Why Invest in Protecting and Promoting Biodiversity?

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Agricultural Biodiversity Offers a Potential Solution to Achieve Improved Nutrition-Related Health Outcomes

A Bioversity International and BFN Report

Summary

All countries in the world, no matter whether rich or poor, are affected by malnutrition in one form or another. In fact, one in three persons in the world suffers either from undernourishment, micronutrient deficiency, and/or overweight and obesity, and diet-related chronic diseases are alarmingly on the rise. Although agriculture and the food industry have made remarkable advances in producing more food in the past decades, their development obviously has not fulfilled health and nutritional needs showing that more food is not equal to better quality food. At least 51 nutrients in adequate and consistent amounts are required to sustain good health, but as efforts have been directed at maximising productivity and production, uniformity has replaced diversity within cultivation systems leading to high losses in agricultural biodiversity and simplification of diets which is why the current food system is barely able to deliver the essential nutrients for human diets. This translates into tremendous economic costs: undernutrition and micronutrient deficiencies are estimated to cost US$1.4–2.1 trillion per year, equivalent to 2–3% of global GDP; non-communicable diseases, for which overweight and obesity are key risk factors, will cost more than US$ 30.4 trillion worldwide over this and the next decade under a 'business as usual' scenario, representing 47.1% of global GDP in 2010 alone. There is no good health without good nutrition, and good nutrition ultimately depends on agriculture and food systems which derive their existence from biodiversity. Thus, fostering agricultural biodiversity, dietary diversity and associated traditional knowledge - as complementary solution to other nutrition and health interventions - has great potential to reduce the health burdens of malnutrition and its associated economic costs.

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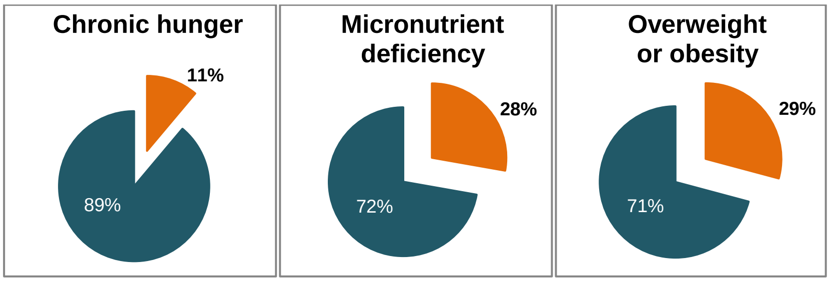
1 Urgent call for change: the inability of the current global food system to fulfil health and nutritional needs

All countries in the world, no matter whether rich or poor, are affected by malnutrition in one form or another – over- and undernutrition - and its health consequences. In fact, the most recent numbers are staggering: more than 800 million people are under-nourished, 2 billion people suffer from one or more micronutrient deficiencies, 2.1 billion individuals worldwide are overweight or obese (Figure 1), and diet-related chronic diseases are alarmingly on the rise, leading to major economic losses (FAO et al. 2014; IFPRI 2014; Ng et al. 2014; FAO 2013; United Nations 2013). Although agriculture and the food industry have made remarkable advances in the past decades in producing more food, their development obviously has not fulfilled health and nutritional needs, and moreover, they have generated massive losses in agricultural biodiversity[1] (Allen et al. 2014). As efforts have been directed at maximising productivity and production, uniformity has replaced diversity within cultivation systems (Figure 2) leading to ecosystem degradation, loss of species and the associated traditional knowledge, and simplification of diets with thousands of important, nutritionally rich species and many more underutilized or neglected crops barely incorporated in consumption patterns. The increase in food supply, which is not equal to better quality food supply, has thus come with important trade-offs that impair the ability of ecosystems to deliver the essential nutrients for human diets (Allen et al. 2014; Khoury et al. 2014; Johns & Eyzaguirre 2006)

Figure 1: Share of people worldwide suffering from malnutrition



Source: (FAO et al. 2014; von Grebmer et al. 2014; Ng et al. 2014)

Obesity is one of the top three social burdens generated by human beings

Impact on global GDP (PPP), 2012:

$2.1 trillion: Smoking
$2.1 trillion: Armed conflicts
$2.0 trillion: Obesity
$1.4 trillion: Alcoholism

(Dobbs et al. 2014)

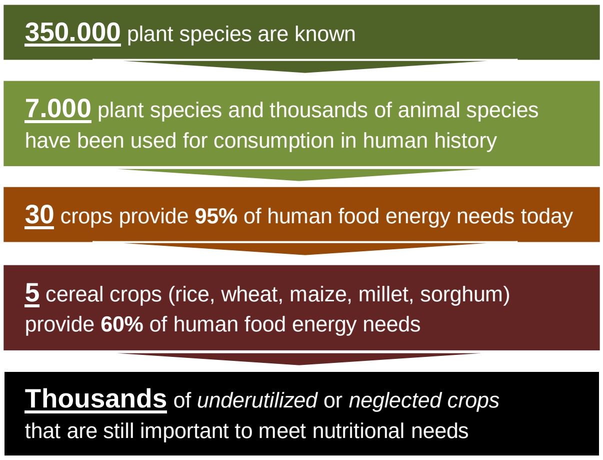
The loss of (agricultural) biodiversity, the increasingly homogenous agricultural output with its associated reduction in dietary diversity, and the current global health crises of malnutrition therefore present new challenges for food systems and urgently call for changes (Allen et al. 2014). The post-2015 Development Agenda thereby presents a fundamental

[1] Agricultural biodiversity is one key component of biodiversity. It is defined as "*the variety and variability of animals, plants and microorganisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil microorganisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems*" (FAO 1999). Biodiversity for human nutrition "*addresses the diversity of plants, animals and other organisms used for food, covering the genetic resources within species, between species and provided by ecosystems*" (Hunter & Fanzo 2013).

opportunity for humanity to put aside business as usual and move towards the real transformative change that is needed to address the major global challenge of malnutrition.

The nexus between biodiversity, agriculture and nutrition has recently been recognized through a series of initiatives and activities from different sectors (such as CBD 2015, CBD 2006, FAO 2013, UN SCN 2013, UNEP 2012 WHO 2012) and could be realized through integration into the new Sustainable Development Goals. Investing in biodiversity might not solve all problems related to the global challenge of malnutrition; however, the evidence and information compiled in the following sections highlight the importance of biodiversity for food and nutrition and show that biodiversity is a bigger and very promising part of the solution to the burdens of malnutrition.

Figure 2: Degradation of agrobiodiversity



Source: (Crops for the Future 2015; CBD 2013)

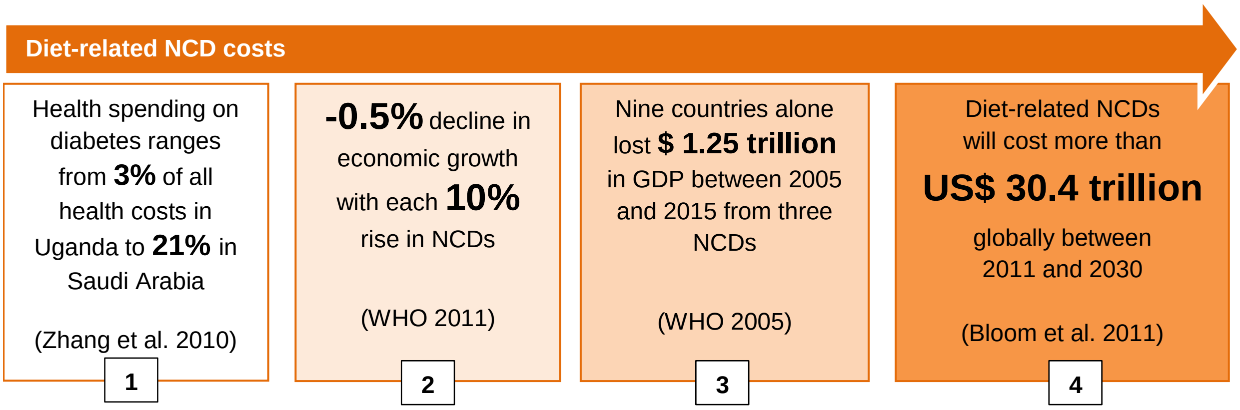
2 The economic costs of malnutrition

Malnutrition and associated impairments and diseases (see Box 1) are not only a blow of fate for affected individuals and their families, but also a major obstacle for sustainable economic development. Since good nutrition is part of human capital it contributes, as such, to economic development (and vice versa). Significant costs of malnutrition to individuals, families, businesses, governments and health systems add up to major macroeconomic impacts and ultimately constrain economic growth in terms of lost GDP and higher budget outlays (World Bank 2006).

2.1 Economic impact of overnutrition and associated chronic diseases

Looking at overweight/obesity and non-communicable diseases (NCDs), for which unhealthy diets are a major common modifiable risk factor, the numbers presented in the following Figure 3 are staggering and highlight that the economic burden of NCDs has the potential to overwhelm health systems and slow economic growth:

Figure 3: Diet-related NCD costs



As illustrated in Figure 3, box (1), a single chronic disease can impose huge economic costs on a country's national economy in terms of health spending. (Zhang et al. 2010) estimated health spending on diabetes alone to range from 3% of all health costs in Uganda to 21% in Saudi Arabia and global expenditure on diabetes totalled more than US$ 376 billion in 2010.

Box 1: Health effects of malnutrition

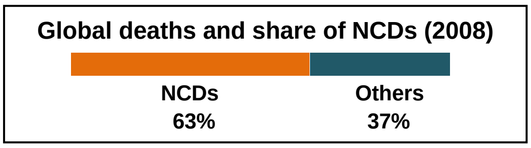
Malnutrition encompasses undernutrition and overnutrition. Overnutrition is a result of excessive energy or micronutrient intake relative to dietary nutrient requirements. Undernutrition is defined as deficiencies in energy, protein, and/or micronutrients, where the latter affect more than a third of the world's population (FAO et al. 2014; von Grebmer et al. 2014). Micronutrients are essential vitamins and minerals required to enhance cellular growth and metabolism. At least 51 nutrients in adequate amounts, consistently, are required to sustain good health and development in children and normal physical and mental functions in adults (IFPRI 2014; Graham et al. 2007; Darnton-Hill et al. 2005). The impact of **micronutrient malnutrition** is already established in early life, leading to severe health consequences such as growth stunting, lethargy and poor attention, lower cognitive abilities, developmental delays, weak immune system, and greater severity and rates of infection (von Grebmer et al. 2014; WHO 2009; Demment et al. 2003). Easy-to-remedy nutritional deficiencies even cause an estimated 1.1 million child deaths per year (von Grebmer et al. 2014; Black et al. 2013). For instance, **iodine deficiency** causes over 20 million babies per year to be born mentally impaired (Darnton-Hill et al. 2005; Hetzel 2005). An estimated 41% of pregnant women and 27% of preschool children worldwide have anaemia caused by **iron deficiency** and over 20% of all maternal deaths in low- and middle income countries are caused by anaemia (WHO 2015a; WHO 2009). Furthermore, the leading cause of preventable blindness in children is **vitamin A deficiency** (WHO 2015b). About 33% of children suffer vitamin A deficiency, mostly in South-East Asia and Africa and over 19% of global diarrhea mortality can be attributed to it (WHO 2009).

All these negative health effects have consequences for individual productivity and brain power thereby reducing the aggregate ability of the population to enhance its well-being and participate in national and global markets (Victora et al. 2008; Demment et al. 2003):

Iodine and iron deficiency may reduce a person's IQ by as much as 10-15% and 8%, respectively	**Elimination of anaemia may result in a 5-17 % increase in adult productivity**	**Low birth-weight and stunting may reduce a person's IQ by 5% and 5-11%, respectively**	**A 1% loss in adult height because of childhood stunting leads to a 1.4% loss in productivity**

(World Bank 2006; Darnton-Hill et al. 2005; Hetzel 2005)

The simplification of ecosystems and diets also becomes manifested in **overweight and obesity** which are associated with lower labour productivity and constitute key risk factors for **chronic**, **non-communicable diseases** (Tilman & Clark 2014; FAO 2013; World Bank 2006). These diseases are increasing so fast, even in poor countries, that this phenomenon has been called *the nutrition transition* (World Bank 2006). In fact, out of 57 million global deaths in 2008, 36 million, or 63%, were due to chronic, non-communicable diseases, principally cardiovascular diseases, diabetes, cancers and chronic respiratory diseases (WHO 2011). About 70-80% of deaths linked to these diseases occur in low- and middle income countries (WHO 2011; Stuckler 2008; World Bank 2006). Nature and quality off diets affect the risk of chronic diseases which makes them largely preventable diseases (Chokshi & Farley 2014; Tilman & Clark 2014; WHO 2005). For instance, dietary factors account for approximately 30% and 20% of cancers in industrialized and developing countries, respectively (WHO 2003; Doll & Peto 1996). In addition, approximately 44% of the diabetes burden and 23% of the ischaemic heart disease burden are attributable to overweight and obesity (WHO 2009).



Speaking about NCDs and their general impact on economic growth (Figure 3, box 2), it could be shown that each 10% rise in NCD prevalence is associated with 0.5% lower rates of annual economic growth (WHO 2011; Stuckler 2008). Thus, for example, the expected 50% increase in chronic diseases in Latin America from 2002 to 2030 would result in more than a 2% slowdown in economic growth each year (Stuckler 2008).

Table 1: Estimated forgone national income due to heart disease, stroke and diabetes, selected countries, 2005-2015 (billions of constant 1998 international dollars)

	Brazil	Canada	China	India	Nigeria	Pakistan	Russia	UK	Tanzania
Income loss in 2005	2.7	0.5	18.3	8.7	0.4	1.2	11.1	1.6	0.1
Income loss in 2015	9.3	1.5	131.8	54.0	1.5	6.7	66.4	6.4	0.5
Accumulated loss in 2015	***49.2***	***8.5***	***557.7***	***236.6***	***7.6***	***30.7***	***303.2***	***32.8***	***2.5***

Source: (WHO 2005)

Translating the economic slowdown into numbers (Figure 3, box 3), a ‘business as usual’ scenario, where intervention efforts remain static and rates of NCDs continue to increase as populations grow and age, would lead to estimated cumulative economic losses of US$ 7 trillion to low- and middle income countries from cardiovascular disease, diabetes, cancer and chronic respiratory diseases over the period 2011-2025. This is an average yearly loss of nearly US$ 500 billion which is equivalent to approximately 4% of these countries current annual output (WEF et al. 2011). Furthermore, Table 1 outlines the forgone national income from stroke, heart disease, and diabetes in nine different (low, middle and high income) countries. The losses during the last 10 years until this year amount to an overwhelming 1.25 trillion of constant (1998) international dollars (WHO 2005). More detailed insights into the economic burden of obesity and diet-related NCDs are provided in boxes 2-4 through country case studies.

Box 2: Case study - Costs of diet-related NCDs in China

The estimated number of deaths in China due to diet-related chronic diseases (CVD, diabetes, hypertension, stroke, and cancers) will be 7.63 million in 2025, representing 52% of all deaths. In 1995, diet-related chronic diseases in China caused total annual costs of about 2.1% of the GDP ($15.1 billion) in terms of lost productivity due to premature deaths and costs to health care systems (hospitalization, outpatient visits, drugs, etc.). 2.57 million people (41.6% of all deaths) died from diet-related chronic diseases in 1995. In 1995, 20-25% of these costs could be traced back to dietary factors whereas estimations show that in 2025 25-45% of these costs will arise because of dietary factors (Popkin 2003; Popkin et al. 2001). Furthermore, (Popkin et al. 2006) estimate that overweight and obesity lowered China’s GNP by 4.06% (US$49 billion) in 2000 and will lower it by 9.23% (US$112 billion) in 2025 whereby the major part will be due to indirect costs including increased mortality before retirement, decreased years of disability free life before retirement, and increased absenteeism from work.

7.63 million people will die in China due to diet-related chronic diseases and overweight/obesity prevalence will **lower** China’s GNP by **9.23%** in 2025

Box 3: Case study - Costs of obesity in the USA and UK

(Wang et al. 2011) projected the probable economic and health consequences for the period 2010-2030 from a continued rise in obesity in the USA and UK. By 2030, 65 million and 11 million more obese adults in the USA and the UK, respectively, are projected by the simulation model, leading to 492,000 - 669,000 additional cases of cancer, 5.7-7.3 million additional cases of heart disease and stroke, and an additional 6-8.5 million cases of diabetes for the USA and UK combined. The authors estimated that the treatment of these preventable diseases would add to health care costs by £1.9-2 billion per year in the UK and by $48 - 66 billion per year in the USA by 2030. This increase in medical costs corresponds about 1.7%-2.6% and 1.7%–2% of the total-health care spending in the USA and UK in 2009, respectively (Wang et al. 2011).

It is estimated that obese patients in the USA generally incur 46% increased inpatient costs, 27% more non-inpatient costs, and 80% increased spending on prescription drugs compared to normal-weight individuals. This translates into medical spending that was on average 41.5% or US$1,429/capita/year greater for obese people compared to normal-weight people in 2006 (in 2008 dollars). In aggregate, annual extra medical cost of all obese patients in the USA (inpatient, non-inpatient, and prescription drug spending) was estimated as $147 billion in 2006 compared to US$74.2 billion in 1998 (in 2008 dollars) and accounted for almost 10% of total health-care expenditure (Finkelstein et al. 2009). Hence, the estimated increase in obesity in the USA until 2030 would further increase annual health care costs devoted to obesity by almost 50% compared to 2006. Furthermore, obesity prevalence incurs economic costs of forgone productivity through lost work days which were expected in the USA as high as US$8.65 billion/year in 2012 for absenteeism (Andreyeva et al. 2014) and US$30.0 billion per year in 2008 for presenteeism (Finkelstein et al. 2010).

Considering a hypothetical 1% BMI reduction across the entire US population (a 1% reduction is equal to a weight loss of approximately 1kg for an adult of average weight), up to 2.4 million incident cases of diabetes, 1.7 million cardiovascular diseases, and 127,000 cases of cancer could be avoided over 20 years until 2030. Hence, even a small change in BMI can have substantial effects on consequent health burdens and economic costs (Wang et al. 2011).

What if?

1% BMI reduction across the entire US population 2010-2030 could **avoid** up to…

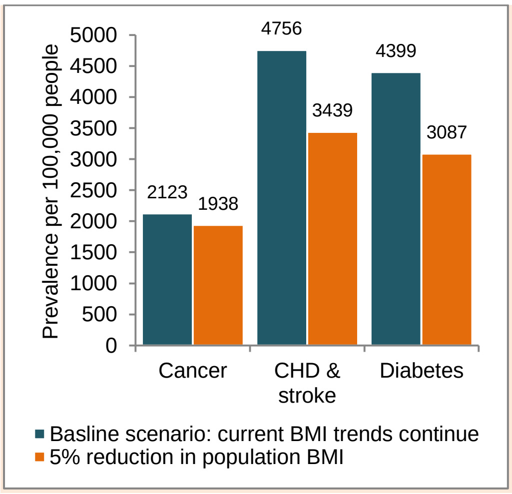
- **2.4 million** incident cases of diabetes
- **1.7 million** cardiovascular diseases
- **127.000** cases of cancer

Box 4: Case study - Costs of obesity in Europe

(Fry & Finley 2005) estimated that the combined direct costs of obesity (related to primary medical consultation, hospital treatment and medicines) and indirect costs of obesity (derived from the number of days taken off for sickness as a result of obesity-related illnesses and from early deaths as a consequence of the same illnesses) in 15 member states of the EU in 2002 were approximately 33 billion Euro.

According to (Webber et al. 2014) obesity prevalence and obesity-related non-communicable disease will drastically increase until 2030 in almost all 53 WHO European region countries. This is worrying given the high economic costs associated with it by (Fry & Finley 2005). The authors therefore modelled the impact of a hypothetical intervention scenario (5% reduction in population BMI) on the incidence of CHD and stroke, cancers, and type II diabetes. It could be shown that

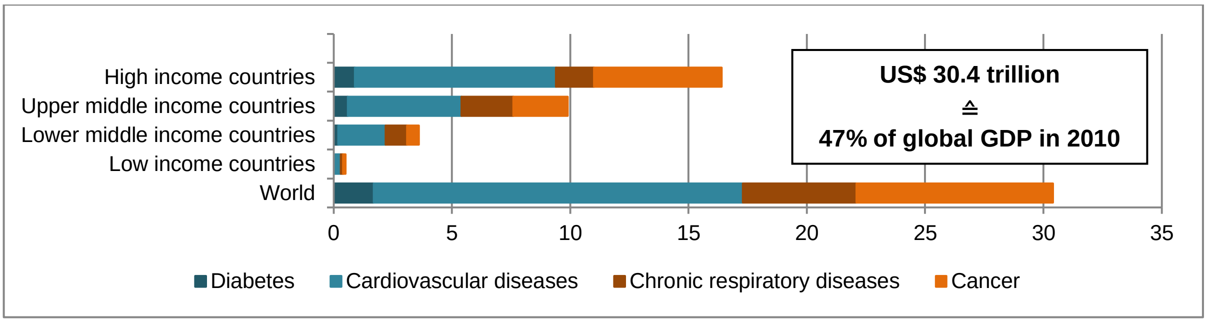
Figure 4: Total projected prevalence of obesity-related NCDs by 2030 for 53 WHO European Region Member States



Source: own illustration based on (Webber et al. 2014) reducing population BMI by 5% relative to the baseline scenario (current BMI trends continue) can lead to a substantial number of disease cases avoided by 2030 (Figure 4) thus decreasing the economic costs of obesity-related NCDs.

Aggregating economic losses from countries or regions to a global scale ultimately illustrates the incredible dimension of the burden imposed by diet-related NCDs (Figure 3, box 4). A recent study estimates a cumulative output loss under a 'business as usual scenario' in low, middle, and high income countries due to NCDs (diabetes, cardiovascular diseases, chronic respiratory diseases, cancer), for which overweight and obesity are key risk factors, of US$ 30.4 trillion over this and the next decade from 2011 to 2030 (Figure 5). This cumulative loss represents 47.1% of global GDP in 2010 alone (Bloom et al. 2011).

Figure 5: Economic burden of diet-related NCDs, 2011-2030 (trillions of US$ 2010)



Remarks: Value of lost output based on WHO's EPIC model
Source: Own illustration based on (Bloom et al. 2011)

2.2 Economic impact of undernourishment and micronutrient deficiencies

As outlined before, undernourishment and micronutrient deficiencies, such as iron deficiency, vitamin A deficiency, or iodine deficiency combined affect more than 2 billion people in the world and incur substantial economic costs: The costs of undernutrition and micronutrient deficiencies are estimated at 2–3% of global GDP, equivalent to US$1.4–2.1 trillion per year, and a reduction in lifetime earnings by 10% (FAO 2013; World Bank 2006). Estimates by (Horton & Steckel 2011) even suggest much higher numbers whereby Asia and Africa lose 11% and Latin America and the Caribbean lose 7% of GNP every year owing to poor nutrition. A report by (African Union Commission et al. 2014) additionally demonstrates that child undernutrition alone lowers GDP for Egypt, Ethiopia, Swaziland, and Uganda by 1.9%, 16.5%; 3.1%; and 5.6%, respectively. In China, the prevention of micronutrient deficiencies is considered being worth between US$2.5 and US$5 billion/year in increased GDP, representing 0.2-0.4% of annual GDP in China (World Bank 2006). Another study even suggests that the costs of individual nutritional deficiencies in China amount up to 0.5-1.8% of lost GDP (Popkin 2003).

Global costs of hunger and micro-nutrient deficiencies per year:
US$ 1.4 - 2.1 trillion

In order to illustrate the economic impact of a specific micronutrient deficiency, let's have a closer look at the case of iron deficiency. Widespread iron deficiency is estimated to adversely affect national productivity with

Annual GDP losses in Bangladesh, India and Pakistan due to physical losses induced by iron deficiency:
$4.2 billion

Table 2: Productivity loss due to iron-deficiency anaemia

	Cognitive loss ($/capita, PV)	Physical loss ($/capita, PV)	Total loss ($/capita, PV)	Total loss (% of GDP, PV)
Bangladesh	12.98	3.23	16.21	**7.9**
India*	15.50	3.87	19.28	**6.0**
Pakistan*	19.44	2.97	22.41	**5.2**
Mali	6.98	1.92	8.90	**4.2**
Tanzania	3.17	0.62	3.79	**2.7**
Egypt*	15.46	1.92	17.38	**2.4**
Oman	359.41	9.09	368.50	**7.2**
Bolivia*	28.14	2.08	30.22	**3.9**
Honduras*	10.92	1.49	12.41	**2.0**
Nicaragua*	10.33	2.56	12.89	**3.8**

Remarks: For countries denoted by asterisk (*), data on anaemia in men were not available, and anaemia in adult males is assumed to be zero (although rates are likely to be higher); hence, figures are an underestimate. The estimates represent present value (PV) of the costs of the current level of anaemia persisting for one additional year. GDP = gross domestic product.
Source: (Horton & Ross 2003)

losses around 2% of GDP (Darnton-Hill et al. 2005). Illustrative calculations for 10 developing countries (Table 2), however, show that the annual productivity losses due to iron deficiency, which impacts on both physical and cognitive ability, can even be up to 7.9% of GDP (median total losses: 4.05% of GDP). Physical productivity losses are particularly large in South Asia (Bangladesh, India, Pakistan), where annual losses in GDP are close to $4.2 billion (Horton & Ross 2003).

Box 5: ***Case study - Childhood nutrition and economic productivity in Guatemala***

The investigation of a nutrition intervention in early childhood on adult economic productivity in Guatemala revealed that the prevention of undernutrition in early childhood leads to hourly earnings that are 20% higher and wage rates that are 48% higher. Furthermore, individuals are 33% more likely to escape poverty and women are 10% more likely to own their own business. Hence, investments in early childhood nutrition can be long-term drivers for economic growth (Hoddinott et al. 2008)

Investments in early childhood nutrition can be long-term drivers for economic growth

Putting it in a nutshell, the effects of malnutrition on national economies are overwhelming. Each year **several trillions of US$ are lost globally** through losses in productivity from poor physical status and losses caused by diseases linked with malnutrition, losses from poor cognitive development and losses in schooling, and losses by increased health care costs due to increased demand for social services and public revenues (World Bank 2006; Demment et al. 2003).

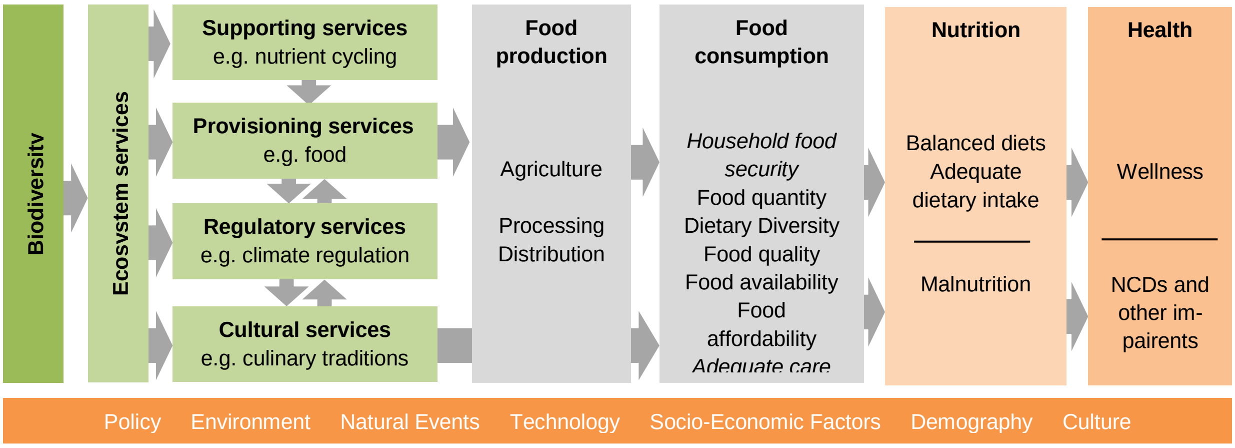
Not addressing malnutrition has high costs in lost GDP and higher budget outlays

But which tools should be applied in order to decrease these massive costs and combat the overwhelming problem of malnutrition and its global health consequences both in the developed and the developing world? How can we improve the nutrition situation of billions of people and thereby relieving the pressure on national budgets? This is where biodiversity for food and nutrition comes into play as one part of the overall solution. Food-based approaches relying on agricultural biodiversity provide local solutions to the previously mentioned nutrition, health and economic concerns.

3 The way forward: Biodiversity for food and nutrition

Using existing food diversity, dietary diversity and associated traditional knowledge, has the potential to help reduce prevalence of undernourishment, micronutrient deficiencies, overnutrition and diet-related chronic diseases, and thus associated economic costs. But in how far is biodiversity linked to nutrition and health? The following Figure 6 takes a system approach and illustrates the complex pathway between biodiversity, nutrition and health.

Figure 6: Linkages between biodiversity, food system and health



Remarks: Application of the Millennium Ecosystem Framework in combination with the UNICEF Child and Maternal Nutrition Framework and the conceptual framework for a food system

Source: adapted from (Remans & Smukler 2013; Pinstrup-Andersen 2012; Hawkes & Ruel 2011; Nugent 2011; Pinstrup-Andersen & Watson II 2011)

Human nutrition is the critical link between agriculture and health (Nugent 2011). There is no good health without good nutrition; and good nutrition ultimately depends on agriculture and food systems which derive their existence from biodiversity. Biodiversity provides ecosystem services whereby food production constitutes one of the ecosystem services most central to human welfare. The capacity of biodiversity and ecosystems to provide us with the energy and nutrition for our daily life fully depends on the foods that agriculture and food systems provide us. Good nutrition requires nutrient diversity and therefore calls for dietary diversity, which, in the end, is provided by agricultural biodiversity. Hence, biodiversity is a crucial component of complex food systems for ensuring the supply of quality nutrients along with staples and human health (Allen et al. 2014; Remans & Smukler 2013; Nugent 2011). In order to illustrate these linkages more in detail, the following section outlines the recent scientific evidence base for nutrition and health benefits of agrobiodiversity.

4 Scientific evidence base for nutrition and health benefits of agrobiodiversity

More diverse production systems contribute to more diverse diets and better health at the *household level*

There are several studies providing insights into aforementioned linkages between biodiversity, food, nutrition and health. A recent study among farming households in Malawi, for example, demonstrates that, after controlling for several confounding variables, more diverse production systems contribute significantly to more diverse diets at the household level, which is an important nutrition outcome associated with nutrient adequacy of diets and nutritional status of individuals (Jones et al. 2014). (Malapit et al. 2013) found production diversity at the household level in Nepal to be positively associated with mothers' dietary diversity and body mass index. Additionally, production diversity positively correlated with dietary diversity for children under two and predicted weight-for-age, weight-for-height, and height-for-age z-scores for children over two years of age. Furthermore, (Remans & Smukler 2013) and (Remans et al. 2011) assessed nutritional diversity of cropping systems in African villages. Although a biodiverse rich environment doesn't mean that people consume biodiverse foods per se (Termote et al. 2012), they found trends between species richness, nutritional functional diversity [2] (FD) and human nutrition at the village or landscape level. The authors found strong correlations between species richness and nutritional FD meaning that as the number of edible species increases, the diversity of nutritional functions that a farm provides also increases. It is concluded that higher species richness and nutritional FD at the village level correspond with higher dietary diversity and food security (more months with adequate food supply). In fact, in villages with greater diversity of species rich in mineral content research has found less prevalence of iron deficiency (Remans & Smukler 2013; Remans et al. 2011).

Higher species richness and nutritional functional diversity at the *village level* correspond with higher dietary diversity and lower nutrient deficiencies among the population

Moving from the household and landscape level to the national level, a recent study by (Remans et al. 2014) found strong associations between nutritional diversity of national food supplies and key human health outcomes, independent of national income, calories available per capita and other socioeconomic factors (diversity of food production and supply was measured by using two ecological diversity metrics – Shannon Entropy and Modified Functional Attribute Diversity – and the percent of energy coming from non-staples). For example, a significant negative relationship between diversity (Shannon diversity) of national food supplies and national prevalence of child wasting, stunting, and being underweight, which reflects a combination of acute and chronic undernutrition, was found. Yet, the relationship between production and supply diversity depends on the income level of the country. For low-income countries, food production diversity strongly predicts food supply diversity available for human consumption. For middle and high income countries, the diversity of foods produced is independent of production diversity and GNI and international trade are better predictors for national supply diversity. All in all, the authors conclude that

Diversity in *national* food systems is crucial for key nutrition health outcomes

[2] The so-called nutritional functional diversity metric bridges agriculture, ecology and nutrition studies, and "reflects the diversity of nutrients provided by the farm and the complementary in nutrients among species on a farm or community" (Remans et al. 2011: 2). With this tool one can identify potential crops, varieties or groups of plants that add nutritional value to the system if conserved, promoted or introduced (Remans et al. 2013).

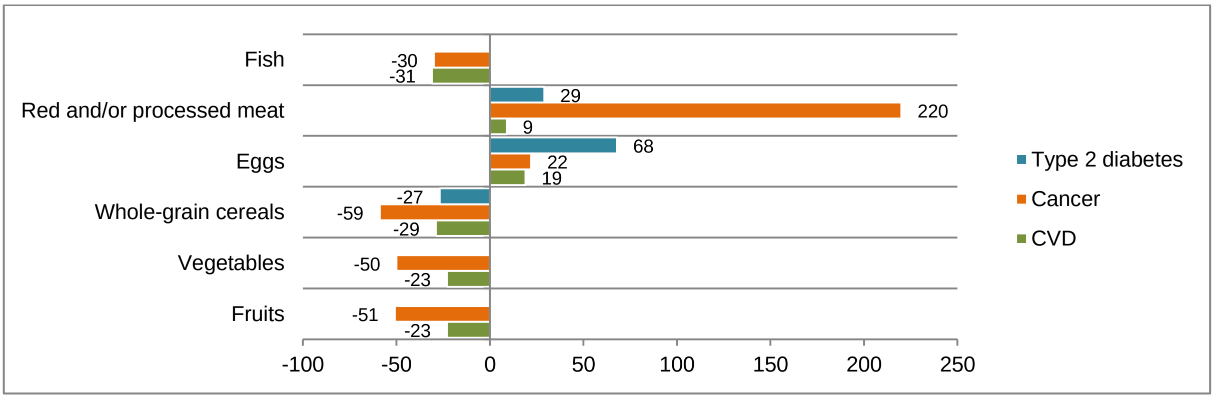
ensuring food supply diversity in terms of species diversity and nutritional diversity at the national level is crucial for achieving healthy food systems.

These findings on country level are confirmed by (Smith & Haddad 2015) who found dietary diversity to have the greatest potential in reducing child stunting prevalence (followed by access to sanitation and women's education). The authors identified key determinants of child stunting in developing countries, measured their strength and could show that a 10% increase in dietary diversity (proxy variable: % of dietary energy derived from non-staples) leads to a 1.5% decrease in the prevalence of child stunting in developing countries.

Hence, biodiversity and subsequent dietary diversity have huge potential to reduce the prevalence of nutrition deficiencies, i.e. stunting, thereby increasing productivity and mental health.

Apart from decreasing the prevalence of micronutrient deficiencies, sufficient, safe and varied food also reduces the risk of chronic diseases (IFPRI 2014; WHO 2003). It is widely agreed that diets relatively high in minimally processed grains, fiber, legumes, vegetables, fruits, and foods of plant origin and low in energy density, fats, saturated fats, salt, and sugar protect against chronic diseases (Popkin et al. 2001; Labarthe 1998). Several studies have reported significant protective associations for chronic diseases with consumption of vegetables and fruits (Liu et al. 2000; Joshipura et al. 1999; Ness & Powles 1997). For example, insufficient intake of vegetables and fruits is estimated to cause around 14% of gastrointestinal cancer deaths, about 11% of ischaemic heart disease deaths and about 9% of stroke deaths worldwide (Bloom et al. 2013; WHO 2009). One of the most recent studies by (Fardet & Boirie 2014) demonstrates how the intake of fruits, vegetables, meat, etc. affects the risk of NCDs (see

Figure 7: Risk associations between food groups and diet-related chronic diseases



Remarks: Numbers based on aggregation of 304 pooled/meta-analyses and systematic reviews published between 1950 and 2013; Percentage points indicate the increased/decreased risk of high consumption compared to the lowest level of consumption/no consumption of the particular food group

Source: (Fardet & Boirie 2014)

Figure 7 for risk associations between several food groups and diet-related chronic diseases). For example, high fruit and vegetable consumption not only reduces weight by 0.22kg and 0.10 kg, respectively, for each daily serving per 4-year period, but also decreases the risk of contracting cancer by up to 51%. In contrast, consuming high amounts of red meet was associated with significantly higher risks of type II diabetes (+29%), CVD (+9%) and several cancers (up to 220%).

Aforementioned arguments highlight that agrobiodiversity and overall dietary diversity and quality have strong impacts on nutrition and health outcomes. Indeed, food-based approaches leveraging agrobiodiversity to address malnutrition have long experience and documented success, and are even considered having the potential to be the most sustainable interventions for micronutrient deficiencies. Yet, these approaches have often failed to gain acceptance and adequate funding which is why there is some ongoing scepticism towards food-based approaches to nutrition and their health impacts (Darnton-Hill 2014; Darnton-Hill et al. 2005). Though, food-based interventions focusing on overall dietary quality "have the potential to be the most sustainable interventions for micronutrient deficiencies" (Darnton-Hill et al. 2005). Supplementation, in contrast, is useful in the short-term. Fortification requires extensive infrastructure for quality control, marketing, and education, and poor households often cannot afford to purchase fortified products (Kennedy et al. 2013). In addition, in contrast to diet/food-based approaches, supplementation and fortification (or single nutrient approaches) ignore the fact that the nutrient they target is simply a marker for more extensive nutrient deficiencies and neglect the importance of a mixed diet including underutilized foods and local varieties. This is why a more sustainable solution can be achieved by focusing on agrobiodiversity (Oejiwedo 2013, Stadlmayr et al. 2011, Johns and Eyzaguirre, 2007). Since there are difficulties and uncertainties about precisely identifying optimal diets and nutrient-nutrient interactions, diversity provides an intrinsic buffer against them which is why safeguarding this diversity is crucial (Kennedy et al. 2013, Johns 2003).

In order to further illustrate the nutrition and health benefits of agrobiodiversity, individual components of diets and the great compositional range in macro-and micronutrients among varieties and species, sustainable diets, traditional bush meals, as well as two examples of successful food-based nutrition interventions are presented below.

4.1 Individual components of a diet: Differences among varieties and species

There are significant compositional differences in micronutrient and macronutrient content among varieties, cultivars and species (Table 4) supporting the statement that the intake of one variety instead of another can make the difference between nutrient deficiency and adequacy (Stadlmayr et al. 2011; Lutaladio et al. 2010). In fact, some lesser known cultivars and wild varieties are superior over other, more extensively utilized cultivars in terms of their micronutrient contents and functional properties (Burlingame et al. 2009). These properties are associated with reduced risks of chronic diseases and improved health overall. Health related-functions of indigenous or local dietary plants include, among others, immunostimulation, antibiosis, nervous system action, antigout, antiinflammatory, detoxification, antioxidant, glycemic and hypolipidemic properties (Johns & Eyzaguirre 2006; Johns et al. 2006; Johns 2003). Reduction in plant (dietary) diversity leads to a loss in micronutrient contents and functional properties which is why the conservation of this diversity needs to be a priority. Evidence of remarkable compositional differences in nutrient contents and health-related functional properties of these plant-based foods is presented below.

Table 4: Examples of nutrient composition within varieties (per 100 g edible portion, raw)

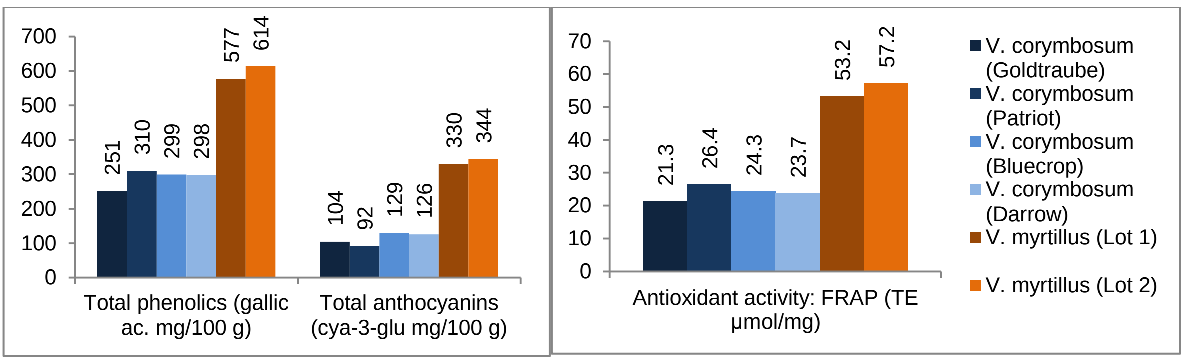
Varieties	Protein, g	Fibre, g	Iron, mg	Vitamin C, mg	β-Carotene, µg
Rice	5.6 - 14.6		0.7 - 6.4		
Sweet potato	1.3 - 2.1	0.7 - 3.9	0.6 - 14	2.4 - 35	100 - 23,100
Potato	1.4 - 2.9	1 - 2.29	0.3 - 2.7	6.4 - 36.9	1 - 7.7
Banana			0.1 - 1.6	2.5 - 17.5	<1 - 8,500
Pandanus				5 - 10	14 - 902
Papaya		0.29 - 0.46			60 - 810
Mango	0.3 - 1.0	1.3 - 3.8	0.4 - 2.8	22–110	20 - 4,320

Source: (Stadlmayr et al. 2011; Burlingame et al. 2009)

4.1.1 Example: Blueberries

Blueberries are rich in phytochemicals such as phenolics and anthocyanins that act as antioxidants. Antioxidants are a key factor in combating many human disorders such as cardiovascular disease, diabetes and cancer through preventing damage to the body's cells and tissues (Giovanelli & Buratti 2009; Johns et al. 2006). A study conducted by (Giovanelli & Buratti 2009) compared a wild crop of blueberry (*Vaccinium myrtillus*) to four varieties of cultivated blueberries (*Vaccinium corymbosum*) in terms of antioxidant activity as related to their phenolic composition. Results reveal that wild berries show values of antioxidant

Figure 8: Total phenolics, total anthocyanins and antioxidant activity of cultivated (*V. corymbosum*) and wild (*V. myrtillus*) blueberries

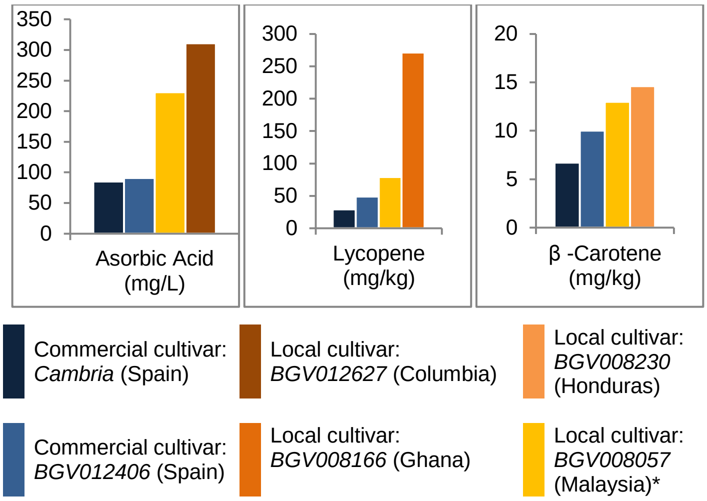


Source: own illustration based on Giovanelli and Buratti (2009) activity being more than double than that of cultivated blueberries (Figure 8). The concentrations of total and anthocyanins phenolics were much higher in the wild fruits (ca. 600 mg/100g) compared to the cultivated ones (ca. 340 mg/100g). Hence, wild blueberries (*Vaccinium myrtillus*) represent a very interesting alternative source of dietary antioxidant compared to cultivated berries.

4.1.2 Example: Tomatoes

Tomatoes are consumed in high quantities all year round making them one of the main sources of minerals, vitamins and antioxidants in many countries (Adalid et al. 2010; Esquinas-Alcazar & Nuez 1995). β-Carotene and lycopene are the tomato carotenes which present the highest nutritional value. In particular, β-carotene is a provitamin A carotenoid and its deficiency can cause, among others, blindness, premature death and chronic diseases such as cancer and diabetes (WHO 2015b; Englberger et al. 2008; World Cancer Research Fund 1997). Lycopene reduces several cancer types and the risk of heart attack (Adalid et al. 2010; Kun et al. 2006; Canene-Adams et al. 2005; Omoni & Aluko 2005). Ascorbic acid, also contained in tomatoes, plays a key role in delaying the pathogenesis of many chronic diseases, such as cardiovascular disease, certain cancers, cataracts and it also prevents DNA mutation induced by oxidative stress (Lutsenko et al. 2002; Marchioli et al. 2001; Byers & Guerrero 1995). Due to these functional properties and health benefits, tomatoes are important in terms of nutrition. Yet, agricultural industrialization has led to a reduction in diversity of organoleptic and nutritional quality characteristics. Hybrids and modern cultivars have replaced most local cultivars because of higher yields and disease resistance (Adalid et al. 2010). However, a study that compared 49 accessions of underutilized tomatoes from 24 countries across four continents reveals the superiority of some of the local cultivars over commercial varieties and suggests recovering their use directly in fields to increase agrobiodiversity (Adalid et al. 2010). Results show that local varieties can contain more than three times the ascorbic acid content than commercial tomatoes. Furthermore, the lycopene and β-carotene contents of local cultivars are up to 9.3 times and 1.5 times higher, respectively (Figure 9). Given the fact that the recommended dietary allowance for vitamin A is 0,9 mg and 0,7 mg per day for men and women, respectively, the consumption of even small amounts of some local tomatoes could easily fulfil these daily

Figure 9: Ascorbic acid, lycopene, and β-carotene contents of commercial and local tomato cultivars



* best mean and balanced content of antioxidants

Consumption of even small amounts of some local tomatoes can fulfil daily vitamin A requirements and reduce deficiency-related health consequences

requirements and reduce deficiency-related health consequences (Adalid et al. 2010; Institute of Medicine 2001).

4.1.3 Example: Banana

A case study from Pohnpei in the Federated States of Micronesia about bananas illustrates the huge variability of micronutrient content among varieties and cultivars: one banana variety can provide less than one percent (*Utin Pihsi*) or more than 200 percent (*Utin Iap*) of the Recommended Daily Intake (RDI) for vitamin A (Englberger, Schierle, et al. 2006). The three *Fe'i* banana cultivars, *Utin Iap*, *Utimwas* (which is closely related to *Utin Iap*), and *Karat*, contained the highest b-carotene levels. For instance, the *Utin Iap* contained over 70 times the β-Carotene level of the common *Williams* banana (of the *Cavendish* group) analyzed in Australia (β-Carotene equivalents/ 100g: 119µg) (Table 4). *Williams* is the most commonly marketed banana worldwide and bananas of the *Cavendish* group (*Musa* sp. AAA group) comprise more than 95% of international banana trade thereby limiting the access to any other type of banana to consumers in many industrialized countries (Englberger, Wills, et al. 2006).

Table 4. Nutrient differences among banana varieties

	Commercial banana *(Cavendish)*	Local banana *Utin Iap (Fe'i)*	Local banana *Karat (Fe'i)*
β-Carotene equivalents (µg/100g edible portion)	119	8508	2473
Riboflavin (mg/100g edible portion)	0.06	1.76	14.3

Source: own depiction based on (Englberger, Schierle, et al. 2006; Englberger, Wills, et al. 2006)

The Federated States of Micronesia and several other Pacific Island countries encounter serious problems of vitamin A deficiency, anaemia, and chronic diseases such as diabetes, cancers, and heart diseases (Englberger, Schierle, et al. 2006). Provitamin A carotenoids are needed for contributing to the vitamin A status and protect against chronic diseases (WHO 2015b; Englberger et al. 2008; World Cancer Research Fund 1997). Furthermore, bananas are the developing world's fourth most important crop in terms of gross value of production, after rice, wheat and maize, and are mainly produced on small farms and eaten locally (Crop Trust 2014). This is why the identification of several carotenoid-rich banana cultivars is important in order to expand the range of bananas having potential for alleviating vitamin A deficiency and other nutritionally related health problems (Englberger, Schierle, et al. 2006).

Another striking result of the case study is the finding of high riboflavin level in *Karat* and to a lesser extent in *Utin Iap* (Table 4). In comparison to the common *Cavendish* banana, the riboflavin content of *Karat* is more than 238 times higher (Englberger, Schierle, et al. 2006). There is increasing evidence that poor riboflavin (vitamin B_2) status infers with iron absorption and utilization. Thus, adequate intake of riboflavin can possibly alleviate anemia (Ma et al. 2008; Powers 2003). In fact, one *Karat* banana containing 200 g edible flesh would provide over 20 times the estimated daily requirement of riboflavin for a non-lactating non-pregnant female (1.1 mg/day). *Karat* also contained high levels of the vitamins α-tocopherol and niacin, and, in contrast to the common banana, a Karat banana with 200 g edible flesh could satisfy 50% of the estimated daily requirements of α-tocopherol (7.5 mg/day) and three times the

In comparison to the common *Cavendish* banana, the riboflavin content of the local *Karat* banana is 238 times higher

estimated requirement of niacin (14 mg/day) for a non-pregnant non-lactating woman (Englberger, Schierle, et al. 2006).

4.1.4 Example: Aquatic organisms

Fish and other aquatic organisms contribute to food security for many households in agricultural landscapes where they are farmed or collected providing valuable sources of highly nutritious food. Generally, inland capture fisheries from aquatic environments such as swamps, flood plains, rivers, or modified rice fields produce a large variety of aquatic organisms. In particular, the availability of and access to fish plays a vital role in nutrition and diversified diets especially for the rural poor. Fish is an important source of nutrients such as calcium, iron, zinc and vitamin A and essential fatty acids, such as omega-3 fatty acids, that are critical for maternal, fetal and neonatal nutrition. Thereby, the nutrient content in different fish species can vary significantly. Small indigenous fish species are of particular importance since they are consumed whole including bones, heads and organs where concentration of micronutrients is highest. In addition, small fish species in developing countries are usually more affordable and accessible than the larger fish and other usual animal-based food and vegetables (Halwart 2013). An illustrative example from Bangladesh highlights the significant differences in the nutritional value of fish species. As it can be seen from Table 5, the vitamin A content of a 100g serving of the raw edible part of the indigenous mola fish is more than 1000 times higher in comparison to the common silver carp. Only 25 g of mola fish per day fulfil the recommended vitamin A intake for a 4-6-year-old child (Tetens et al. 1998). Hence, aquatic diversity can have great positive nutritional effects for local households (Halwart 2013).

Table 5: Content of vitamin A and calcium in small and big Bangladeshi fish species (per 100g raw edible part)

Fish species	Vitamin A (µg)	Calcium (mg)
Small indigenous fish		
Mola (*Amblypharyngodon mola)*	1960	1071
Dhela (*Rohtee cotio)*	937	1260
Chanda (*Chanda* sp.)	341	1162
Puti (*Puntius* spp.)	37	1059
Big fish		
Hilsa *(Hilsa ilisha)*	69	126
Rui *(Labeo rohita)*	27	317
Silver carp (*Hypophtalmichthys molitrix)*	17	268

Source: (Tetens et al. 1998)

Aforementioned examples show that individual components of a diet can have huge influences on adequate nutrient intakes. The following paragraphs will move to the diets themselves thus emphasizing a more holistic picture of biodiversity for food and nutrition. Furthermore, food-based interventions taking advantage of agrobiodiversity are presented.

4.2 Sustainable diets: Traditional Mediterranean diet

In order to combat the prevalence of hunger, micronutrient deficiencies, obesity and the increase in diet-related chronic diseases, new food behaviours need to be developed. In this context, the Mediterranean diet represents a striking example of a so-called sustainable diet (Gamboni et al. 2012). Sustainable diets have low environmental impact and contribute to food and nutrition security and to healthy life for present and future generations. They are "protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources" (FAO 2012). Sustainable diets are therefore an excellent example of how biodiversity and traditional food culture share key synergies in biodiversity conservation and for human health (Johns & Eyzaguirre 2006).

Exemplary ingredients of a Mediterranean diet

Source: Gamboni et al. (2012)

There are many reasons why the Mediterranean diet in particular can be considered as sustainable: (1) great diversity ensuring food nutritional quality of diet and recognizing relevance of biodiversity; (2) great variety of food preparation techniques and food practices; (3) main foods are beneficial to health, such as olive oil, cereals, dried of fresh fruits and vegetables, pulses, spices, fermented milk; (4) strong commitment to culture and traditions; (5) respect for seasonality and human nature; (6) diversity of landscapes contributing to well-being; (7) low environmental impact due to low consumption of animal products (Lozano et al. 2012). The nutritional model of the Mediterranean diet has remained constant over time and space and some diets, such as the Crete diet, are nearly the same as they were in 4500 BC (Gamboni et al. 2012; Petrillo 2012; Zeghichi et al. 2003).

In fact, recent studies underline the substantial health benefits and disease prevention potential associated with the Mediterranean diet. (van Dooren et al. 2014), for example, compared six different diets (average Dutch, recommended Dutch Dietary Guidelines, semi-vegetarian, vegetarian, vegan, Mediterranean) and found the Mediterranean diet to score best in terms of health gains (Table 6). (Maillot et al. 2011) modelled a nutritional adequate diet that simultaneously meets a whole set of nutrient goals while deviating the least from the observed diet of French adults in terms of food content. Whichever model was applied, the food categories most increased (e.g. up to 300% in the case of unsalted nuts) were those typical of the traditional Mediterranean diet, suggesting that the shortest way to reach nutritional goals in this Western population is to follow the traditional Mediterranean diet patterns. A study by (Castro-Quezada et al. 2014) confirms these results and highlights that greater adherence to Mediterranean diet patterns (in comparison to western diet patterns) is related to a higher prevalence of individuals showing adequate intake of micronutrients and lower percentage of energy coming from total fat and saturated fat acids. The authors conclude that "the Mediterranean diet could be used in public health nutrition policies in order to prevent micronutrient deficiencies in the most vulnerable population groups" (Castro-Quezada et al. 2014: 231).

The shortest way to reach nutritional goals in some Western diets is to follow the traditional Mediterranean diet patterns

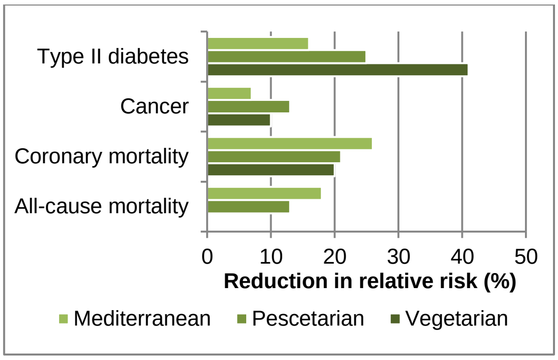
Table 6: health gains and scores of the six diets, based on ten indicators

Indicators		Reference value		Diets					
Category	Description	DHC/WHO (index = 100)	Unit	Average Dutch	DD G	Semi-vegetarian	Traditional vegetarian	Vegan	Mediterranean
1	Vegetables	200	g	64	100	100	100	150	115
2	Fruits	200	g	52	100	100	100	100	125
3	Total fatty acids	30**	en%	102	116	122	128	151	132
4	Saturated fatty acids	10**	en%	83	105	109	114	155	131
5	Trans fats	1**	en%	140	140	150	150	160	150
6	(free) Sugars	10**	en%	46	104	104	104	135	124
7	Fibre	30	g	67	99	98	98	113	109
8	Salt	6**	g	75	85	93	102	117	95
9	(fatty) Fish	37	g	24	100	49	0	0	100
10	Energy balance	2000	kcal	98	100	100	100	100	100
	Health score	**100**		**75**	**105**	**103**	**100**	**118**	**122**

Remarks: **Upper limits; DHC=Dutch Health Council; DDG= Recommended Dutch Dietary Guidelines
Source: (van Dooren et al. 2014)

Apart from tackling the problem of micronutrient deficiencies, (Tilman & Clark 2014) showed that alternative, sustainable diets such as the Mediterranean, vegetarian and pescetarian diet can decrease the risk of non-communicable diseases. Indeed, after controlling for confounding variables, the relative risk of diabetes, cancer, coronary heart disease mortality and of all-cause mortality can be reduced by 16%, 7%, 26%, and 18%, respectively, through changing from a conventional omnivorous diet to the local, diverse Mediterranean diet (Figure 10).

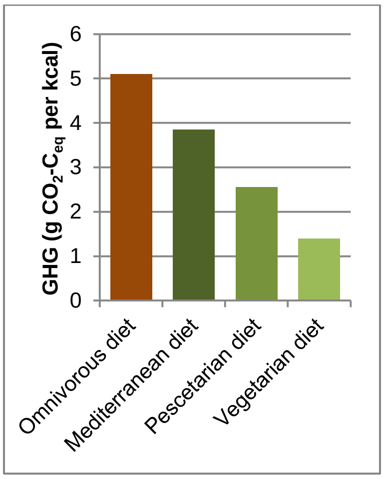
Figure 10: Diet-dependent reductions in relative non-communicable disease risks



Remarks: Diet-dependent percentage reductions in relative risk of type II diabetes, canacer, coronary heart disease mortality and of all-cause mortality when comparing each alternative diet (Mediterranean, pescetarian and vegetarian) to its region's conventional omnivorous diet
Source: (Tilman & Clark 2014)

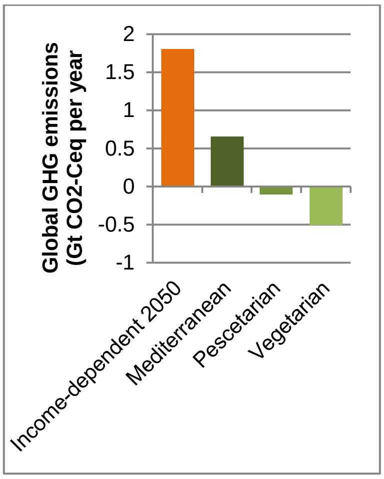
Besides health benefits, (van Dooren et al. 2014) and (Tilman & Clark 2014) also emphasize the environmental benefits of alternative diets compared to the omnivorous reference diet with high meat consumption and empty calories. (Tilman & Clark 2014) illustrate that diet-related GHG emissions per kilocalorie from 'cradle to farm gate' are much lower for said alternative diets than for the omnivorous diet (Figure 11). In addition, if widely adopted, changes to healthier diets could significantly reduce future global agricultural greenhouse gas emissions. There would be no net increase in food production emissions by 2050 if the global diet had become the average of the vegetarian, pescetarian and Mediterranean diet in comparison to the global-average income-dependent diet projected for 2050 (Figure 12). Furthermore, land clearing and resultant species extinctions can be significantly reduced by changing to healthier dietary patterns. Estimated changes in cropland from 2009 to 2050 for each diet show that the impact of healthy diets on cropland is much lower than in the case of projected income-dependent diet (Figure 13).

Figure 11: Average diet-related GHG emissions per kilocalorie



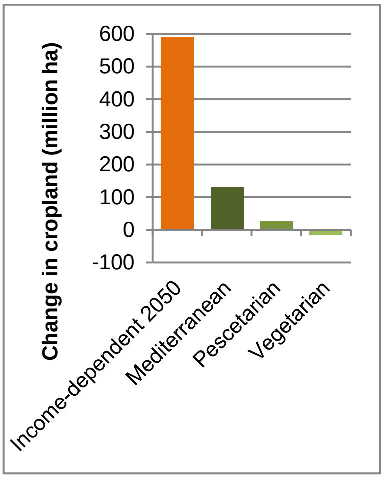
Remarks: Diet related GHG emissions expressed as CO_2 warming equivalents in grams of CO_2 carbon equivalents
Source: (Tilman & Clark 2014)

Figure 12: Mean forecasted 2009 to 2050 changes in global food-related GHG emissions for each diet



Remarks: 2009 value set to 0
Source: (Tilman & Clark 2014)

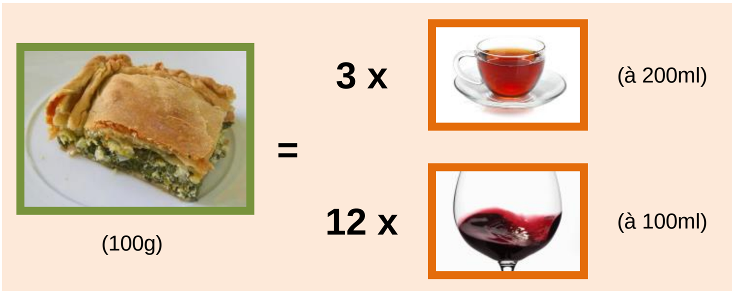
Figure 13: Mean forecasted 2009 to 2050 changes in crop land demand for each diet



Source: (Tilman & Clark 2014)

One specific example for a traditional Mediterranean diet is the Greek diet which includes a range of more than 150 edible wild-gathered greens. These greens are characterized by high nutrition and low energy containing very high amounts of antioxidants, vitamins and phytochemicals which provide protection against oxidation and free radicals in turn associated with playing a role in more than 60 different health conditions, such as cancer, aging and atherosclerosis. For instance, the wild green *Rumex obtusifolius* contains twice as much quercetin (an important flavonol/antioxidant) than onions which are, for example, the principal source of this flavonoid in the Netherlands. Two pieces of Cretan green pie (100 g) contain three times more quercetin than a cup of black tea (200 ml), and about 12 times more quercetin than one glass of red wine (Figure 14) whereby red wine and black tea are the main sources of quercetin in North European Countries. Furthermore, wild edible greens, which are usually consumed with virgin olive oil, contain significant quantities of micronutrients such as iron, even approaching the iron content of spinach. Due to these characteristics, wild Cretan greens and the Crete diet may be a reference standard for modern human nutrition and a model for defence against diseases of affluence (Zeghichi et al. 2003; Trichopoulou et al. 2000).

Figure 14: Quercetin content of Cretan pie



Source: own illustration based on (Zeghichi et al. 2003; Trichopoulou et al. 2000)

Once traditional food systems are lost, it is hard to recreate them (Johns and Eyzaguirre 2006). Safeguarding traditional Mediterranean food systems and its inherent biodiversity is therefore key for sustaining nutritious diets in order to address the health problems, i.e. non-communicable diseases, which contemporary society is confronted with (Johns & Sthapit 2004; Johns 2003).

Safeguarding traditional Mediterranean food systems and inherent biodiversity are key for sustaining nutritious diets to address contemporary health problems

4.3 Sustainable diets: New Nordic Diet

The New Nordic Diet (NND) has recently been developed in the Nordic countries in collaboration with a world-leading Copenhagen gourmet restaurant to promote a food-based dietary concept that emphasizes gastronomy, health and environment. Based on traditional food culture and dietary habits, the NND strongly relies on diverse, regional foods in season such as berries, cabbages, pears, apples, root vegetables, oats, rye, and fish - all of them traditional Nordic foods that have been ascribed beneficial nutrition and health effects (Poulsen et al. 2014; Olsen et al. 2011). Preliminary evidence shows that compliance with NND and its traditional healthy foods is related to lower mortality among middle-aged Danes (Olsen et al. 2011), increased weight loss and improved blood pressure reduction in centrally obese individuals (Poulsen et al. 2014), and significantly higher micronutrient (e.g. iodine 11%, vitamin D 42%) intake among school children aged 8-11 compared to control groups (Andersen et al. 2014). Furthermore, estimates from Denmark indicate that shifting from the Average Danish Diet to NND leads to overall socioeconomic savings of 42-266€/person per year due to reduced environmental impacts and their associated costs (Saxe 2014). The example of NND shows that locally oriented and culturally appropriate dietary patterns based on traditional, biodiverse foods can successfully be developed in order to reach societal nutritional goals as well as decrease environmental impacts (Saxe 2014; Bere & Brug 2009).

4.4 Traditional bush meals and wild foods

Screening of the nutritional composition of northern Cameroon's food deriving from biodiversity was conducted in 2012 in order to improve the population's food intake and to preserve local biodiversity (Roger et al. 2012). Samples were derived directly from local 'families' reserve' and included 16 cereal and cereal products, 12 tubers, roots and their products, 17 meats, poultry, fish, insects and their products, as well as 68 vegetable, fruits and their products. Wild food plays a fundamental role in the diet of North Cameroonian's rural population. Yet, the access to some species has been restricted by the government. The results of the study, however, show that edible wild food products from biodiversity are of great nutritional importance. The food provided by local biodiversity meets all the nutritional standards for a proper meal (carbohydrates, lipids and protein from cereals, tubers, vegetables, meat, etc. and vitamins and micronutrients from fruits and seeds) as recommended by the (U.S. Department of Agriculture & U.S.

Table 7: Recommended macronutrient proportions by age in comparison to macronutrient content of "bush meals"

	Carbohydrate	Protein	Fat
Young children (1-3 years)	45-65%	5-20%	30-40%
Older children and adolescents (4-18 years)	45-65%	10-30%	25-35%
Adults (19 years and older)	45-65%	10-35%	20-35%
Bush meal	**52%**	**15%**	**30%**

Source: own depiction based on (Roger et al. 2012; U.S. Department of Agriculture & U.S. Department of Health and Human Services 2010; Institute of Medicine 2005)

Department of Health and Human Services 2010) and the (Institute of Medicine 2005), as illustrated in Table 7 (Roger et al. 2012).

Results show that the macronutrient composition of bush meals is, for all ages, within the ranges for the percentage of calories in the diet that should come from carbohydrate, protein, and fat (U.S. Department of Agriculture & U.S. Department of Health and Human Services 2010; Institute of Medicine 2005). Furthermore, biodiverse foods from Cameroon's forests such as *B. toxisperma*, *P. macrophyllam,* and *T. abut* provide 100% daily Vitamin C and E requirements for both adults and children, and approximately 200g of either *P. macrophyllam* or *B. toxisperma* can supply 100% recommended iron and zinc intake for children aged 1-3years (Fungo et al. 2015). Based on these facts, biodiversity and its edible wild food products should be given greater consideration in plans to manage and conserve natural resources for socio-economic development.

1 billion
people use wild foods in their diet

This example also shows that more than 12,000 years after the domestication of plants and the dawn of agriculture, many people still gather wild edible plants for consumption. In fact, it is estimated that that at least one billion people worldwide use wild food in their diets (Aberoumand 2008). For instance, estimates for 24 developing countries across three continents show that the environmental income accounts for 28% of total household income, a major part (77%) of it coming from natural forests. Thereby, food products, including fish, bush meat, wild fruits, vegetables, and mushrooms, were the second-most important category (30.3%) and likely to help meet nutritional, medicinal, utilitarian and ritual needs of these households (Angelsen et al. 2014). A study by (Shackleton & Shackleton 2004) among 14 rural villages in South Africa demonstrated that on average, 96% of households ate wild spinaches, 88% consumed wild fruits, 54% consumed edible insects, 52% ate bushmeat and 51% ate honey. Hence, using wild foods increases dietary diversity of people and communities who extensively use it.

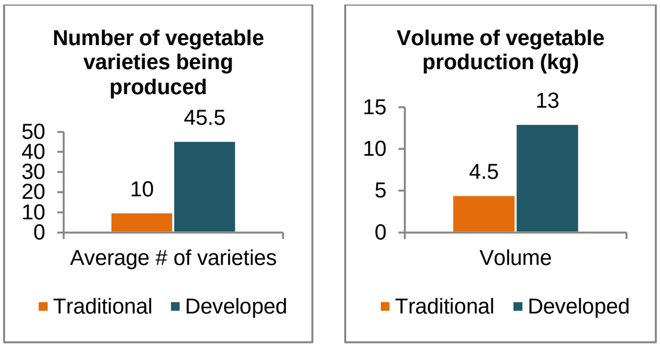
Wild biodiversity constitutes a 'safety net' during periods of food shortage

Apart from supplementing staples with micronutrients, wild edible plants and animals can also constitute a 'safety net' during periods of food shortage due to shocks such as drought, loss of cash income, etcetera and represent cheap but quality nutrition for large segments of the population (Termote et al. 2010; Shackleton & Shackleton 2004). For example, the Yanomani Indians in Venezuela regularly consume 20 wild plant species but when they face food shortages, they consume an additional 20 plants which they do not use during normal times (Fentahun & Hager 2009). People in Konso in southern Ethiopia use more than 120 different wild plant species wherefrom 25 species are only used in times of food shortages (Ocho et al. 2012).

4.5 Homestead food production programs in Asia

Helen Keller International (HKI) has been implementing homestead food production programs coupled with nutrition education in four Asian countries in order to combat micronutrient malnutrition through an increased year-round availability and intake of micronutrient-rich food in poor households (Talukder et al. 2010). The evaluation of the programs by (Talukder et al. 2010) for the project period 2003-2007 showed that dietary diversification was significantly improved through the establishment of developed, year-round homestead gardens. For instance, the number of varieties increased on average from 10 to 45 varieties of vegetables and the volume of vegetables produced increased by a factor of 3 in developed gardens compared with traditional, seasonal gardens (Figure 15). Frequency of consumption of vegetables by children was also 60% higher among children in households that have developed gardens relative to traditional gardens. Children living in households with developed gardens consumed a mean of 13 types of vegetables compared with only four types by children living in households with traditional gardens. Animal food consumption increased from 24% to 46% (chicken liver) and from 2 to 5 (eggs per week). Furthermore, the sale of homestead garden products improved household income which was mostly spent (up to 92% in Cambodia, for example) on purchasing additional food, hence contributing to food security (Talukder et al. 2010). Anaemia prevalence among children aged 6-59 months decreased in all program communities; whereby significant differences between program and control groups in Bangladesh (from 63.9% to 45.2%) and the Philippines (from 42.9% to 16.6%) could be found (Talukder et al. 2014; Nielsen et al. 2013; Talukder et al. 2010). Yet, the evaluation of three Helen Fischer

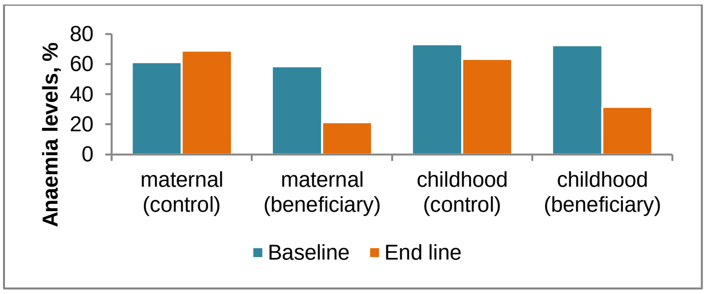
Figure 15: Impact of homestead food production on dietary diversity



Remarks: Findings from endline evaluation survey in Bangladesh and Cambodia program villages
Source: (Talukder et al. 2010)

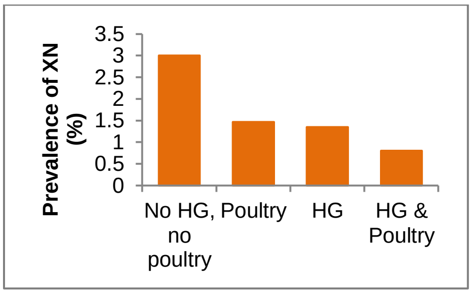
Remarks: Volume of vegetable production in the two months prior to the endline survey in Bangladesh and Cambodia program villages
Source: (Talukder et al. 2010)

Figure 16: Maternal and childhood anaemia prevalence before and after project intervention



Remarks: maternal and childhood anaemia levels for landless (< 0.05ha) HHs
Source: own depiction based on (Hillenbrand & Waid 2014)

Figure 17: Prevalence of night blindness (XN) among children in Bangladesh



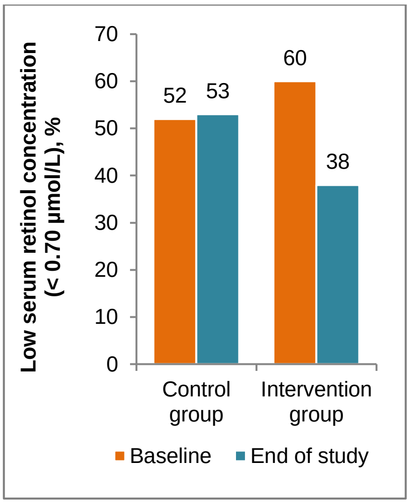
Remarks: Prevalence among children aged 12-59 months who had not received a vitamin A supplement, by home garden (HG) and poultry ownership (n=4298).
Source: (Talukder et al. 2010) based on National Vitamin A Survey in Bangladesh in 1999.

International homestead food production projects in Bangladesh (2003-2008) by (Hillenbrand & Waid 2014) found drastic significant decreases of maternal and child anaemia prevalence whereas anaemia rates mostly rose among the control group (see Figure 16). Furthermore, the prevalence of night blindness due to vitamin A deficiency among children less than five years who had not received a vitamin A supplement was significantly lower in households with a garden and/or poultry than households without a garden and poultry (Figure 17) (Talukder et al. 2010; de Pee et al. 2000). Thus, the program, which among others reaches more than 5 million people in Bangladesh and covers 12 (out of 75) of the most food insecure districts within five provinces in Cambodia, has successfully improved household garden practices, micronutrient-rich food consumption, dietary diversity and income, as well as reducing anaemia among children (Talukder et al. 2014; Nielsen et al. 2013). Similar findings were reported by (Faber et al. 2002). The development of an integrated health and gardening system in South Africa adapted to local conditions and gardening practices, and focusing on the production of yellow and dark-green leafy vegetables significantly increased the vitamin A status of 2-5 year old children (Faber et al. 2002). So, it can be highlighted that home gardens link agricultural diversity, nutritional status and health (Johns 2003).

4.6 Agriculture and nutrition intervention with orange-fleshed sweet potato

Vitamin A deficiency (VAD) affects 71% of all children aged 6-59 months in Mozambique and constitutes generally a huge health problem in Sub-Saharan Africa (Low et al. 2013). A two-year quasi-experimental intervention study assessed the effectiveness of orange-fleshed sweet potato (OFSP) of increasing vitamin A intake and serum retinol concentrations in young children in Mozambique. This agriculture and nutrition intervention aimed to increase farmers' access to OFSP vines, increase nutrition knowledge and create demand for OFSP; and ensure sustainability through market development (Low et al. 2007). OFSP contains high levels of β-Carotene which is highly bioavailable in many varieties (100–1,600 µg retinol activity equivalent (RAE)/100 g for varieties in Africa) and is well accepted by young children. Just 100-125 g of boiled or steamed OFSP can meet the daily recommended intake levels of vitamin A for children less than 5 years of age. Furthermore, OFSP is an excellent source of energy, it's easy to cultivate and fairly drought resistant once established (Low et al. 2013; Low et al. 2007). Evaluation results after two agricultural cycles reveal that intervention children were more likely than control children to eat OFSP three or more days per week during harvest season (55% vs. 8%, $P < 0.001$). Furthermore, vitamin A intakes were much higher than those of control children (median 426 vs. 56 µg retinol activity equivalents, $P < 0.001$). After controlling for infection/inflammation and other confounders, mean serum retinol increased by 0.1 µmol/L

Figure 18: Prevalence of low serum retinol concentration (vitamin A deficiency) in intervention and control children



Remarks: Prevalence in children with <5 mg/L plasma C-reactive protein (CRP). This acute phase protein is a marker for inflammation/infection and is used to help distinguish low serum retinol due to infection and inflammation from that due to inadequate intakes and body stores. CRP levels of .5.0 mg/L indicate acute infection/inflammation (Low et al. 2007)
Source: adapted from (Low et al. 2007)

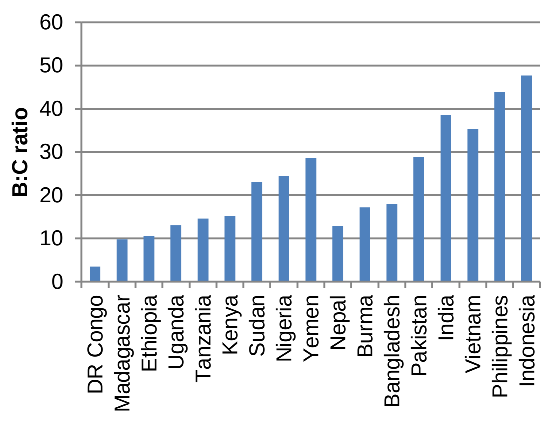
(SEM 0.024; P < 0.001) in intervention children and did not increase significantly in control subjects. Hence, it could be shown that a 15% decline in the prevalence of VAD was attributable to the integrated intervention (Low et al. 2013; Low et al. 2007). The public health importance of intervention effect is demonstrated by changes in prevalence. Prevalence of low serum retinol concentrations (vitamin A deficiency) remained the same in control areas and dropped from 60 to 38% in intervention areas (Figure 18). Hence, it could be shown that OFSP is an excellent food security crop and that the integrated food-based intervention using agrobiodiversity significantly increased the health status of children suffering from Vitamin A deficiency.

4.7 Affordability of nutritious diets and returns on investments

Having a closer look at the affordability of fully nutritious diets at the ***household level***, (Parlesak et al. 2014) showed that using local, nutrient-dense foods in order to diversify diets and meet nutrient recommendations can be low-cost and thus affordable to lower socio-economic groups. For instance, on the one hand, only 20% of Mozambican households could afford a fully nutritious food basket with a spectrum of standard Mozambican foods commonly consumed in Mozambique. On the other hand, the cheapest diet that provides the recommended amounts of energy, protein, and fat supplies insufficient amounts of micronutrients. Applying a dietary diversification strategy by adding micronutrient-dense, local foods (i.e. beef heart or liver, dried fish and wild, at no monetary cost available fresh moringa leave) as to overcome specific micronutrient deficiencies, decreased the price of the fully nutritious basket by a factor of up to 2.6 so that more than 60% of Mozambique's population could afford a fully nutritious diet (Parlesak et al. 2014). Furthermore, (Hoddinott et al. 2008) could show that preventing child stunting through better nutrition can increase hourly earnings by up to 20% during adulthood suggesting that there can be substantial benefits of nutrition interventions on the household level. Furthermore, Bioversity International research in Kenya has shown that incorporating wild, biodiverse food - namely *Solanum nigrum* L., a wild leafy vegetable, and four wild fruits, *Balanites aegyptiacus* (L.) Delile, *Ximenia Americana* L., *Berchemia discolor* (Klotzsch) Hemsl., and *Ziziphus mauritiana* Lam - into the diet can help reduce the daily financial cost of obtaining a more nutritious diet by up to 65%, although additional research is needed to understand what associated opportunity cost may be (Termote et al. 2014).

Focusing on the ***national level***, it can be highlighted that nutrition interventions can generate benefits for the state that are larger than many other development interventions. (Hoddinott et al. 2013) calculated the benefit:cost ratio of nutrition interventions aimed at reducing stunting in 17 countries with high burden of stunting (including the quantitative and qualitative improvement of children's diet) while controlling for

Figure 19: B:C ratios for nutrition investments to reduce stunting in selected high-burden countries



Source: (Horton & Hoddinott 2014)

confounding variables. The benefit:cost ratios calculated range from 3.5:1 (DR Congo) to 47.7:1 (Indonesia) applying a 5% discount rate (Figure 19). This shows that there are significant benefits from investing into nutrition interventions. Hence, by scaling up nutrition interventions, countries can generate and sustain broad-based wealth which is why nutrition interventions need to be a top development priority.

4.8 Other benefits: win-win scenarios of BFN

Apart from tremendous health benefits, fostering (agricultural) biodiversity also leads to other benefits wherefrom some of them have already been outlined in the Mediterranean diet paragraph. The following table briefly summarizes additional benefits of a high degree of (agricultural) biodiversity.

Table 8: Win-win scenarios of biodiversity for Food and Nutrition

Benefits	Comments
Resilience	Certain species are able to buffer against harsh environmental conditions or provide a critical resource for other. Therefore the probability that some of these species can react in a functionally differentiated way to external shocks and disturbances of the system and changing environmental conditions increases with higher numbers of functionally different species. Hence, biodiversity acts as insurance against environmental risks (Wydra 2011, Di Falco et al. 2010). This is why higher diversity in agro-ecosystems, for example through using neglected or underutilized crops more widely, provides multiple options to build spatial and temporal heterogeneity into uniform cropping patterns and thus supports resilience to abiotic and biotic stress and maintains the system productivity under challenging climate conditions (Ebert et al. 2014, Wydra 2011, Di Falco and Chavas 2006).
Adaptation to climate change	Genetic resources for food and agriculture are important to cope with and adapt to climate change in a world of limited resources (CGRFA 2015; Kotschi 2007). Increasing the diversity within production systems provides complementarity, option values (value associated with retaining an option to a good or service in the future) and risk avoidance which are important to adapt to future challenges imposed by climate change such as rising temperatures, changing rainfall patterns, increasing climate variability, rising sea levels and the greater frequency of extreme events (CGRFA 2015; Jarvis et al. 2011).
Stability	Biodiversity increases stability of ecosystem functions over time. Theory and data both support the assumption that temporal stability of a community property like total biomass is greater at higher levels of diversity. Diversity has an impact on variation of ecosystems through time and it could be shown that, in general, total resource capture and biomass production are more stable in more diverse communities (Cardinale et al. 2012)
Maintenance and stimulation of ecosystem services	Biodiversity per se either directly influences or is strongly correlated with many ecosystem services (Cardinale et al. 2012). For example, agricultural biodiversity stimulates many ecosystem services such as water and soil conservation, maintenance of soil fertility and biota, carbon sequestration, pest and disease control (biocontrol), and pollination, which are fundamental to human survival (CBD 2015; Cardinale et al. 2012). In fact, (Iverson et al. 2014) recently demonstrated that well-designed polycultures can produce win-win outcomes in agricultural ecosystem services, for example between yield and biocontrol.
Increased production and cash income	Higher agrobiodiversity can deliver important pay offs in terms of production which means that keeping more varieties in the field can be a viable strategy to increase agricultural production (Di Falco et al. 2010). Diverse ecological communities are characterized by niche portioning or positive species interactions, and contain key species that have a large influence on productivity (Cardinale et al. 2012). Furthermore, many traditional varieties such as Asian (*Solanum melongena*) eggplant, drumstick tree (*Moringa oleifera*), bitter gourd (*Momordica charantia*) or winged bean (*Psophocarpus tetragonolobus*) are of considerable commercial value and can therefore make a significant contribution to household income and livelihoods (Ebert 2014).
Less fertilizer use	Diversification of cropping patterns can result in significant decreases in the use of agrochemicals and fossil hydrocarbons without negatively influencing yield and profitability (Ebert 2014; Liebman et al. 2013).

Reduced GHG emissions and land use	If carefully chosen, Life Cycle Analysis shows that healthy diets based on diversity have the potential to reduce GHG emissions from food production and the prevalence of land clearing for agriculture (Tilman & Clark 2014)
Gender empowerment	Women are key players in food systems. For instance, in Africa they account for 70% of farm labour and carry out 80% of food processing (Pinstrup-Andersen 2012). Traditional systems of seed management, food preferences, food habits, and preparation methods as well as the socio-cultural and ritual significance attached to specific crops, are all variables on which crop diversity depends. These traditional systems are mostly managed and conserved by women which is why they are the custodians of agrobiodiversity (Goodrich 2012). Hence, fostering agrobiodiversity has the potential to empower women (Darnton-Hill et al. 2005).

5 Structural barriers and possibilities to overcome them

Although fostering biodiversity can be a useful instrument to increase peoples' nutritional and health status, there are several structural barriers and certain scepticism

The seed market and power of seed companies: The breeding of major crops has mostly been taken over by large private companies and only a few smaller firms breed underutilized crops. In fact, the ten largest international seed companies control two-thirds of the global seed market and focus exclusively on major staple crops to ensure high returns of investment over the next few years. It is alarming that even interest in wheat receives less attention by breeders due self-pollinating characteristics of this crop and subsequent lower license fees paid by farmers which might lead to lead to a further concentration of dominating crops (Ebert 2014; Stamp et al. 2012; Fischer & Edmeades 2010).

Furthermore, because of having been neglected by breeders, traditional crops typically don't meet modern standards for uniformity and other characteristics thus being even less competitive in the market place compared with commercial cultivars (Ebert 2014; Stamp et al. 2012). This is why the management of agrobiodiversity cannot depend on the market alone and state authorities need to take responsibility and outsource research on improving underutilized crops to special institutes or companies (Fischer & Edmeades 2010).

Low yielding underutilized crops: One barrier/criticism of advocating greater use of local agrobiodiversity in the form of traditional crops, wild-harvested and underutilized species to address malnutrition is precisely that it is local and low-yielding and therefore assumed to have only little global impact (Heywood 2013). Yet, there are 1.5 billion men and women farmers working on 404 million small-scale farms of less than 2 ha. More than 20% of the world food supply comes from these traditional agricultural landscapes and many of the species grown in small-scale farms are 'underutilized' local (Altieri 2009; IAASTD 2009). Hence, fostering local agrobiodiversity reaches billions of people and can have huge impacts.

The example of Teff, an ancient, local grain from Ethiopia, shows that a local crop can go global and diversify diets worldwide. Although Teff is a major food grain in Ethiopia, it is a minor cereal crop worldwide. It is of gluten-free nature and has a very attractive nutrient profile (Table 9), making it a suitable substitute for wheat and other cereals in their food applications as well as foods for people with celiac disease (Gebremariam et al. 2014).

Table 9: nutrient profile of Teff in comparison to other cereals

Component	Gluten rich cereals			Gluten-free cereals				
	Barley	Wheat	Rye	Teff	Maize	Brown rice	Sorghum	Pearl millet
Crude fiber (g/100g)	3.7	2.0	1.56	**3.0**	-	1.0	0.6	0.5
Calcium (mg/100g)	34	39.45	31.5	**165.2**	48.3	6.85	50	46
Iron (mg/100g)	2.43	3.5	2.7	**15.7**	4.8	0.57	6	

Source: adapted from (Gebremariam et al. 2014)

Teff has recently and frequently been mentioned in newspapers and magazines as the 'new super food' (e.g. Renton 2014, The Guardian) and has already found niches in the health food market and as a gourmet food in the USA and the EU, and several recipes that suit Western tastes have been developed from teff flour (Gebremariam et al. 2014).

Stringent food safety regulations for novel foods: Many states or political blocs have stringent food safety regulations for novel foods which makes it extremely hard to bring traditional biodiverse foods and their products to the respective markets. One of these demanding standards is the European Union's Novel Foods regulation (NFR) which has emerged as a non-tariff barrier for heritage foods from developing countries that are perceived as exotic from the EU perspective. Foods not present in the EU before 1997 must extensively be documented with regard to food composition, suggested intake levels, toxicological assessments and allergenic potential in order to be approved for the European Market. The costs, complexity, length and uncertain outcomes of NFR procedure have discouraged investments in supply chains and market development and curtail income opportunities for poor producing countries. Since 1997 this regulation has denied approval for several traditional foods such as the natural sweetener *Stevia rebaudiana*, nangai nuts from Pacific trees of the genus *Canarium* and the Andean root maca (*Lepidium meyenii*), all of them having untroubled history of safe use in their country of origin. This is why there is a need for establishing a separate novel food category in EU law for exotic traditional foods, as opposed to innovative products with no history of long-term consumption outside the EU. Thus, taking into account the history of safe use in the country of origin, food safety evidence requirements would be proportionate to the risks traditional exotic foods may impose and would not hinder the development of healthy food markets (Hermann 2009).

The modern globalized food system and inequality of power: The nutrition transition, associated with industrialization, globalization, modernization and inherent normalization of inappropriate diets imposes huge public health challenges worldwide (as explained in the previous chapters). Tremendous marketing expenditures accelerate this transformation: US food, beverage and restaurant industries, for example, together spent US$11.26 billion on advertising compared to US$9.55 million spent on marketing of public health in the US. Marketing health thus receives only 0.0001% of industry's spend. Further, the annual marketing budgets of two giant food corporations dwarf the biannual budget of the World Health Organization (Lang 2009; Lang et al. 2006). This emphasizes the fact that food is subject to extremely powerful lobbies and that commercial interests dominate food messaging space and junk food can easily triumph. Although the language of consumerism accords primacy to the consumer, power and markets are highly concentrated in most countries which lead to the emergence of a global food elite. This inequality of power in the food system therefore needs to be rebalanced by, for example, controls on marketing.

Yet, apart from competition policy it is also health policy that is lagging far behind commercial reality. Public health bodies have been relying too much on soft health policy measures such as health education, labelling, or advice, rather than on population wide or hard measures including fiscal or championing regulatory interventions. Both hard and soft measures are required but whichever is used, emphasis is needed on tackling producer and lobby behaviour and not just consumer behaviour (Lang 2009).

Negative perceptions and limited awareness: Living in a biodiverse rich environment doesn't necessarily mean that individuals living in close proximity actually use the nutritional quality provided (Termote et al. 2012). On the one hand, there might be limited awareness. Some people simply might not know about the nutritional value of the food surrounding them

(Smith 2013; Termote et al. 2012). On the other hand, traditional plants, crops, crop varieties and their use are often perceived as old-fashioned and unattractive in comparison to modern crops which is why they are also abandoned by research and policy groups (Kahane et al. 2013). Ironically, in the developing world, people consider traditional diets as a sign of backwardness and poverty and gravitate to fashionable 'modern' foods and 'Western' diets - while in industrial societies people increasingly look to traditional diets such as the Mediterranean or those of East Asia since they are deemed as good for nutrition and health (Frison et al. 2006). Hence, greater attention is needed to raising awareness of the importance of agricultural biodiversity for nutrition among target groups and to providing appropriate information on its use in order to overcome this barrier (Termote et al. 2012).

Inadequate agricultural and food security policies: The widespread adoption of agricultural production practices that embody a greater use of biodiversity for food and nutrition is also hindered by the fact that modern farming systems based on major cereal staples receive very large amounts of financial support and all sectors of the food and agriculture industries are linked in to this vastly subsidized system (Hunter & Fanzo 2013; FAO & PAR 2011). Additionally, ensuring low food prices and affordable basic foodstuffs for all sectors of society is still the major priority and paradigm of many agricultural and food security policies. This has tended to lead to a disinterest in the nature of agricultural production systems thereby diminishing the dietary role of more nutritious species and varieties in regions where they were traditionally grown (FAO & PAR 2011). Therefore, agricultural policies represent a very strong barrier to the development of new production approaches. Yet, agrobiodiversity can be efficiently scaled up with adequate support and investment from governments if there is the political will. For example, after a decade long struggle by civil society and several NGOs, in 2013 India recognized traditional millet varieties as national food security grains thus enriching India's public food system with biodiversity (Satheesh 2014; Zwart et al. 2014).

Inadequate trade policies: Trade policies can seriously hamper the promotion and consumption of biodiversity for food and nutrition (Hunter & Fanzo 2013). In fact, during the last decades trade liberalization has facilitated global availability of highly processed, calorie-rich, nutrient poor food contributing to the simplification of diets and increase of food imports (Blouin et al. 2009; Rayner et al. 2006). A striking example is the Pacific Islands where the importation of unhealthy and cheap foodstuffs contributed significantly to nutrition-related health problems (Hawkes et al. 2015). Pre-1945, each nation was basically self-sufficient and free of NCDs, but during the subsequent years of development and trade liberalization, countries became more reliant on imports of 'Western' food with tremendous impacts on diets and local production systems. Today, more than 75% of deaths are due to diet-related NCDs (Snowdon & Thow 2013; Rayner et al. 2006).

Furthermore, liberalization of finance is part of trade regulations and encourages foreign direct investments (FDI). FDI into food processing, service and retail has risen in such a way that foreign affiliates of transnational food companies are among the largest companies in low- and low- to middle-income countries today. Thus, more FDI make more highly processed foods available to more people contributing as such to the nutrition transition. In fact, between 1988 and 1997, food industry FDI increased from US$222 million to US$3.3

billion in Latin America and US food companies sell 500% more (US$150 billion) through FDI sales than through export sales. This is why FDI could be an appropriate entry-point for fostering agrobiodiversity and public health policies to 'redirect' the nutrition transition, for example by health-oriented conditions on FDI (Hawkes 2007). In general, since trade has such a huge influence on agrobiodiversity and healthy diets, the consideration and use of trade policy tools in food and nutrition policies, and vice versa, is important in order to foster biodiversity for food and nutrition (Rayner et al. 2006).

Poorly developed infrastructure and markets: Increasing production of traditional food crops is also constrained by a lack of market infrastructure and support for the marketing of local foods and products (Smith 2013). Producing smaller volumes of traditional or underutilized crops is challenging in times where there is demand for increased uniformity, larger quantity and reliable supply no matter the season (Bowman & Zilberman 2013). Even if there are markets where consumers demand local, sustainable, organic and diverse food, high costs of certification and marketing as well as transporting small volumes can impede market consolidation of these products (Bowman & Zilberman 2013; Hardesty & Leff 2009). Since the supply chain lacks proper coordination, transaction costs for bringing traditional crops from the farm to the table can be high leading to a loss in competitiveness of biodiversity in terms of price, quality and presentation. Building more alliances among farmers and user groups as well as strengthening supply chains and marketing is therefore needed in order to successfully commercialize neglected species (Gruère et al. 2009).

Box 6: Biodiversity hotspots and malnutrition - a case study from the Pacific Islands

The Pacific Island countries have remarkable biodiversity and constitute four biodiversity hotspots

The insular tropical Pacific is recognized as a highly biodiverse part of the world constituting four biodiversity hotspots (Keppel et al. 2014). For instance, Pohnpei – part of the Federate States of Micronesia which are one of the biodiversity hotspots – has remarkable plant biodiversity with 171 yam, 133 bread fruit, 55 banana, 24 giant swamp taro, nine tapiocas and many pandanus varieties documented (Englberger & Johnson 2013; Englberger et al. 2008; Englberger, Schierle, et al. 2006). Yet, although being extremely rich in biodiversity, much of it highly nutritious (such as the famous *Karat* banana), the Pacific Island countries (PICs) paradoxically are among the unhealthiest regions in the world: a staggering 50-90% of the population are overweight, obesity prevalence ranges from 30-80%, and essentially eight of the ten most obese countries worldwide are PICs (WHO Global Infobase); diabetes prevalence among adults is the highest in the world ranging from 14% to 47% (compared with 13% in mainland USA); micronutrient deficiencies are also common whereby in 15 out of 16 countries more than one fifth of children and pregnant women are anaemic (WHO 2010). About 40% of the Pacific island region's population of 9.7 million has been diagnosed with at least one NCD and in total, 75% of all deaths are due to NCDs. Indeed, life expectancy is even stagnating or declining in some states due to NCDs - bearing in mind that in the early 1900s the islands were relatively free of NCDs (Snowdon & Thow 2013; WHO 2010). But how could this happen? One of the major reasons for this paradoxical situation is the alarming shift towards consumption of low quality imported processed foods accompanied by a neglect of traditional food systems based on nutritious crops, coconut, fish and seafood, fresh fruits, sugar cane, and pandanus. The Pacific Islands used to be self-sufficient due to their remoteness, but during the years of development and trade liberalization, they became more and more reliant on food imports leading to losses of agricultural biodiversity, traditional knowledge, customs and culture (Snowdon & Thow 2013; Englberger & Johnson 2013; Rayner et al. 2006). Several factors contributed to this process (Table 10):

Today, 75% of deaths in Pacific island countries are due to NCDs – whereas in the early 1900s, the islands were relatively free of diet related diseases

"Pacific islanders pay heavy price for abandoning traditional diet"
WHO (2010)

Table 10: Factors that influenced the shift from local to imported foods in PICs

Lack of negotiator resources:

Trade policy is complex and requires skilled negotiators who understand the implications for all sectors of the economy and who identify opportunities to improve the terms of negotiations for their own countries. PICs have limited financial and negotiator resources and are barely able to maintain a presence at the WTO. For instance, Vanuatu's WTO accession agreement contains far more onerous terms in comparison to much larger countries (Snowdon & Thow 2013; Plahe et al. 2012).

Disadvantage through advanced trade agreements:

Efforts to advance trade agreements are largely driven by the larger trading partner countries such as the EU who, for example, want to push for more access to Pacific fish supplies. PICs have not as much to gain since they could access all involved benefits as developing countries anyway. (Snowdon & Thow 2013; Stevens 2008; Morrissey et al. 2007)

Conflict between aid and trade:

PICs receive substantial aid from a number of key countries (such as Australia, USA, France, New Zealand, China, Japan) which leads to a conflict between aid and trade. For instance, New Zealand provided aid for controlling NCDs while at the same time exporting high-fat mutton offcuts to the region. When Fiji implemented a ban on importation of mutton flaps, New Zealand even threatened to pursue sanctions (Snowdon & Thow 2013; Wyber et al. 2009; Kelsey 2004).

Export of local nutritious food:

Commercial scale fishing and the fees paid for it are a critical source of revenue for PICs although concern continues about the risks of overfishing of both local reef fish and high-priced tuna. Most of the fish caught - which is an important part of a local healthy diet - is not even landed in the region but exported (Snowdon & Thow 2013; Barnett 2010; Hanich et al. 2010)

Ambiguous agricultural policy:

PICs tried to emphasize import substitution and export promotion through agricultural policy several times. Yet, this didn't lead to the production of traditional foods but to the cultivation of non-traditional crops such as lettuce, rice, sugar and cocoa (Snowdon & Thow 2013; Thow et al. 2011)

Weak food quality policy and food industry regulations:

Laws that govern the quality of foods sold are outdated or weak which allows for the importation of substandard and poorly labeled produces. For example, food labels vary as much as the countries the food comes from (Australia, France, China, Philippines, etcetera) meaning that nutrition labels are not only inconsistent but often not in English, the most common language spoken among PICs (Snowdon & Thow 2013; WHO 2010)

Stakeholder competition:

Conservation efforts of biodiversity are hampered by little consultation or collaboration, duplicated conservation effort and wasted resources among the many stakeholders involved (such as government departments, United Nations agencies, regional intergovernmental agencies, local and international NGOs, community-based groups, academic institutions and landowners) (Keppel et al. 2014).

Flashiness of imported foods:

Traditional foods have been neglected by consumers since the 1970s due to the 'glamour and flashiness' and easy preparation of imported processed foods (Englberger & Johnson 2013; WHO 2010).

Source: own depiction based on sources indicated within the table

Several efforts have been made to tackle the problem of loss of agricultural biodiversity and diet-related diseases. Taxation-based approaches were used to alter the prices of healthier and less healthy foods (Snowdon & Thow 2013). For example, sugar sweetened beverages are heavily taxed in several countries, such as Nauru that imposed a special import levy of 30%, in order to bring substantial health and financial benefits (Thow et al. 2011). Furthermore, several Pacific Islands have reduced the supply of unhealthy imported foods and other commodities by import bans. Fiji, for instance, banned the supply of mutton flaps in 2000 (Snowdon & Thow 2013). There are also 'go local' campaigns in Micronesia and other countries to promote agrobiodiversity and locally grown, nutritious and less energy-dense traditional foods. Local agriculture and fishing sectors are thereby challenged to strike a balance between local supply and commercialization (Englberger & Johnson 2013; WHO 2010).

All in all, many variables influenced the process that lead to the severe situation of malnutrition and diet-related chronic diseases in the biodiverse-rich PICs. Going back local, using and fostering agricultural biodiversity and traditional crops, and correcting trade, agricultural and food policies are key in order to return to a healthy lifestyle.

6 From theory to practice: Brazil and the BFN project

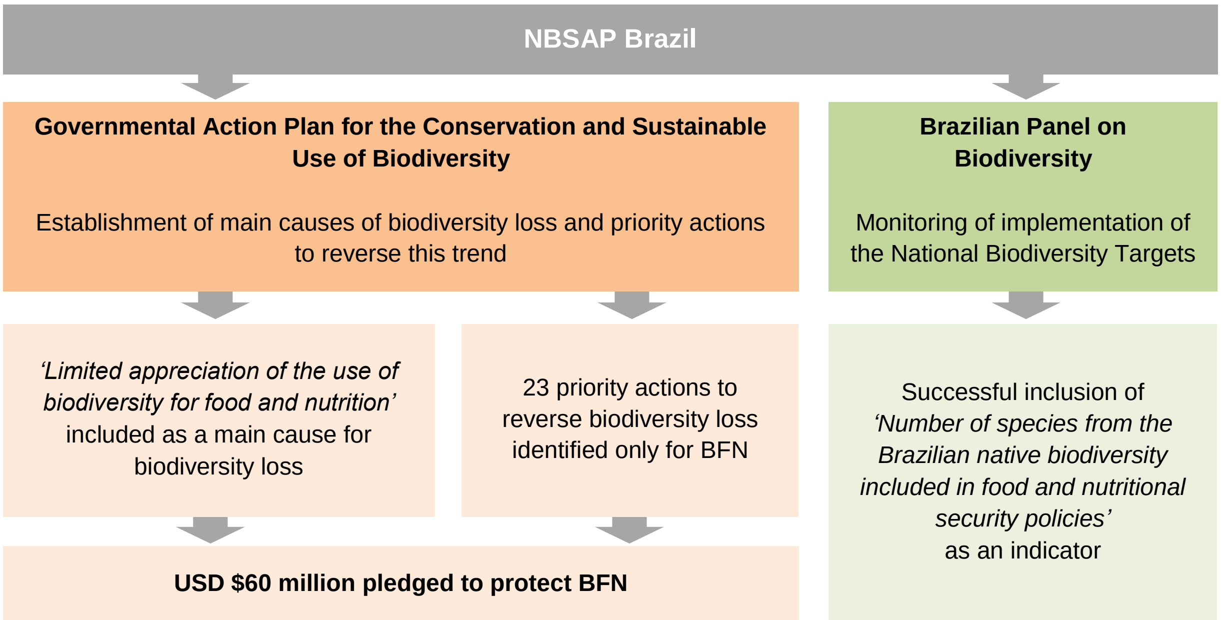
There are several research and development project around the world attempting to put into practice the conservation of agrobiodiversity in order to improve nutrition and health. One notable example is the GEF funded Biodiversity for Food and Nutrition Project – officially the 'Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Nutrition and Well-being' project – which was launched in 2012. The project is led by Brazil, Kenya, Sri Lanka and Turkey, and coordinated by Bioversity International with implementation support from UNEP and FAO. Its aim is to address growing concerns in the four project countries over the rapid disappearance of agricultural biodiversity, particularly traditional crops and wild species with nutritional potential, and the trend of high consumption of nutritionally-poor ultra-processed foods that are dominating diets world-wide and contributing to epidemics of obesity and diet-related chronic diseases. The project provides cross-sectoral platforms and spaces to bring together multiple stakeholders from agriculture, health and environment sectors to work together to mainstream agricultural biodiversity into policies and programs at the national and global level (Bioversity International 2015; MMA 2015). The example of Brazil illustrates how biodiversity for food and nutrition can successfully be mainstreamed into policy and programs thus positively influencing population's well-being.

After reviewing existing policies and programs that impact biodiversity conservation and/or nutrition, various entry points for mainstreaming BFN could be identified. Several policies and programs such as the Food Acquisition Program, the National School Feeding Program and Minimum Price Guarantee Policy for Sociobiodiversity Products have been influenced since then. Yet, because of the nature of the BFN project and its main focus on protecting biodiversity, the ongoing revision of the NBSAP in order to comply with the Aichi Biodiversity Targets was chosen to serve as key entry point for mainstreaming BFN into national policies. The BFN project team successfully managed to integrate BFN into the policy tools used for the revision of the NBSAP which is why they are presented in the following paragraph (Oliveira et al. 2014; Oliveira 2013).

In order to prevent further biodiversity loss, Brazil has been reviewing and updating its NBSAP and National Biodiversity Targets using a multi-stakeholder policy. More than 19 institutions across 5 sectors (business, academia, environmental NGOs, federal and state government, indigenous peoples and traditional communities) were engaged during the revision process called *Dialogues on Biodiversity* which led to the reduction of the former 51 to 20 national targets. The revision includes the drafting of a *Governmental Action Plan for the Conservation and Sustainable Use of Biodiversity* whereby the first step was to establish the main causes for biodiversity loss. Thirty-two government agencies took part in the process driven by the Ministry of the Environment and the Ministry of Planning and due to the mainstreaming efforts of the BFN project team the cause "limited appreciation of the use of biodiversity for food and nutrition" was included as one of the main causes for biodiversity loss. Furthermore, 23 priority actions to reverse biodiversity loss and help achieve National Biodiversity Targets were identified by the participants only for BFN. As a result, USD $60 million have been pledged to protect BFN. Mainstreaming BFN within the NBSAP revision process was also achieved through biodiversity target indicators which were set up by the *Brazilian Panel on Biodiversity* in order to monitor the implementation of the National

Biodiversity Targets: The BFN Project team was able to successfully include "number of species from the Brazilian native biodiversity included in food and nutritional security policies" as an indicator (MMA 2015; Oliveira et al. 2014).

Figure 20: Mainstreaming BFN in Brazil



Source: own illustration based on (Oliveira et al. 2014; Oliveira 2013)

All in all, one can say that Brazil's Trojan horse for mainstreaming BFN is the NBSAP. Although BFN is not explicitly mentioned in the National Biodiversity targets yet (the final targets will be published in mid-2015), BFN could be integrated into the NBSAP policy instruments like the *Governmental Action Plan for the Conservation and Sustainable Use of Biodiversity* and the *Brazilian Panel on Biodiversity*. The revision of the NBSAP has brought together stakeholders from many different sectors thereby making it possible to raise awareness of the importance and cross-sectoral character of BFN.

7 Conclusions

This report summarized current evidence for the global burden of malnutrition and its possible reduction by using agricultural biodiversity. It could be shown that all countries in the world, no matter whether rich or poor, are affected by malnutrition. Globally, one in three people suffers either from undernutrition, micronutrient deficiency, and/or overweight and obesity, with huge consequences on national human capital and economies. Undernutrition and micronutrient deficiencies are estimated to cost US$ 1.4–2.1 trillion per year, equivalent to 2–3% of global GDP, while diet-related health conditions will cost the world more than US$ 30.4 trillion over this and the next decade unless measures are taken. This is equivalent to the amount it would take to feed and educate every child on Earth for the next 355 years. In order to address the global challenge of malnutrition and its economic costs, the nexus between biodiversity, agriculture and health has recently been put into focus as a solution. It has been recognized through a series of initiatives and activities from different sectors. Several examples highlighted in this report show that agricultural biodiversity has the potential to serve as part of the solution to reduce malnutrition. For instance, one variety or another can make the difference between nutrient adequacy and nutrient deficiency. Furthermore, Bioversity research has shown that a more diverse crop production in low income countries leads to a greater supply diversity available to consumers, and that greater supply diversity leads to a reduction in nutrition-related diseases and health conditions. For instance, countries like Brazil are actively investing in agricultural biodiversity. Nutrition interventions can yield up to 47 dollars for every dollar invested which is why they are some of the best investments countries can make to generate and sustain broad-based wealth. Biodiversity for food and nutrition is thus a promising part of the solution to the burdens of malnutrition.

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