database for developing countries), AGRICOLA and AGRIS (agricultural database); and Google scholar which was used to retrieve documents through hand search. A second search was conducted in October 2010 to update our database with studies published after the main search. This second search was directed only in ISI web of knowledge, Science direct, and PubMed since these databases provided most of the selected papers in the first search. The second search, however, did not yield new papers. The search results were imported and managed using reference software (Endnote X2, The Thompson Corporation, NY, USA).

The initial search syntax was developed using the following key search terms "(food OR diet OR nutrition) AND biodiversity", combined with wildcards and indexed terms specific to the database. The detailed search syntax for each database is included in Table 1. The search results were further refined for energy and micronutrient intake, and dietary diversification by means of the key words "energy", "energy intake", "micronutrient", "dietary diversity", and "food diversity".

Articles' full titles were screened by the first author. Only studies potentially referring to food biodiversity and human nutrition were retained. Studies on animal nutrition, biofuels, food production simulations and/or modelling, microbiology, and genetically modified organisms were excluded, as well as short communications and reviews. Reviews were used as secondary sources for hand search. A second screening was conducted by reading the abstracts and selecting only studies with nutritional or dietary assessment of food biodiversity. When it was not clear from the abstract what type of methodology was used, the paper was referred to the full text review.

The full text evaluation of selected articles was carried out independently by the first and second author; when there was disagreement a third author was consulted. Eligibility criteria for the selection of the full papers of the review were (i) the study was an original study, (ii) food (plant or animal) biodiversity in the human diet was assessed, and (iii) results included dietary outcomes. Search was done for all years and restricted to languages familiar to the authors (i.e., English, French, Spanish, Dutch, and Portuguese).

The results were reported following the guidelines of STrengthening the Reporting of OBservational studies in Epidemiology (STROBE 2007), and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Moher et al. 2009). An adapted summary table from FAO was used to extract the information for every study (FAO 2010a). This summary table was used by us to discuss the results and to structure the findings of this review. We present the results for each of the categories regarding the contribution of biodiversity to diets (i.e., energy intake, micronutrients contributions, and dietary diversity) in Table 2.

Results

General Findings

The search process, the number of studies initially retrieved, and the number of excluded studies are illustrated in Fig. 1. A total of 34 unique studies were selected for this review. We retrieved 7, 14, and 17 studies in relation to energy intake, micronutrient intake, and dietary diversification, respectively. Five studies reported findings for more than one category. The studies were mainly carried out in areas of high biodiversity of low- and middle-income countries, and focused on the dietary contribution of local foods (whether from wild or agricultural sources) particularly from plant origin (Table 3). Only five studies assessed the contribution of local foods in the diet of populations in high income countries as Canada (Kuhnlein et al. 2004, 2006) and Italy (Pieroni et al. 2005; Nebel et al. 2006; Orban et al. 2006), but these were limited to specific traditional diets. All studies were descriptive and mostly based on convenience sampling.

Biodiversity and Energy Intake

The seven studies on energy intake reported a variety of outcome indicators including per capita energy intake of local foods (Begossi and Richerson 1993), proportion of total energy derived from local foods (Mennen and Mbanya 2000; Kuhnlein et al. 2004; Roche et al. 2008), and contributions of locally produced foods to energy requirements (Rajasekaran and Whiteford 1993; Orban et al. 2006; Rais et al. 2009). None of the studies quantified the energy intake from foods that were identified up to species level, which did not allow us to associate the absolute energy contribution of the species eaten.

Studies quantifying dietary intake as percentage of the total energy supplied by local foods included Mennen and Mbanya (2000), Kuhnlein et al. (2004), Roche et al. (2008); yet, these studies used only common names to refer to the

Table 1. Search strategy used to retrieve documents on biodiversity and the contribution to human diets

Database	Activity	Search term
AGRICOLA	Search (English) (articles)	Database name: article citation database search request: command = (food OR diet OR nutrition) AND biodiversity
	Refinement (energy)	(food OR diet OR nutrition) AND biodiversity AND energy
	Refinement (micronutrient)	(food OR diet OR nutrition) AND biodiversity AND micronutrient
	Refinement (dietary diversity)	(food OR diet OR nutrition) AND biodiversity AND "dietary diversity"
AGRIS	Search (all fields)	(food OR diet OR nutrition) AND biodiversity
	Limits (language) (articles)	(food OR diet OR nutrition) AND biodiversity; English, Spanish, French, Dutch, Portuguese
Bioline International	Search (all publications)	Biodiversity, AND, food
	Refinement (energy intake)	(by hand)
	Refinement (micronutrient intake)	(by hand)
	Refinement (dietary diversity)	(by hand)
EMBASE	Search (limits)	"food"/exp/mj OR food OR "diet"/exp/mj OR diet OR "nutrition"/exp/mj OR nutrition AND ("biodiversity"/exp/mj OR biodiversity) AND ([article]/lim OR [article in press]/lim OR [review]/lim) AND ([biochemistry]/lim OR [immunology and haematology]/lim OR [paediatrics]/lim OR [public health]/lim) AND ([dutch]/lim OR [english]/lim OR [french]/lim OR [portuguese]/lim OR [spanish]/lim) AND [humans]/lim AND [embase]/lim
	Refinement (energy)	AND energy
	Refinement (micronutrient)	AND micronutrient
	Refinement (dietary diversity)	AND dietary AND diversity
IngentaConnect	Search (title/keywords/abstract) in articles	(food OR diet[a] OR nutrition) AND biodiversity
	Refinement (energy intake)	(food OR diet[a] OR nutrition) AND biodiversity AND energy
	Refinement (micronutrient intake)	(food OR diet[a] OR nutrition) AND biodiversity AND micronutrient
	Refinement (dietary diversity)	(food OR diet[a] OR nutrition) AND biodiversity AND dietary diversity
ISI web of knowledge[a]	Search (by topic in Web of Science® and Inspec® databases)	(food OR diet[a] OR nutrition) AND biodiversity
	Limits (publication type and language)	Topic = [(food OR diet[a] OR nutrition) AND biodiversity]. Refined by: document type = (ARTICLE OR REVIEW) AND languages = (ENGLISH OR FRENCH OR PORTUGUESE OR SPANISH). Timespan = all years
	Refinement (energy)	Topic = [(food OR diet OR nutrition) AND biodiversity]. Refined by: document type = (ARTICLE OR REVIEW) AND languages = (ENGLISH OR FRENCH OR PORTUGUESE OR SPANISH) AND topic = (energy). Timespan = all years
	Refinement (micronutrient)	Topic = [(food OR diet OR nutrition) AND biodiversity]. Refined by: document type = (ARTICLE OR REVIEW) AND languages = (ENGLISH OR FRENCH OR PORTUGUESE OR SPANISH) AND topic = (micronutrient). Timespan = all years

Table 1. continued

Database	Activity	Search term
	Refinement (dietary diversity)	Topic = [(food OR diet[a] OR nutrition) AND biodiversity]. Refined by: document type = (ARTICLE OR REVIEW) AND languages = (ENGLISH OR FRENCH OR SPANISH OR PORTUGUESE) AND Topic = (diet[a] diversity). Timespan = all years
	Refinement (food diversity)	Topic = [(food OR diet[a] OR nutrition) AND biodiversity]. Refined by: document type = (ARTICLE OR REVIEW) AND languages = (ENGLISH OR FRENCH OR SPANISH OR PORTUGUESE) AND topic = (food variety). Timespan = all years
PubMed[a]	Search (by topic)	(food OR diet OR nutrition) AND biodiversity
	Limits (English, French, Spanish, Dutch, Portuguese, MEDLINE, PubMed Central)	(food OR diet OR nutrition) AND biodiversity Limits: English, French, Spanish, Dutch, Portuguese, MEDLINE, PubMed Central
	Refinement (energy)	(food OR diet OR nutrition) AND biodiversity AND energy
	Refinement (nutrient)	(food OR diet OR nutrition) AND biodiversity AND micronutrient
	Refinement (dietary diversity)	(food OR diet OR nutrition) AND biodiversity AND (dietary diversity)
Science direct[a]	Search (all fields)	ALL((food OR diet OR nutrition) AND biodiversity)
	Limits (subject) (only articles)	[(food$ OR diet[a] OR nutrition) AND biodiversity] agricultural and biological science, environmental science, medicine and dentistry, nursing and health professions
	Limits (topics)	[(food$ OR diet[a] OR nutrition) AND biodiversity] AND EXCLUDE(topics, "national park, food web, microbial community, sustainable development, forest management, biological control, fatty acid, soil microbial, community structure")
	Refinements (energy intake)	{[(food$ OR diet[a] OR nutrition) AND biodiversity] AND EXCLUDE(topics, "national park, food web, microbial community, sustainable development, forest management, biological control, fatty acid, soil microbial, community structure")} and energy intake
	Refinements (micronutrient)	{[(food$ OR diet[a] OR nutrition) AND biodiversity] AND EXCLUDE (topics, "national park, food web, microbial community, sustainable development, forest management, biological control, fatty acid, soil microbial, community structure")} and micronutrient$
	Refinements (dietary diversity)	{[((food$ OR diet[a] OR nutrition) AND biodiversity) AND EXCLUDE (topics, "national park, food web, microbial community, sustainable development, forest management, biological control, fatty acid, soil microbial, community structure")] and "dietary diversity"} and dietary diversity AND EXCLUDE (smi, "6845, 4972, 6776, 5819, 6035, 5995, 6806, 6963, 5163, 5836, 5161, 5934", "Journal of Arid Environments, Aquaculture, Estuarine, Coastal and Shelf Science, Marine Pollution Bulletin, Deep Sea Research Part II: Topical Studies in Oceanography, Ecological Economics, Gastroenterology, Molecular Phylogenetics and Evolution, Soil Biology and Biochemistry, Science of The Total Environment, Small Ruminant Research, Ecological Modelling")

Table 1. continued

Database	Activity	Search term
The Cochrane library of systematic reviews	Search (all text)	(food OR diet OR nutrition) AND biodiversity
Worldcat	Search (keywords, subject title)	"kw: (food OR diet OR nutrition) AND biodiversity"
	Limits (English and articles)	"kw: (food OR diet OR nutrition) AND biodiversity" > "Article" > "English"
	Refinement (energy intake)	"kw: (food OR diet OR nutrition) AND biodiversity AND energy intake" > "Artikel" > "Engels"
	Refinement (micronutrient)	"kw: (food OR diet OR nutrition) AND biodiversity AND micronutrient" > "English" > "Article"
	Refinement (dietary diversity)	"kw: (food OR diet OR nutrition) AND biodiversity AND (dietary diversity)" > "Article" > "English"

[a]Data bases used for the second search of October 2010. Only these three were used by being the main providers of selected studies in the main search. None of the documents retrieved by the 2nd search were selected based on the criteria.

foods. The reported energy contributions from local foods ranged between 10 and 90%, and these were associated with the consumption of about ten local food items in rural areas (Mennen and Mbanya 2000), forest (Roche et al. 2008), or arctic areas (Kuhnlein et al. 2004). Amongst these, several local or traditional foods including (but not limited to) banana, caribou, cassava, moose, seal, and whitefish were found to be important caloric contributors in the investigated areas.

One study (Begossi and Richerson 1993) reported energy intakes (per capita) of local animal food consumption (mainly fish) and named the species eaten, providing thereby some insight on the relevance of the local fish species to local fishermen. However, the results are based on intake estimations and are limited to animal consumption, during lunch time and dinner.

Various studies reported the percentage of energy requirements supplied by locally available foods. The results show that from 23% (Rajasekaran and Whiteford 1993) to 52% (Rais et al. 2009) of the recommended daily energy intake could be supplied by local foods. These studies, however, were based on estimated consumption of crab and agricultural products. In addition, one study reported that recommended protein and fat intakes can be reached by eating a serving of local fish (Orban et al. 2006).

Biodiversity and Micronutrient Intake

Studies on the contribution of local food intake to meet micronutrient recommendations reported nutrient adequacy of diversified diets (Hatloy et al. 1998; Roos et al. 2003), the proportion of micronutrient intake supplied from local foods (Ogle et al. 2001c; Kuhnlein et al. 2006; Singh and Garg 2006; Roche et al. 2008), and the percentage of recommended intake covered by the usual consumption of local foods (Ogle et al. 2001a; Englberger et al. 2006; Roos et al. 2007a, b; Englberger et al. 2008; Davey et al. 2009; Englberger et al. 2009, 2010b). Both studies evaluating micronutrient adequacy of local diets were based on actual intake, one used mean adequacy (Hatloy et al. 1998) and the other nutrient contribution ratios (Roos et al. 2003) to report the results. The latter reported the second highest proportion (31 and 40%) of the recommended intake of calcium and vitamin A, respectively, attributed to the consumption of small fish species. Hatloy et al. (1998) reported mean adequacy ratios for seven micronutrients as well as energy, fat, and protein, but did not describe the different food sources.

Table 2. Evidence (n = 34) on the contribution of biodiversity to energy intake, micronutrient intake, and dietary diversification

Category	Reference	Study design	Findings
Energy intake	Begossi and Richerson (1993)	Randomly selected 12 families	Local animal consumption, mainly of fish, contributes to 564.1 kcal/person/day
	Kuhnlein et al. (2004)	Randomly selected HH in 3 Canadian arctic regions: 797 in Yukon, 1007 in Dene, 1604 in Inuit	Ten to 36% of energy intake is derived by traditional foods. The mean total energy intake (kJ/day) and the percentage of energy from protein of meals containing traditional foods is higher than meals without traditional foods
	Mennen and Mbanya (2000)	Convenient sample of one rural and one urban area: 1058 (HH) urban and 746 (HH) rural for the survey 156 subject for the food intake study	10 Local foods delivered 52% (in rural) to 47% (in urban) of the total energy, being cassava the provider of 10% of the total energy
	Orban et al. (2006)	Samples of Whitefish *Coregonus lavaretus* in 3 italian lakes: Bolsena, Bracciano, and Salto	A serving of 150 g of whitefish *Coregonus lavaret*us would contribute with 35–40% of daily recommended protein intake for adults and less than 10% of the daily recommended fat intake
	Rais et al. (2009)	Randomly selected HH in 2 areas: 349 HH including 2441 adults in Tarikhet, and 263 HH including 1729 adults in Ukhimath	Agricultural production contributes with 13.6–17.8 GJ/year, which is 34 (Tarikhet) to 52% (Ukhimath) of required energy per household (7 members)
	Rajasekaran and Whiteford (1993)	Randomly selected HH of 3 groups: marginal farmers, permanent labourers and wage labourers: 20% of all HH for each group	Local rice-crab production contributes to 32 (wage labourers) to 23% (marginal farmers) of recommended daily allowance of protein of resource poor households. 5820 kcal/day consumed in crab peak season
	Roche et al. (2008)	Convenient sample of individuals:49 mothers and 34 children	Traditional diets (all foods, including 1 kg cassava/day eaten by adults and 0.65 kg/day by children) contribute to more than 90% of total energy intake
Micronutrient intake	Davey et al. (2009)	Selected 171 Musa genotypes	Eating 100 g (fresh weight) of banana cultivars containing the highest pro-vitamin A carotenoids could provide ~95% of vitamin A estimated average requirements for children and 47% for adults

Table 2. continued

Category	Reference	Study design	Findings
	Englberger et al. (2006)	Selected 13 Pandanus cultivars	Normal consumption patterns (20–50 keys/day by adults and 5 keys/day by children) of 10 pandanus cultivars could contribute to Recommended Safe Intakes of carotenoids
	Englberger et al. (2010b)	Selected 10 Musa cultivars	Eating 0.4–6.6 fruits from 7 Fe'I banana cultivars (characterized by upright bunches) containing high pro-vitamin A carotenoids could contribute to meet estimated vitamin A requirements of adults and pre-school children
	Englberger et al. (2009)	Selected 11 Pandanus cultivars	Normal consumption patterns (up to 50 fruits/day) of pandanus cultivars could contribute to meet recommended safe intakes of vitamin A intake for women
	Englberger et al. (2008)	Selected 34 Cyrtosperma cultivars	Consumption patterns of starchy foods (up to 1000 g/day), including *Cyrtosperma*, could contribute to meet vitamin A requirements
	Hatloy et al. (1998)	Randomly selected 77 HH with children	Diets with food variety scores of 15 and dietary diversity scores of 5 were nutritional adequate (mean adequacy ratio of 0.75 including Fe, riboflavin, niacin, vitamin C, Ca, folic acid, and vitamin A)
	Kuhnlein et al. (2006)	Randomly selected HH in 3 regions: 797 in Yukon, 1007 Dene, and 1604 in Inuit	Inuit diets are nutrient adequate for vitamin A, with 23% of the total vitamin A coming from traditional food portion. For Dene, Yakon, and Inuit the percentage of Cholecalciferol coming from traditional food portion is 62, 54 and 87%, respectively; and for α tocopherol was 37, 24, and 37%
	Ogle et al. (2001a)	Randomly sampled HH on 2 regions: 211 (HH) in Mekong Delta, 103 (HH) in central highlands Samples of 28 vegetables species	Natural occurring vegetables contribute with 16 (Central Highlands) to 30% (Mekong Delta) of recommended daily allowance for vitamin A, with 5–6% for Zn, and 40% for Ca

Table 2. continued

Category	Reference	Study design	Findings
Micronutrient intake	Ogle et al. (2001c)	Convenient sample of adults♀ in 2 regions: 211 in Mekong Delta, 103 in central highlands Samples of 16 vegetables species	14 and 21% of total folate intakes is provided by wild vegetables in Central Highlands, and Mekong Delta, respectively. From 44% (Mekong Delta) to 46% (Central Highlands) of the dietary folate is supplied by staple foods (including cassava, rice, and sweet potato)
	Roche et al. (2008)	Convenient sample of individuals: 49 mothers and 34 children	Greater traditional food diversity scores are associated (partial correlation from 0.38 to 0.64) with higher Fe, thiamine, riboflavin, and vitamin A intakes in women and in children
	Roos et al. (2007a)	Selected 29 fish species	Local fish availability (50–74 g person/day) could contribute to meet 5–15% of total vitamin A daily recommended intake
	Roos et al. (2003)	Convenient sample of HH: 59 fish-producing HH, 25 non-fish producer HH	The intake of small indigenous fish species has nutrient contribution ratios of up to 40% for vitamin A, 31% for Ca, and 9% for Fe
	Roos et al. (2007b)	Convenient sample of 31 HH Selected 16 fish species	A serving of sour soup meal, containing 49 g *Esomus longimanus*, could contribute to 45% of daily median Fe requirements
	Singh and Garg (2006)	Selected 6 cereals, 9 vegetables, and 20 spices	Consumption of local spices (25 g/day) contribute to the 7.5% of the daily dietary intake for Cr, Fe, Mn and Zn, and 5% for Cu, P, Se
Dietary Diversification	Akrofi et al. (2008)	Convenient sample of HH: 32 HIV+ and 48 HIV− HH	Home gardens contribute to dietary diversity score of 6–5.8 on HIV+ and 6.6–6.8 HIV− HH, local foods include 9.7 crop species, 2.6 vegetables species, 2.8 fruit species
	Batal and Hunter (2007)	Convenience sample of individuals: 52 adults in focus groups; 28♀ + 24♂ 799 adults surveyed; 48%♀ + 52%♂	Local recipes are prepared using 10 wild edible plants
	Begossi and Richerson (1993)	Randomly selected 12 families	Local animal consumption of fishermen families is based on 65 food items

Table 2. continued

Category	Reference	Study design	Findings
	Dovie et al. (2007)	Convenience sample of randomly selected 45 HH	Mean daily wild edible herbs consumption of 0.2 ± 0.05 kg are based prominently on *Cleome gynandra*, *Cleome monophylla*, *Amaranthus hybridu*, *A. thunbergii*, *Bidens pilosa*, and in less extend on *Cucumis zeyheri*, and *Corchorus tridens*
	Ekesa et al. (2008)	Multistage random sampling: 114 HH	Agricultural biodiversity contributes to 48.5% to dietary diversity of school children. About 46% of the sampled children have a food variety score from 13 to 17, but also 45% eat less than 12 food items
	Frei and Becker (2004)	Convenient sample of households: 36 (HH) for the interviews	Local diets consist of 49 upland varieties and 2 indigenous of rice, 13 species of vegetables and 20 species of fruit, with rice being eaten 3 times/day
	Hatloy et al. (1998)	Randomly selected 77 HH with children	A total of 75 food items compose local diets, in a population with a mean food variety score of 20.5 (consuming at minimum 13 food variety score and 29 maximun) and a mean dietary diversity score of 5.8
	Kennedy et al. (2005)	Randomly selected 313 HH covering 10 villages	Rice varieties consumed locally comprise 21 different cultivars
	Lykke et al. (2002)	Convenient sample of HH in 2 areas: 8 HH in Silmogou and 5 HH in Ningare corresponding to 26 adults	Local meals, eaten in a frequency of 1.8–2.9 times/day, contain 4.5–6.1 food items/meal, and 30–45 food items/day. Local diets are based on 52 food items
Dietary diversification	Nebel et al. (2006)	Convenient sample of individuals: 18 adults for the field study 36 elders for in-depth interview 7 HH and its 22 adults for the food intake study	Local diets consist in 40 wild food species
	Nordeide et al. (1996)	Cluster sampling of HH in 2 areas: 179 urban, 111 rural HH for the rainy season, and 148 urban, 102 rural HH for the dry season 2 focus groups	Local diets include 7 species of green leaves, 11 fruit species, 4 species of roots, 1 seed, and 1 flower. In addition, 26 different gathered fruits used only in rainy season

Table 2. continued

Category	Reference	Study design	Findings
	Ogle et al. (2001b)	Convenient sample of adult♀ in 2 regions: 211 in Mekong Delta and 103 in central highlands	Women's diets with food variety scores $\geq$ 21 consume a higher variety of vegetables than those with low food varieties scores ($\leq$15), locally 62 species of vegetables are eaten
	Osemeobo (2001)	Convenient sample of 2 rural markets, 16 settlements, and 1025 stakeholders	Wild foods eaten everyday embrace 27 wild gathered plants, this mostly in rural areas where foods are coming mostly from natural forest
	Passos et al. (2007)	Convenient sampling of 459 adults	Local patterns of food consumption include 6.6 fish-meals/week, and 11 fruits/week. A total of 40 fruit species are eaten
	Pieroni et al. (2005)	Convenient sample of individuals: 850 adults for the survey 86 elderly in the interviews	Seventy-five taxa of non-cultivated and semi cultivated local food plants and mushrooms are found to be consumed in different frequencies
	Rais et al. (2009)	Randomly selected HH in 2 areas: 349 HH including 2441 adults in Tarikhet, and 263 HH including 1729 adults in Ukhimath	Local diets consist of 15 species of local field crops (rice, wheat soybean), $\sim$27 species of local vegetables, $\sim$21 species of local fruits
	Roche et al. (2008)	Convenient sample of individuals:49 mothers and 34 children	Traditional diets are based (but not limited to) 10 food items. Mean traditional food diversity score for women of 9.5 $\pm$ 3.5 and 8.7 $\pm$ 3.6 for children
	Steyn et al. (2001)	Convenient sample of 39 informants eating wild greens Sample of 32 species	Thirty-two wild leafy vegetables are consumed locally. Eight species are eaten in a frequency of 5–7 times/week, 8 species are eaten 3–4 times/week, 3 species are eaten 3–7 times/week; 5 species eaten anytime

♀ female; ♂ male; *Ca* calcium; *Cal* calories; *Cr* chromium; *Cu* cupper; *d* day; *Fe* iron; *G* giga; *g* grams; *h* hour; *HH* household; *J* joule; *k* kilo; *Mn* manganese; *P* phosphorous; *y* year; *Zn* zinc; *Se* selenium.

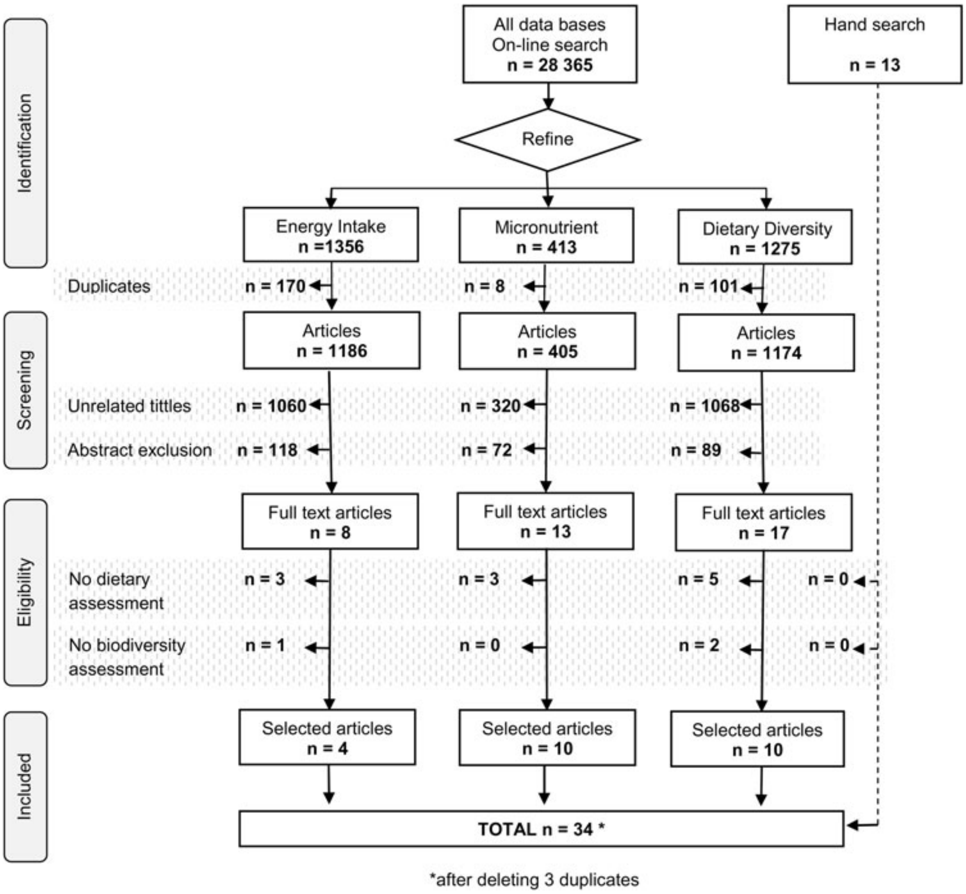

Figure 1. Flow diagram of search strategy and selection process of articles on the contribution of biodiversity to human diets.

Three studies evaluated the proportion of micronutrient supplied from the consumption of traditional foods (Ogle et al. 2001c; Kuhnlein et al. 2006; Roche et al. 2008). Kuhnlein et al. (2006) and reported that 87, 23, and 37% of the total daily intake of cholecalciferol, vitamin A, and tocopherol, respectively, is supplied by the traditional food portion of arctic diets. Ogle et al. (2001c) reported the contribution of wild vegetables and staple foods to folate only, with values of 21 and 46%, respectively; whereas Roche et al. (2008) studied the contribution of all traditional foods to more than one micronutrient (i.e., iron, thiamine, riboflavin, and vitamin A).

Studies focusing on the micronutrient composition of some target foods were mainly based on chemical analysis, and used dietary estimations to report the contribution to daily recommendations. The study of Davey et al. (2009) and those of Englberger et al. (2006, 2008, 2009, 2010a, b) identified several vitamin A-rich *Musa* fruit varieties, *Cyrtosperma*, and *Pandanus* that could, under normal consumption patterns, potentially contribute to meet dietary recommendations for vitamin A. In addition, Ogle et al. (2001a) found that the daily intake of some naturally occurring vegetables can potentially contribute to meet up to 30 and 40% of the recommended allowances of vitamin A and calcium, respectively. Roos et al. (2007a, b) reported local fish consumption to contribute with 15 and 45% of the daily vitamin A and iron requirements, respectively. The study of Singh and Garg (2006) showed that the daily intake of a spice mix can contribute with 5–7% to the recommended daily intake of some micronutrients (i.e., chromium, iron, manganese, zinc, copper, phosphorous, and selenium).

Biodiversity and Dietary Diversity

Studies investigating the contribution of biodiversity to dietary diversification reported mainly the number of food items within the diet (Begossi and Richerson 1993; Nordeide et al. 1996; Osemeobo 2001; Steyn et al. 2001; Frei and Becker 2004; Kennedy et al. 2005; Pieroni et al. 2005; Nebel et al. 2006; Batal and Hunter 2007; Dovie et al. 2007; Passos et al. 2007; Rais et al. 2009). In addition, few studies used specific indicators of dietary diversification (Hatloy et al. 1998; Ogle et al. 2001b; Akrofi et al. 2008;

Table 3. Food biodiversity investigated geographical regions

Region	Country	Investigated foods	Reference
Africa	Burkina Faso	All local foods	Lykke et al. (2002)
	Cameroon	Local *Musa* cultivars	Davey et al. (2009)
		All local foods	Mennen and Mbanya (2000)
	Ghana	All home garden foods	Akrofi et al. (2008)
	Kenya	All agricultural foods	Ekesa et al. (2008)
	Mali	All local foods	Hatloy et al. (1998)
		Wild gathered plants	Nordeide et al. (1996)
	Nigeria	Wild plants	Osemeobo (2001)
	South Africa	Wild edible herbs	Dovie et al. (2007)
		Wild edible greens	Steyn et al. (2001)
	Uganda	Local *Musa* cultivars	Davey et al. (2009)
Middle east	Lebanon	Local wild plants	Batal and Hunter (2007)
North	Italy	Wild edible plants	Nebel et al. (2006)
		Local whitefish	Orban et al. (2006)
		Local food plants	Pieroni et al. (2005)
	Canada	Traditional arctic foods	Kuhnlein et al. (2004), Kuhnlein et al. (2006)
Oceania	Hawaii	Local Musa cultivars	Davey et al. (2009)
	Marshal Islands	Local Pandanus cultivars	Englberger et al. (2006)
	Micronesia	Local Pandanus cultivars	Englberger et al. (2009)
		Local *Cyrtosperma* cultivars	Englberger et al. (2008)
	Solomon Islands	Local *Musa* cultivars	Englberger et al. (2010b)
South America	Brazil	Local animals	Begossi and Richerson (1993)
		Local fruits	Passos et al. (2007)
	Peru	Wild edibles	Roche et al. (2008)
South East Asia	Cambodia	Local *Musa* cultivars	Davey et al. (2009)
		Local freshwater fish	Roos et al. (2007a, b)
	Philippines	Local *Musa* cultivars	Davey et al. (2009)
		All agricultural foods	Frei and Becker (2004)
	Vietnam	Wild vegetables and staple foods	Ogle et al. (2001a, b, c)
South Asia	India	All agricultural products	Rais et al. (2009)
		Local rice-crab	Rajasekaran and Whiteford (1993)
		Local spices	Singh and Garg (2006)
	Bangladesh	Local rice cultivars	Kennedy et al. (2005)
		Local small fish	Roos et al. (2003)

Ekesa et al. 2008; Roche et al. 2008). The number of foods reported as part of habitual diets varied considerably. The highest reported values include 76 fish and other animal species (Begossi and Richerson 1993), 32 and 62 vegetables species (Ogle et al. 2001b; Steyn et al. 2001), 26 and 40 fruit species (Nordeide et al. 1996; Passos et al. 2007), and between 21 and 51 varieties of rice (Frei and Becker 2004; Kennedy et al. 2005). The studies also reported a wide interval of consumption frequencies for some foods, going from several times per day to a different number of times per year, and some indicated seasonal variations (data not shown).

Dietary diversity was expressed as diversity scores (DDS), food variety scores (FVS), and traditional food variety scores (TFVS). Ekesa et al. (2008), Hatloy et al. (1998), and Ogle et al. (2001b) reported the level of dietary diversity of local diets using both DDS and FVS. DDS was used to report dietary diversification by foods groups (i.e., 8 or 12 foods groups according to the context). When referring to the total number of food items consumed over a time period (usually 7 days), FVS was used. The highest reported value of FVS was 20.5, indicating that up to 21 food items were consumed in a week period in the investigated area. A more specific indicator used was the TFVS (Roche et al. 2008), which is the number of traditional/local foods present in a diet assessed by 24-h dietary recall. The indicator showed that diets of Peruvian communities in the Amazon area contain a mean of 9.5 local foods items per day, being wild or cultivated.

Additional Findings

The methodologies applied by the consulted studies estimated the contribution of biodiversity to diets and were very diverse. We identified three different methodologies that were categorized as: dietary assessment methods (tools to describe or record diets), nutritional assessment methods (tools to estimate the nutrient content of the investigated food items), and local food biodiversity assessment methods (tools to record, identify and list the local edible plant or animals included in the diet). Table 4 details the methods used to measure the contribution of biodiversity in the diet.

Often, a combination of dietary and nutritional assessments were used ($n = 18$). Only a few of these studies used a quantified dietary intake assessment (Rajasekaran and Whiteford 1993; Mennen and Mbanya 2000; Kuhnlein et al. 2004, 2006; Roche et al. 2008). Other studies (Begossi and Richerson 1993; Ogle et al. 2001a; Steyn et al. 2001; Lykke et al. 2002; Kennedy et al. 2005; Batal and Hunter 2007; Akrofi et al. 2008) used a combination of local food biodiversity and dietary assessments, exploring thereby the intake of local foods and naming the species involved.

The most frequently applied dietary assessment method was dietary recalls ($n = 11$), especially on energy intake studies (Begossi and Richerson 1993; Mennen and Mbanya 2000; Kuhnlein et al. 2004; Roche et al. 2008); followed by food frequency questionnaires ($n = 8$) which were particularly used to record dietary diversity (Nordeide et al. 1996; Ogle et al. 2001b; Ekesa et al. 2008). The dietary recalls were mostly 24-h recall (Rajasekaran and Whiteford 1993; Mennen and Mbanya 2000; Kuhnlein et al. 2004; Kennedy et al. 2005; Akrofi et al. 2008; Roche et al. 2008), recalls in relation to specific meals (Begossi and Richerson 1993), and recorded intakes on various days (Roos et al. 2003; Pieroni et al. 2005; Passos et al. 2007).

Local food biodiversity was mainly documented using a combination of interviews and by field observations (Rajasekaran and Whiteford 1993; Nordeide et al. 1996; Mennen and Mbanya 2000; Ogle et al. 2001a; Lykke et al. 2002; Kennedy et al. 2005; Englberger et al. 2006; Nebel et al. 2006; Orban et al. 2006; Dovie et al. 2007; Englberger et al. 2008, 2009, 2010b). These studies belong mostly to the category of dietary diversification.

Discussion

Sustainable use of wild and agricultural biodiversity is important to address the prevailing nutritional problems and global food supply. This review brings together the available evidence on the contribution of edible plant and animal biodiversity to human diets, information which was currently lacking (CBD 2006). We reviewed 34 studies reporting on biodiversity and energy intakes, micronutrient intakes, and dietary diversification. It was surprising to find this limited number of studies for a hot topic widely discussed in academia (Johns 2003; Wahlqvist 2003; Frison et al. 2006; Toledo and Burlingame 2006; Vinceti et al. 2008; Frison et al. 2011) and of global public concern.

All summarized information indicated biodiversity to be the mainstay of a variety of plant and animal food products and an important element in the local diets. However, this evidence was mainly restricted to highly biodiverse areas, such as rural and forest zones in which these studies were conducted. Since, the studies were on the diet of people who subsist from locally available foods, the dietary importance of biodiversity in these diets is hardly a surprise. It is not surprising that biodiversity investigations have been conceptualised and conducted in areas of high biodiversity, such as tropical forest. Answers to the global food security issues of the next generation, however, will require research and solutions to feed an increasingly urban population, in particular in low and middle-income countries. Urbanization not only leads to loss of arable land, it drives intensification of food provision and straining of existing agricultural and food provision systems (Godfray et al. 2010). Policy makers will need to carefully consider the role of agricultural biodiversity, local food supply, and small holder agriculture when designing the food system of tomorrow (UN 2010). Our review demonstrates how the current research on biodiversity and diets falls short to provide the necessary evidence to design agro-ecological models with respect to sustainable biodiversity preservation.

The evidence regarding local food biodiversity and its dietary energy contribution was reported mainly by the proportion of the total energy supplied by local foods. This and all other reported energy outcomes highlighted local and traditional foods as essential suppliers of enough calories to the people living on the investigated communities. Daily consumption of local foods is for people living in traditional societies and rural areas imperative for food security. In addition, reported outcomes on micronutrient intakes show that consumption of local and traditional foods contributes to meet daily micronutrient recommendations. This suggests that micronutrient deficiencies can be addressed through local food-based approaches, par-

Table 4. Assessment tools (dietary, nutritional, and biodiversity) applied by studies exploring biodiversity and its contribution to human diets (n = 34)

Assessment	Tool	Reference
Dietary	Focus groups[a]	Frei and Becker (2004), Pieroni et al. (2005), Batal and Hunter (2007)
	Food frequency questionnaire	Nordeide et al. (1996), Mennen and Mbanya (2000), Ogle et al. (2001a, b, c), Kuhnlein et al. (2004), Kuhnlein et al. (2006), Ekesa et al. (2008)
	Food grouping[a]	Hatloy et al. (1998), Ogle et al. (2001b), Frei and Becker (2004), Akrofi et al. (2008), Ekesa et al. (2008)
	Intake recall	Begossi and Richerson (1993), Rajasekaran and Whiteford (1993), Mennen and Mbanya (2000), Roos et al. (2003), Kuhnlein et al. (2004), Kennedy et al. (2005), Pieroni et al. (2005), Kuhnlein et al. (2006), Passos et al. (2007), Akrofi et al. (2008), Roche et al. (2008)
	Food record/diaries	Mennen and Mbanya (2000), Lykke et al. (2002), Kuhnlein et al. (2004), Kuhnlein et al. (2006)
	Food weighing	Hatloy et al. (1998), Ogle et al. (2001b), Roos et al. (2007b)
	Inferred intake/observations[a]	Begossi and Richerson (1993), Englberger et al. (2006), Orban et al. (2006), Singh and Garg (2006), Roos et al. (2007a, b), Englberger et al. (2008), Davey et al. (2009), Englberger et al. (2009), Rais et al. (2009), Englberger et al. (2010b)
	Interviews	Osemeobo (2001), Steyn et al. (2001), Lykke et al. (2002), Frei and Becker (2004), Nebel et al. (2006), Batal and Hunter (2007), Dovie et al. (2007), Roos et al. (2007b), Rais et al. (2009)
	Recipes record	Mennen and Mbanya (2000), Ogle et al. (2001a), Batal and Hunter (2007), Roos et al. (2007b)
Nutritional	Chemical analysis	Ogle et al. (2001a), Frei and Becker (2004), Englberger et al. (2006), Kuhnlein et al. (2006), Orban et al. (2006), Singh and Garg (2006), Batal and Hunter (2007), Roos et al. (2007a, b), Englberger et al. (2008, 2009, 2010b)
	Food composition tables/literature[a]	Rajasekaran and Whiteford (1993), Mennen and Mbanya (2000), Ogle et al. (2001ac), Steyn et al. (2001), Kuhnlein et al. (2004), Kuhnlein et al. (2006), Batal and Hunter (2007), Roche et al. (2008)
Local food biodiversity	Interviews (local names)	Rajasekaran and Whiteford (1993), Nordeide et al. (1996), Hatloy et al. (1998), Mennen and Mbanya (2000), Ogle et al. (2001a, b, c), Osemeobo (2001), Lykke et al. (2002), Kuhnlein et al. (2004), Kennedy et al. (2005), Englberger et al. (2006), Kuhnlein et al. (2006), Nebel et al. (2006), Orban et al. (2006), Batal and Hunter (2007), Dovie et al. (2007), Passos et al. (2007), Englberger et al. (2008), Roche et al. (2008), Englberger et al. (2009), Rais et al. (2009), Englberger et al. (2010b)
	Literature (scientific names)[a]	Roos et al. (2003, 2007a, b)

Table 4. continued

Assessment	Tool	Reference
	Observations/field, market visits (local names)[a]	Rajasekaran and Whiteford (1993), Nordeide et al. (1996), Mennen and Mbanya (2000), Ogle et al. (2001a), Lykke et al. (2002), Kennedy et al. (2005), Englberger et al. (2006), Nebel et al. (2006), Orban et al. (2006), Singh and Garg (2006), Dovie et al. (2007), Ekesa et al. (2008), Englberger et al. (2008, 2009, 2010b)
	Plant/animal identification (scientific names)	Nordeide et al. (1996), Ogle et al. (2001a), Steyn et al. (2001), Frei and Becker (2004), Pieroni et al. (2005), Englberger et al. (2006), Nebel et al. (2006), Batal and Hunter (2007), Passos et al. (2007), Akrofi et al. (2008), Englberger et al. (2008), Davey et al. (2009), Englberger et al. (2009), Rais et al. (2009), Englberger et al. (2010b)

[a]Considered as indirect assessment

ticularly by the consumption of micronutrient rich varieties (Tontisirin et al. 2002; Krawinkel 2009). Furthermore, the available evidence indicates that diets of people eating from highly biodiverse areas are also very diversified.

Animal foods were found to be important sources of biodiversity in the diet. Concerns have been raised, however, on how recommendations should be formulated with regard to the consumption of animal foods. Although, animal source food adds important sources of nutrients in diets of populations in low and middle-income countries (Allen 2003), the consumption has raised globally up to levels of overconsumption in various population groups (WHO 2003). Environmental concerns have been raised with regard to the contribution of the intensive production of animal source food production on greenhouse-gas emissions and fisheries on the depletion of oceans (McMichael et al. 2007; Bell et al. 2009; Godfray et al. 2010). Healthy promotion strategies should also incorporate recommendations for sustainable diets. The latter are defined as those diets with low environmental impacts, protective, and respectful of biodiversity and ecosystems; culturally acceptable, accessible, economically fair, and affordable; nutritionally adequate, safe, and healthy (Burlingame et al. 2011). A key strategy is to investigate which local consumption patterns are sustainable with regard to agriculture biodiversity and to incorporate these into the programming and interventions. Unfortunately, to date not one single study is available in this regard.

Our findings are constrained by the type and nature of the collected information. The reported outcomes varied widely and did not allow us to further generalize the main outcomes. In addition, a wide variety of assessment methodologies were used. This could be partially attributable to the use of both biodiversity and dietary assessments by all of the studies, which was a pre-condition of our selection criteria. Being a multidisciplinary topic, we believe that the use of combined methodologies is imperative to conduct this type of research. In addition, we acknowledge that the biggest obstacle for investigating biodiversity and its contributions to human nutrition is the absence of a standardized methodology that quantifies dietary intake of locally produced or wild foods, involves food identification and distinction of species and subspecies, and analyses food composition of the investigated genetic pools. Importantly, the initiative of FAO on nutrition indicators for biodiversity has given a first step by launching measurement tools and indicators to help to overcome these shortcomings (FAO 2008, 2010a).

Indexed terms and key words that would accurately retrieve the desired documents were not available. We therefore used a combination of dietary, health, and agricultural terms for the search and used a series of databases from various disciplines. However, a limited number of studies were retrieved, and these were mostly indexed under agricultural biodiversity terms. Given the limited use of quantified dietary assessment methods in the studies retrieved, this would suggest that research on biodiversity and human nutrition has been mainly conducted by botanists and agronomists and received less attention by nutritionist and health scientists. The complexity of linking agricultural and health research seems to be a setback to engage in a large comprehensiveness of this topic. Only future multidisciplinary research, incorporating appropriate biodiversity and nutritional assessment methodologies, would lead to a better understanding of the dietary contributions of local food biodiversity and diets.

Conclusions

Biodiversity could contribute to human diets with energy, micronutrient, and many a number of foods that count for dietary diversification, particularly in highly biodiverse areas, but strong evidence is lacking. Methodologically, better instruments to measure the dietary contribution of local biodiversity are needed. A standardized methodology would enable to better substantiate the link between biodiversity and the quality of the diet. Deeper knowledge on high biodiverse diets would contribute to design dietary guidelines which would be not only healthy but sustainable. Further research on the contribution of biodiversity in diets of industrialized countries and urban settings, however, is needed to gain knowledge on biodiversity contributions of other ecosystems.

References

Abegunde DO, Mathers CD, Adam T, Ortegon M, Strong K (2007) The burden and costs of chronic diseases in low-income and middle-income countries. *The Lancet* 370:1929–1938

Akrofi S, Struik PC, Price LL (2008) Interactive effects of HIV/AIDS and household headship determine home garden diversity in the eastern region of Ghana. *NJAS Wageningen Journal of Life Sciences* 56:201–217. doi:10.1016/S1573-5214(08)80008-5

Allen LH (2003) Interventions for micronutrient deficiency control in developing countries: past, present and future. *The Journal of Nutrition* 133:3875S–3878S

Arimond M, Ruel MT (2004) Dietary diversity is associated with child nutritional status: evidence from 11 demographic and health surveys. *Journal of Nutrition* 134:2579–2585

Batal M, Hunter E (2007) Traditional Lebanese recipes based on wild plants: an answer to diet simplification? *Food and Nutrition Bulletin* 28:303–311

Begossi A, Richerson PJ (1993) Biodiversity, family income and ecological niche—a study on the consumption of animal foods on Buzios Island (Brazil). *Ecology of Food Nutrition* 30:51–61

Bell JD, Kronen M, Vunisea A, Nash WJ, Keeble G, Demmke A, et al. (2009) Planning the use of fish for food security in the Pacific. *Marine Policy* 33:64–76

Burlingame B, Charrondiere R, Halwart M (2006) Basic human nutrition requirements and dietary diversity in rice-based aquatic ecosystems. *Journal of Food Composition and Analysis* 19:770

Burlingame B, Charrondiere R, Mouille B (2009) Food composition is fundamental to the cross-cutting initiative on biodiversity for food and nutrition. *Journal of Food Composition and Analysis* 22:361–365

Burlingame B, Dernini S, Charrondiere UR, Stadlmayr B, Mondovi S, Dop M-C, et al. (2011) Biodiversity and sustainable diets. Nutrition Assessment and Requirements Group, Nutrition and Consumer Protection Division. Food and Agriculture Organization of the United Nations, Rome

CBD (2006) COP 8 Decision VIII/23 Agricultural biodiversity. Cross-cutting initiative on biodiversity for food and nutrition. Convention on Biological Diversity http://www.cbd.int/doc/decisions/cop-08/cop-08-dec-23-en.pdf. Accessed 12 Apr 2010

Davey MW, Van den Bergh I, Markham R, Swennen R, Keulemans J (2009) Genetic variability in Musa fruit provitamin A carotenoids, lutein and mineral micronutrient contents. *Food Chemistry* 115:806–813. doi:10.1016/j.foodchem.2008.12.088

Dovie DBK, Shackleton CM, Witkowski ETF (2007) Conceptualizing the human use of wild edible herbs for conservation in South African communal areas. *Journal of Environmental Management* 84:146–156. doi:10.1016/j.jenvman.2006.05.017

Ekesa B, Walingo M, Abukutsa-Onyango M (2008) Influence of agricultural biodiversity on dietary diversity of preschool children in Matungu division, Western Kenya. *African Journal of Food, Agriculture, Nutrition and Development* 8:390–404

Englberger L, Aalbersberg W, Schierle J, Marks GC, Fitzgerald MH, Muller F, et al. (2006) Carotenoid content of different edible pandanus fruit cultivars of the republic of the Marshall Islands. *Journal of Food Composition and Analysis* 19:484–494. doi:10.1016/j.jfca.2005.11.003

Englberger L, Schierle J, Kraemer K, Aalbersberg W, Dolodolotawake U, Humphries J, et al. (2008) Carotenoid and mineral content of Micronesian giant swamp taro (Cyrtosperma) cultivars. *Journal of Food Composition Analysis* 21:93–106. doi:10.1016/j.jfca.2008.12.001

Englberger L, Schierle J, Hofmann P, Lorens A, Albert K, Levendusky A, et al. (2009) Carotenoid and vitamin content of Micronesian atoll foods: Pandanus (*Pandanus tectorius*) and garlic pear (*Crataeva speciosa*) fruit. *Journal of Food Composition and Analysis* 22:1–8. doi:10.1016/j.jfca.2008.12.001

Englberger L, Kuhnlein H, Lorens A, Pedrus P, Albert K, Currie J, et al. (2010) Pohnpei, FSM case study in a global health project documents its local food resources and successfully promotes local food for health. *Pacific Health Dialog* 16:129–136

Englberger L, Lyons G, Foley W, Daniells J, Aalbersberg B, Dolodolotawake U, et al. (2010b) Carotenoid and riboflavin content of banana cultivars from Makira, Solomon Islands. *Journal of Food Composition and Analysis* (DOI: 10.1016/j.jfca.2010.03.002)

FAO (1995) Expert advice on energy and nutrient requirements. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/V7700T/V7700T00.htm. Accessed 12 Apr 2010

FAO (1997) The state of world's plant genetic resources. Food and Agriculture Organization of the United Nations, Rome

FAO (1998) Human vitamin and mineral requirements. Food and Agriculture Organization of the United Nations/World Food Organization of the United Nations. ftp://ftp.fao.org/es/esn/nutrition/Vitrni/vitrni.html. Accessed 12 Apr 2010

FAO (2008) Expert consultation on nutrition indicators for biodiversity 1: food composition. Food and Agriculture Organization of the United Nations. ftp://ftp.fao.org/docrep/fao/010/a1582e/a1582e00.pdf. Accessed 14 May 2010

FAO (2010a) Expert consultation on nutrition indicators for biodiversity 2: food consumption. Food and Agriculture Organization of the United Nations. http://www.fao.org/infoods/biodiversity/FoodConsumptionIndicatorfinaloct2010.pdf. Accessed 19 Oct 2010

FAO (2010b) International scientific symposium biodiversity and sustainable diets, United against hunger: final document. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/humannutrition/23781-0e8d8dc364ee46865d5841c48976e9980.pdf. Accessed 15 Nov 2010

FAO (2010c) The state of food insecurity in the world. Addressing food insecurity in protracted crises. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/013/i1683e/i1683e.pdf. Accessed 15 Nov 2010

Flyman MV, Afolayan AJ (2006) The suitability of wild vegetables for alleviating human dietary deficiencies. *South African Journal of Botany* 72:492–497

Frei M, Becker K (2004) Agro-biodiversity in subsistence-oriented farming systems in a Philippine upland region: nutritional considerations. *Biodiversity and Conservation* 13:1591–1610. doi:10.1023/B:BIOC.0000021330.81998.bb

Frison E, Smith O, Swaminathan MS (2005) Agricultural biodiversity and elimination of hunger and poverty: UN Millennium Development Goals Five years later The Chennai platform for action. Bioversity International. http://www.underutilized-species.org/documents/PUBLICATIONS/chennai_declaration_en.pdf. Accessed 7 June 2010

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

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

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. (2010) Food security: the challenge of feeding 9 billion people. *Science* 327:812–818 (DOI: 10.1126/science.1185383)

Hatloy A, Torheim LE, Oshaug A (1998) Food variety-a good indicator of nutritional adequacy of the diet? A case study from an urban area in Mali, West Africa. *European Journal of Clinical Nutrition* 52:891–898

Hoddinott J, Yohannes Y (2002) Dietary diversity as a household food security indicator. Food and Nutrition Technical Assistance Project, Academy for Educational Development, Nutrition Technical Assistance. http://www.fantaproject.org/downloads/pdfs/DietaryDiversity02.pdf. Accessed 18 Oct 2010

Johns T (2003) Plant biodiversity and malnutrition: simple solutions to complex problems. Theoretical basis for the development and implementation of a global strategy linking plant genetic resource conservation and human nutrition. *African Journal of Food Agriculture Nutrition and Development* 3:45–52

Johns T, Eyzaguirre PB (2006) Linking biodiversity, diet and health in policy and practice. *Proceedings of the Nutrition Society* 65:182–189

Johns T, Eyzaguirre PB (2007) Biofortification, biodiversity and diet: a search for complementary applications against poverty and malnutrition. *Food Policy* 32:1–24

Kennedy G, Islam O, Eyzaguirre P, Kennedy S (2005) Field testing of plant genetic diversity indicators for nutrition surveys: rice-based diet of rural Bangladesh as a model. *Journal of Food Composition and Analysis* 18:255–268. doi:10.1016/j.jfca.2004.10.002

Kennedy GL, Pedro MR, Seghieri C, Nantel G, Brouwer I (2007) Dietary diversity score is a useful indicator of micronutrient intake in non-breast-feeding Filipino children. *The Journal of Nutrition* 137:472–477

Krawinkel MB (2009) The value of Asian-Africa collaboration in food and health security. *Asia Pacific Journal of Clinical Nutrition* 18:570–576

Kris-Etherton PM, Hecker KD, Bonanome A, Coval SM, Binkoski AE, Hilpert KF, et al. (2002) Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. *American Journal of Medicine* 113:71–88

Kuhnlein HV, Receveur O, Soueida R, Egeland GM (2004) Arctic indigenous peoples experience the nutrition transition with changing dietary patterns and obesity. *Journal of Nutrition* 134:1447–1453

Kuhnlein HV, Barthet V, Farren A, Falahi E, Leggee D, Receveur O, et al. (2006) Vitamins A, D, and E in Canadian Arctic traditional food and adult diets. *Journal of Food Composition and Analysis* 19:495–506. doi:10.1016/j.jfca.2005.02.007

Kuhnlein HV, Erasmus B, Pigelsky D (2009) Indigenous peoples' food systems: the many dimensions of culture, diversity and environment for nutrition and health. Food and Agriculture Organization of the United Nations, Rome

Lang T, Barling D, Caraher M (2001) Food, social policy and the environment: towards a new model. *Social Policy & Administration* 35:538–558. doi:10.1111/1467-9515.t01-1-00252

Lykke AM, Mertz OLE, Ganaba S (2002) Food consumption in rural Burkina Faso. *Ecology of Food Nutrition* 41:119–153

McMichael AJ, Powles JW, Butler CD, Uauy R (2007) Food, livestock production, energy, climate change, and health. *The Lancet* 370:1253–1263

Mennen LI, Mbanya JC (2000) The habitual diet in rural and urban Cameroon. *European Journal of Clinical Nutrition* 54:150–154

Moher D, Liberati A, Tetzlaff J, Altman D (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. The PRISMA Group

Monteiro CA, Conde WL, Popkin BM (2004) The burden of disease from under nutrition and over nutrition in countries undergoing rapid nutrition transition: a view from Brazil. *American Journal of Public Health* 94:433–434

Mouillé B, Charrondière UR, Burlingame B (2010) The contribution of plant genetic resources to health and dietary diversity. Food and Agriculture Organization of the United Nations. Nutrition Assessment and Nutrient Requirements Group, Nutrition and Consumer Protection Division. http://www.fao.org/docrep/013/i1500e/i1500e17.pdf. Accessed 15 Jan 2011

Nebel S, Pieroni A, Heinrich M (2006) Ta chòrta: wild edible greens used in the Graecanic area in Calabria, Southern Italy. *Appetite* 47:333–342

Nordeide MB, Hatloy A, Folling M, Lied E, Oshaug A (1996) Nutrient composition and nutritional importance of green leaves and wild food resources in an agricultural district, Koutiala, in Southern Mali. *International Journal of Food Sciences and Nutrition* 47:455–468. doi:10.3109/09637489609031874

Ogle BM, Dao HTA, Mulokozi G, Hambraeus L (2001) Micronutrient composition and nutritional importance of gathered vegetables in Vietnam. *International Journal of Food Sciences and Nutrition* 52:485–499

Ogle BM, Hung PH, Tuyet HT (2001) Significance of wild vegetables in micronutrient intakes of women in Vietnam: an analysis of food variety. *Asia Pacific Journal of Clinical Nutrition* 10:21–30. doi:10.1046/j.1440-6047.2001.00206.x

Ogle BM, Johansson M, Tuyet HT, Johannesson L (2001) Evaluation of the significance of dietary folate from wild vegetables in Vietnam. *Asia Pacific Journal of Clinical Nutrition* 10:216–221. doi:10.1046/j.1440-6047.2001.00261.x

Orban E, Masci M, Nevigato T, Di Lena G, Casini I, Caproni R, et al. (2006) Nutritional quality and safety of whitefish (*Coregonus lavaretus*) from Italian lakes. *Journal of Food Composition and Analysis* 19:737–746. doi:10.1016/j.jfca.2005.12.014

Osemeobo GJ (2001) Wild plants in everyday use: conservation towards sustainable livelihoods in Nigeria. *International Journal of Sustainable Development and World Ecology* 8:369–379

Passos CJS, Mergler D, Fillion M, Lemire M, Mertens F, Guimarães JRD, et al. (2007) Epidemiologic confirmation that fruit consumption influences mercury exposure in riparian communities in the Brazilian Amazon. *Environmental Research* 105:183–193. doi:10.1016/j.envres.2007.01.012

Pieroni A, Nebel S, Santoro RF, Heinrich M (2005) Food for two seasons: culinary uses of non-cultivated local vegetables and mushrooms in a south Italian village. *International Journal of Food Sciences and Nutrition* 56:245–272. doi:10.1080/09637480500146564

Rais M, Pazderka B, van Loon GW (2009) Agriculture in Uttarakhand, indiabiodiversity, nutrition, and livelihoods. *Journal of Sustainable Agriculture* 33:319–335. doi:10.1080/10440040902773152

Rajasekaran B, Whiteford MB (1993) Rice-crab production in South India: the role of indigenous knowledge in designing food security policies. *Food Policy* 18:237–247. doi:10.1016/0306-9192(93)90080-U

Roche M, Creed-Kanashiro H, Tuesta I, Kuhnlein H (2008) Traditional food diversity predicts dietary quality for the Awajún in the Peruvian Amazon. *Public Health Nutrition* 11:457–465. doi:10.1017/S1368980007000560

Roos N, Islam MM, Thilsted SH (2003) Small indigenous fish species in Bangladesh: contribution to vitamin A, calcium and iron intakes. *Journal of Nutrition* 133:4021–4026

Roos N, Chamnan C, Loeung D, Jakobsen J, Thilsted SH (2007) Freshwater fish as a dietary source of vitamin A in Cambodia. *Food Chemistry* 103:1104–1111. doi:10.1016/j.foodchem.2006.10.007

Roos N, Thorseng H, Chamnan C, Larsen T, Gondolf UH, Bukhave K, et al. (2007) Iron content in common Cambodian fish species: perspectives for dietary intake in poor, rural households. *Food Chemistry* 104:1226–1235. doi:10.1016/j.foodchem.2007.01.038

Ruel MT (2003) Operationalizing dietary diversity: a review of measurement issues and research priorities. *Journal of Nutrition* 133:3911–3926

Savy M, Martin-Prevel Y, Sawadogo P, Kameli Y, Delpeuch F (2005) Use of variety/diversity scores for diet quality measurement: relation with nutritional status of women in a rural area in Burkina Faso. *European Journal of Clinical Nutrition* 59:703–716

Singh V, Garg AN (2006) Availability of essential trace elements in Indian cereals, vegetables and spices using INAA and the contribution of spices to daily dietary intake. *Food Chemistry* 94:81–89. doi:10.1016/j.foodchem.2004.10.053

Steyn NP, Olivier J, Winter P, Burger S, Nesamvuni C (2001) A survey of wild, green, leafy vegetables and their potential in combating micronutrient deficiencies in rural populations. *South African Journal of Science* 97:276–278

Steyn N, Nel J, Nantel G, Kennedy G, Labadarios D (2006) Food variety and dietary diversity scores in children: are they good indicators of dietary adequacy? *Public Health Nutrition* 9:644–650. doi:10.1079/PHN2005912

STROBE (2007) Checklist of items that should be included in reports of cross-sectional studies STROBE statement: strengthening the reporting of observational studies in epidemiology. http://www.strobe-statement.org/index.php?id=available-checklists. Accessed July 2010

Toledo Á, 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

Tontisirin K, Nantel G, Bhattacharjee L (2002) Food-based strategies to meet the challenges of micronutrient malnutrition in the developing world. *Proceedings of the Nutrition Society* 61:243–250 (DOI: 10.1079/PNS2002155)

Torheim LE, Ouattara F, Diarra MM, Thiam FD, Barikmo I, Hatloy A, et al. (2004) Nutrient adequacy and dietary diversity in rural Mali: association and determinants. *European Journal of Clinical Nutrition* 58:594–604

UN (2010) Promotion and protection of all human rights, civil, political, economic, social and cultural rights, including the right to development. United Nations

Vinceti B, Eyzaguirre P, Johns T (2008) The nutritional role of forest plant foods for rural communities. In: *Human Health and Forests*, Colfer Pierce CJ (editor), London: Earthscan, pp 63–96

Wahlqvist ML (2003) Regional food diversity and human health. *Asia Pacific Journal of Clinical Nutrition* 12:304–308

Wahlqvist ML (2005) Diversification in indigenous and ethnic food culture. In: *Diet Diversification and Health Promotion*, Elmadfa I (editor), Basel: Karger Publishers, pp 52–61

WHO (2003) *WHO technical report series: Diet, Nutrition and the Prevention of Chronic Diseases*, Geneva: World Health Organization