Food Sec.
DOI 10.1007/s12571-013-0288-2

ORIGINAL PAPER

# Plant breeding for nutrition-sensitive agriculture: an appraisal of developments in plant breeding

**Anja Christinck · Eva Weltzien**

Received: 11 June 2013 / Accepted: 30 July 2013

**Abstract** Plant breeding for nutrition-sensitive agriculture (NSA) has to address the various aspects of food and nutrition security by taking on an integrated approach. In our article, we summarize past and current developments in plant breeding that are relevant to nutrition in this broader context. We outline how plant breeding can contribute to availability of, access to and utilization of food, and give examples of how the concept of NSA is differently addressed in selected plant breeding projects. Effective targeting towards the needs of vulnerable groups seems to be a key success factor. Differences exist with regard to the underlying concept of technology diffusion, the importance given to agrobiodiversity for improving food and nutrition security, and the degree and quality of participation of target groups. We conclude that the potentials of crop and variety improvement for NSA are far from being tapped. Plant breeding for NSA requires that the inherent focus of most breeding programs on crops and varieties be broadened towards people and their needs. It is thus required to integrate complementary expertise into breeding programs, and to overcome the divide between technology-oriented and system or actor-oriented approaches. Furthermore, it should be acknowledged that commercial breeding needs to be complemented by other initiatives and institutions that focus particularly on food and nutrition security of vulnerable groups. Any efforts to further harmonize agricultural, nutrition, health, environmental, and educational policies, also with international policy frameworks and obligations, could help to create an enabling policy environment for NSA.

**Keywords** Plant breeding · Nutrition · Food security · Agrobiodiversity · Adaptation · Impact

A. Christinck (✉)
Agricultural Communication and Extension, Gichenbach 34, D-36129 Gersfeld, Germany
e-mail: mail@seed4change.de

E. Weltzien
Sorghum Breeding and Genetic Resources, ICRISAT, B.P. 320, Bamako, Mali

## Plant breeding for nutrition-sensitive agriculture: the framework for this study

The emerging concept of Nutrition-Sensitive Agriculture (NSA) as described by Jaenicke and Virchow (2013) as well as Kriesemer (2013), puts a focus on the relationship between agricultural production and human nutrition and health, thus acknowledging the fact that more or sufficient agricultural production does not automatically lead to improved nutrition and health of human populations. The concept strongly relates to the definition of food and nutrition security, which is based on the three pillars of availability, access and utilization of food (CFS 2012). The utilization dimension, which includes food processing and composition of meals according to dietary needs of individuals, is given particular importance. Further important aspects that address the broader framework of nutrition-sensitive agriculture are a clear orientation towards vulnerable groups, and process-related criteria, such as the human rights principles of participation, non-discrimination and empowerment.

In order to assess how plant breeding could contribute to the development of NSA, we summarize past and current developments in plant breeding that may be of relevance. We further use a simple framework which puts human nutrition and health at the center and relates to the three aforementioned aspects of food security: availability, access to food and food utilization, with stability being treated as inherent in all three. Similar frameworks are being used by aid organizations for assessing food security.[1] We thus relate to concepts known from human nutrition science, but do so from the perspective of plant breeding and agriculture.

The environment includes the natural resource basis upon which human food and nutrition security originally depends. We understand the agricultural production system as a system that depends on and is shaped by human activities and that is managed by people to serve their needs and goals, of which nutrition is an important one. As such, the agricultural system

---

[1] See for example http://www.fantaproject.org/focus/foodsecurity.shtml (accessed August 8, 2013)

includes a social dimension, because human needs and goals as well as the resources and activities applied to achieve them, may depend on gender, age and other social categories. The importance of including a gender perspective into the overall concept of NSA has been elaborated by Beuchelt and Badstue (2013), and we relate some of our findings to it.

Positive or negative effects on both the environment and human nutrition and health, can occur as a result of plant breeding activities, either due to particular properties of varieties, or indirectly as a result of agricultural practices associated with their cultivation. Figure 1 summarizes specific topics relating to plant breeding within this structure. Finally, we will give examples of how the emerging concept of nutrition sensitive agriculture has been differently addressed in plant breeding projects, and draw conclusions for the future orientation of breeding programs aiming at a more nutrition-sensitive agricultural development.

## Breeding approaches and their relevance for food and nutrition security and NSA

### Breeding approaches and their successes and limitations

In the past, the central concern of nearly all plant breeding programs for developing countries was to increase productivity. While plant breeding undoubtedly has contributed to many profound changes in agricultural production, the benefits have been distributed unevenly, in terms of crops, target production environments, and traits. High yield increases have indeed been achieved with precious few crops – maize, rice and wheat and mainly where agro-ecological and economic conditions favor high yields. In most semi-arid regions affected by chronic food insecurity, there has been little or no yield increase recorded in the past 30 years for the most important food crops of these regions. The comparison of yield increases in East or West Africa with those obtained in North America and Europe over the same time period is striking[2] (Fig. 2).

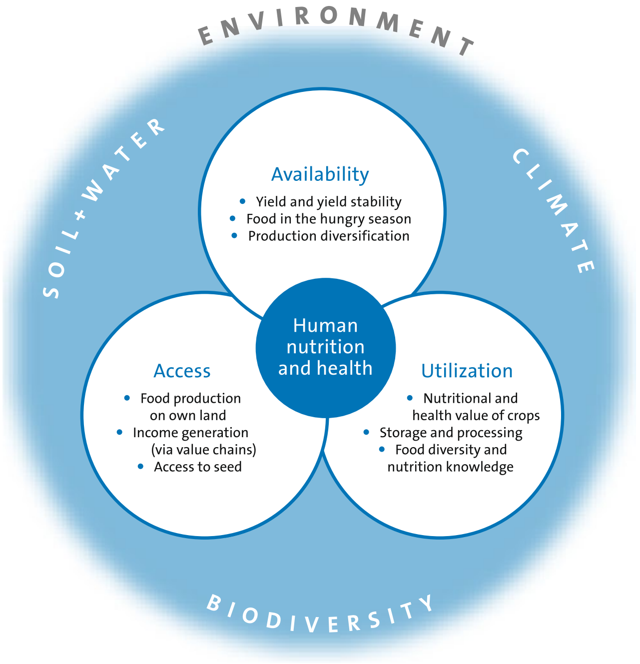

**Fig. 1** The three dimensions of food and nutrition security and how they can be addressed by plant breeding activities; the human nutritional needs are put in the center, they are the goal to which plant breeding activities could contribute if appropriately targeted

### Targeting marginal environments where food and nutrition insecurity prevail

In general, plant breeders favor varieties that perform above average across many different locations, a concept called 'breeding for broad adaptation'. This is mainly due to economic considerations, because such varieties can be commercially diffused into larger regions, as long as quite similar agro-ecological conditions prevail. Many official variety release programs build on broad adaptation, in the sense that a new variety, in order to be released, has to outperform existing 'check varieties' across many official test sites, usually research stations. These test sites, however, hardly reflect the conditions of resource-poor farmers in marginal environments where food and nutrition security are most regularly at risk.

Several studies have looked at the yield performance of modern varieties under these marginal production conditions. They show that high-performing varieties of barley, durum wheat and pearl millet did not achieve higher yields under these production conditions than the local farmer varieties and were often lower (Abay and Bjørnstad 2009; Annicchiarico et al. 2009; van Oosterom et al. 2003; Yadav and Weltzien 2000). Under optimal conditions, on the other hand, the high-performance varieties were superior to the local cultivars.

This phenomenon, often referred to as the 'crossover' type of genotype by environment interaction, has attracted some specific research interests in recent years (Ceccarelli et al. 2000; Dawson et al. 2008). Plant breeding programs usually focus on specific environmental factors causing low productivity, such as low nitrogen soils, low P-availability, or drought stresses. Combining such insights on specific stresses, some breeders have looked deeper into the adaptation mechanisms of crop varieties to highly variable climatic conditions and less predictable stresses. Haussmann et al. (2012) focused on pearl millet and sorghum breeding for adaptation to climate variability in West Africa, and drew conclusions with regard to the genetic structures of cultivars and selection strategies for adaptive traits, and these differed in various aspects from strategies pursued by conventional plant breeding programs in the past. Particularly, the importance of genetic diversity for adaptation to climate variability appeared in a new light.

---

[2] This yield increase is only partly due to breeding progress.

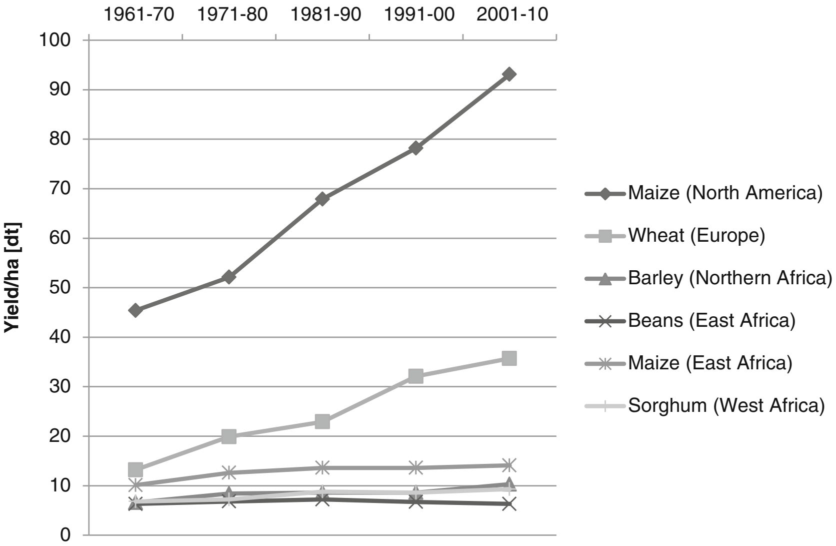

**Fig. 2** Development of average yields for various crops and regions per decade (Data: FAOSTAT); the average yields for sorghum (West Africa), beans (East Africa) and barley (Northern Africa) have remained below 10 dt (1 metric ton) per hectare with a slight increase for sorghum and barley

### Neglected crops

Despite being of vital importance to food security at local and regional levels, only few of the minor (neglected) crops have been integrated into formal breeding programs. Included in this category are many tropical tubers and legumes as well as some modestly diffused cereal types, such as millet species, but also the traditional varieties of major food crops. The importance of these neglected crops and varieties for food and nutrition security has various dimensions; one of which is the nutritional value. Leafy vegetables, fruits, legumes, roots, tubers, spices and herbs are essential for human nutrition and complement staple crops such as rice or maize. Many leguminous crops, such as cowpeas and winged beans, are excellent sources of protein and micronutrients. Tropical fruits – including citrus fruits, mangoes and lychees – have high vitamin and mineral content. The same applies to many African vegetables, such as the various squashes, or the 'Tinangkong' variety of sweet potato grown in the Philippines, the leaves of which contain significant amounts of Vitamin A (Gari 2004). Even if grown in small areas, these crops can be important for improving the diets of children or people who are ill; for example, the health status of people affected by chronic diseases or HIV/Aids can be influenced positively through diverse, nutrient rich diets based on the aforementioned crops (Gari 2004). Furthermore, some of these neglected crops can help to reduce transitory food insecurity during hungry seasons.[3]

### Neglected traits

Quality aspects in general have been given much less importance than yield in breeding programs. This refers to the nutritional value as well as other quality aspects, such as adaptation to local conditions for storage and processing in developing countries, and culinary quality.

It is known that with increased yield level, the nutrient content of crops can decrease. This phenomenon is called the 'dilution effect'. Dilution effects have also been reported when historical varieties were compared to modern varieties. Evidence for the dilution effect is available for wheat and maize, as well as some vegetables. The lower yielding historical cultivars tend to have higher nutrient and micronutrient contents. In maize, for example, a protein decline of 13 % was observed when comparing varieties that were cultivated 80 years ago to contemporarily grown varieties, whereas in wheat and barley the protein decline is much more pronounced (30–50 %), according to Davis (2009). Murphy et al. (2008) compared modern and historical spring wheat varieties and found a significant decrease in content for seven micronutrients in the modern varieties (Cu: −16 %; Fe: −11 %; Mg: −7 %; Mn: −7 %; P: −9 %; Se: −50 %; Zn: −25 %). A negative correlation with yield was observed for some, but not all minerals, and some moderate or higher yielding varieties showed high mineral content as well – a fact that indicates that selection for mineral nutrient content, along with agronomic traits, could be successful.

The large increase in the percentage of people suffering from micronutrient malnutrition over the last four decades coincides with the global expansion of high-yielding, input-responsive cereal cultivars (Welch 2002; Welch and Graham 2002). Murphy et al. (2008) related the lower micronutrient content of modern wheat varieties to food intake and Recommended

---

[3] The period before harvesting the staple crops, when the previous year's stock is depleted.

Dietary Allowances (RDA) of various micronutrients for different genders and age groups, resulting in considerably more food intake required to meet the dietary needs. For example, females aged 19 to 30 would have to eat 10.6 slices of whole wheat bread made with flour from historical cultivars that are high in Zn to reach the RDA, but would require 15.2 slices of bread made with flour from modern cultivars to achieve the same RDA. For males aged 31 to 50, it would be 13 versus 19 slices of bread, respectively, to reach the RDA for copper (Cu). They further drew attention to the fact that the enhanced yield of modern cultivars could potentially increase the quantity of mineral 'harvested' per area of grain production, but the mineral concentration per grain or loaf of bread (or other end products) would be reduced.

Genetic variation for micronutrient content as well as other nutrition-relevant traits has been reported in various crops. Some of the germplasm collections held by the CG centers have been characterized for nutritionally relevant traits, as summarized by Tumwegamire (2011) (Table 1).

However, nutritional quality has not played an important role in most breeding programs in the past, so that the potential for nutritional improvements based on the existing diversity for relevant traits has remained largely untapped.

## Biofortification

On the other hand, increasing the nutrient contents of food crops has recently become a goal pursued by some breeding programs that are especially focused on this issue. Food fortification via breeding is called 'biofortification'. Food fortification in general means enriching basic foods with particular micronutrients, mostly vitamins or minerals, such as iron. However, this requires industrial processing of food and functioning food distribution systems - and presupposes that the target group has access to such food systems. Biofortification could help to overcome this bottleneck, as the food harvested would already contain the critical nutrients, irrespective of further processing and distribution pathways.

The biofortification approach is thus meant to better target people in rural areas (HarvestPlus 2012), and it is currently being applied to a number of staple foods, namely sweet potatoes, cassava, maize, rice, wheat, pearl millet and also beans and other legumes (Hawkes et al. 2012; HarvestPlus 2011)). In fact, biofortification efforts have been successful in various crops – in the sense that the micronutrient content of some crop varieties has been increased. The most renowned outcome is the successful development of an orange-fleshed sweet potato variety with higher *ß*-carotene content, which has been introduced to farmers in Mozambique and Uganda, resulting in documented higher levels of Vitamin A intake of children and other vulnerable groups (HarvestPlus 2012; Hotz et al. 2012).

Biofortification may sound like a special breeding technology, which, in fact, it is not: basically, it means nothing more than including a nutritional objective into a breeding program.

It thus includes the normal steps of a conventional breeding program:

- *Prebreeding*: Screening existing germplasm collections for variation in relevant nutrition-related traits (e.g. *ß*-carotene content).
- *Recombination:* Crossing identified materials with other breeding partners, i.e. advanced breeding material containing other relevant agronomic and/or quality traits.
- *Selection and testing*, leading to further improvement of cultivars.
- *Adaptive breeding:* Crossing experimental cultivars with various commercial varieties, in order to meet the requirements of farmers and consumers in different countries or regions.
- *Variety release* and distribution.

In a breeding program focusing on biofortification, all kinds of breeding techniques can be applied. Most biofortification programs, so far, have been based on conventional breeding, with the exception of 'Golden Rice', which is a transgenic (GM) crop.

Biofortification is not a quick solution to the problem of micronutrient deficiencies: an assessment of cost-effectiveness conducted by IFPRI (Meenakshi et al. 2007) is based on a

**Table 1** Range of variability in key micronutrient content in various crops (based on Tumwegamire 2011)

| Crop | Collection | Accessions | Nutrients analyzed | Range of contents (in brackets: average) |
|---|---|---|---|---|
| Bean | CIAT | > 1000 | Fe, Zn | Fe: 34 – 89 µg/g (55 µg/g)<br>Zn: 21 – 54 µg/g (35 µg/g) |
| Cassava | CIAT | 630[a] | *ß*-carotene | 0.1 – 2.4 mg/100 g |
| Wheat | CIMMYT | | Fe, Zn | Fe: 28 – 56.5 µg/g (37.3 µg/g)<br>Zn: 28 – 56.5 µg/g (37.3 µg/g) |
| Maize | CIMMYT | 1840 | Fe, Zn | Fe: 9.6 – 63.2 µg/g (23.76 µg/g)<br>Zn: 12.9 to 57 µg/g (33.27 µg/g) |
| Sweet potato | CIP | ? | *ß*-carotene | Up to 8 mg/100 g |

[a] A core collection representing more than 5,500 accessions

timeframe of 30 years, of which the first 10 years are assigned only to breeding, and the peak adoption is expected to occur after 20 years. Cost-effectiveness can thus only be estimated *ex ante* based on various scenarios. It is different for each crop, and varies between countries, depending on the losses that may occur with local post-harvest treatments, dishes prepared, the daily intake, and the bioavailability that can be expected for vulnerable population groups.

### Plant breeding and system diversity

Focusing more attention on biodiversity conservation, including crop plants and their varieties, is another recent development in plant breeding. Apart from being a resource for future uses, agro-biodiversity preservation and enhancement underpins the food and nutrition security of populations living in marginal environments. This close link between poverty reduction and food security on the one hand and preservation and use of agro-biodiversity on the other was highlighted by the 'Chennai Platform for Action' (MSSRF 2005), but lacks full integration into most relevant policy fields, such as agricultural, health, education and research policies.

However, more decentralized breeding programs based on local biodiversity and incorporating innovative production and diffusion models for seed, could represent a major step toward more diversity and simultaneously toward better varieties for marginal production systems and food-insecure people. As a result of the commitments made by countries in signing international agreements (e.g. CBD,[4] ITPGRFA[5]) there is growing interest, even in the industrialized nations, in establishing and strengthening breeding programs with broader genetic bases and decentralized forms of organization.

### Nutrition relevant developments in breeding methodologies

Plant breeding methodologies are evolving rapidly in three different ways: (1) Precision and efficiency for transferring specific genes, (2) organizational forms, communication for involving users and generally stakeholders, and (3) the precision and scale with which specific traits can be observed.

All of these developments provide new opportunities for addressing food and nutrition security related issues in significant ways. Analytical tools for observing traits related to nutritional quality, such as X-ray fluorescence (XRF) for mineral concentrations or near infrared spectrometry (NIRS) for starch or protein qualities, make it possible to include nutritional quality as a trait for large numbers of genotypes in applied variety development programs; it is thus feasible to target the development of improved varieties which reach specific standards, for example for mineral concentrations (ICRISAT 2012: 8–9). Developments of genetic markers for specific alleles, e.g. adaptation to aluminium toxicity in sorghum, make it possible to breed for adaptation to specific marginal production conditions, or enhance specific traits, such as protein or starch qualities (Gilding et al. 2013). In combination with new bioinformatics tools, it will become more feasible to consider selection for several traits together more effectively, as well as using a wider range of diverse materials.

User involvement, and the testing of diverse forms of collaboration between breeders, farmers and a range of other stakeholders has opened up the possibilities, of targeting more specifically traits of crucial importance for farmers and local consumers, such as 'improved food yield' for sorghum in West Africa, the result of increased grain yield, reduced decortication losses, and appropriate starch qualities for local food processing (Hama et al. 2011). New forms of collaboration in breeding also allow for the development of seed system innovations that address farmers' primary concerns, and build on their skills as outlined by Sperling and Christinck (2005). New communication tools and technologies are bound to increase the reach, and effectiveness, of these approaches.

## How can plant breeding contribute to selected aspects of NSA?

In this section, we will outline how plant breeding programs can contribute to the three aspects of food and nutrition security (availability, access and utilization), following the evaluation framework given in Fig. 1. Furthermore, the broader context of plant breeding in its relationship to human health and environment will be briefly addressed.

### Plant breeding and the availability of food

For developing NSA, the plant breeding approaches that target increasing food availability in marginal production systems are of particular interest, for example rain-fed farming systems in the semi-arid tropics, where the greatest share of people afflicted by food and nutrition insecurity live.

Crop yields in general can be increased and/or stabilized through agronomic advantages, enhanced environmental adaptation, resistance to pests and diseases, improved drought tolerance and tolerance to other stress factors. When newly developed varieties fit well in the farming system – that is, for example, they are suitable for integrated crop and livestock production systems, giving high nutritive values in the crop residues as well as good stover yield – they create advantages and positive interaction across the entire farming system.

Although most 'improved' varieties cannot fully produce their yield potential under marginal production conditions (see Section Breeding approaches and their relevance for food and

---

[4] CBD= Convention on Biological Diversity

[5] ITPGRFA=International Treaty on Plant Genetic Resources for Food and Agriculture

nutrition security and NSA), there are cases where varieties from formal breeding programs were adopted by farmers for these conditions. An example is a high-tillering, single-cross hybrid variety of pearl millet (HHB 67) which was released in 1990 and continues (in a further improved form) to be grown on approx. 500,000 ha in two semi-arid states of India, Rajasthan and Haryana.[6] Given its short growing cycle and widely accepted grain quality, it provides farmers the additional option of sowing millet even if rains are delayed, or where fields have reduced water availability. Higher yields and improved yield stability also form an important part of decentralized plant breeding strategies involving farmer participation participatory plant breeding (PPB). A number of PPB programs have seen substantial yield increases within a few years, and indeed in areas where breeding has had little success in the past. In one of the first PPB projects to be published in detail in a scientific journal, Sperling et al. (1993) showed that female farmers in Rwanda were able to realize an average yield increase of 38 % by selecting for breeding lines of beans in their own fields. They were not even selecting directly for yield but for other characteristics associated with adaptation to their cultivation system and environment.

Christinck et al. (2000) established that farmers in Rajasthan, India, associate specific morphological traits in pearl millet with drought tolerance. These traits include a narrow diameter for the stem and panicles, thin leaves, the presence of numerous basal and nodal tillers, as well as small, hard grain of a yellowish color. Through consistent observation of these traits in the breeders' own selections, populations emerged within a few years combining the higher yield potential of the modern varieties in 'good years' with yield stability under drought conditions, as seen in the local landraces. Under drought conditions, higher yield as well as higher yield stability was attained (vom Brocke et al. 2003).

Progress with regard to productivity gains was also achieved in a breeding project for sweet potatoes in Uganda. Three PPB varieties emerged within a few years that delivered as high or higher yields than the previously existing varieties, at various sites in Uganda and in Tanzania. These PPB varieties were also tested for other characteristics such as resistance against disease and harmful insects. In some cases, yields were double that of the existing local varieties, with one PPB variety 26 % above the trial average. By the third year of the program, the farmers had begun consuming the new varieties at home; by the fourth year, these varieties were appearing in the local markets (Mwanga et al. 2009). With a conventional breeding program, it would have taken twice as long to develop and release such a new variety, because the official release procedures normally takes 2–3 years. Only then would these varieties reach farmers for testing and without any guarantees that the new sweet potato would be adopted by the farmers.

Another example of the rapid spread of improved varieties through PPB is the diffusion of two upland rice varieties in India ('Ashoka varieties'). These varieties were officially released in five Indian states and are the first newly bred upland varieties ever to be widely adopted by farmers of this region. The reasons for their popularity are earlier harvest, higher yield and superior drought tolerance combined with improved cooking quality and taste. An impact assessment conducted by DFID resulted in an estimated 400,000 hectares of Ashoka Rice that would be grown by nearly 3 million households in the four states of Rajasthan, Jharkand, Madhya Pradesh and Gujarat; the seed has spread to other Indian states via informal farmer networks (Conroy et al. 2009). This example shows that PPB is not necessarily restricted to improvements on a local scale, and can contribute to agrobiodiversity at village level, as most farmers grew the Ashoka varieties in addition to existing landraces (Witcombe et al. 2011).

Of special interest for food availability, aside from higher yields, are those crop varieties with a short growing cycle that can be harvested somewhat earlier, resulting in the length of the hungry season being substantially shortened. Classen et al. (2008) report that a considerable shortening of the hungry season could be attained with the new maize varieties developed in a PPB program in Honduras, from an average of just under 6 weeks down to an average of less than 2 weeks. The longest hungry period reported among the program participants was 8 weeks; among the non-participants 20 weeks.

In many farming systems, crops or varieties existed that were specifically grown in 'emergency situations'. These are typically crops or varieties with a very short growing cycle, but high nutritious value. For example, buckwheat is a traditional crop cultivated in parts of China and the Himalayan region. It is well adapted to mountain areas with their poor and often degraded soils. It has a short growing cycle and its cultivation can therefore help ease seasonal food shortages and failures of other crops. In addition, buckwheat grains, unlike many cereals and tuber crops, contain proteins of excellent quality (GTZ 2006).

The success of PPB for increasing yield and yield stability under marginal production conditions is largely due to two factors:

(1) 'Adoption' of the farmers' multifunctional approach to farming, where yield as such is only one aspect among others, and multiple traits that are usually neglected in profitability analyses play an important role; the complex and diverse livelihood and farming systems of resource-poor farmers could be seen as an effort to reduce vulnerability and enhance food and nutrition security (Badstue et al. 2012).

(2) A better understanding of adaptation, particularly to erratic or adverse environmental conditions, resulting in populations that can respond to such conditions (Haussmann et al. 2012).

---

[6] www.apcoab.org/uploads/files/1276753523hhb7_pub.pdf (accessed August 8, 2013)

## Plant breeding and access to food

An individual person's access to food depends on the position in the food distribution chain from where this person can obtain food. There are obviously large differences between urban and rural consumers, and again between rural people with access to their own land, and others. Also, distribution practices within households, families and communities, especially with regard to gender differences, have to be considered.

Farmers have the easiest access to food which is grown on their own land. For them, accessing food is directly linked to food availability, and any progress in yield or yield stability which works for their farming conditions, as outlined in the previous section, is progress for accessing food as well. However, intra-household dynamics, particularly gender inequality, with regard to food allocation as well as control over resources, i.e. access to land or control over harvest and income, need to be taken into account in order to address vulnerability of certain groups, e.g. women and children.

Many resource-poor farmer families are also net food buyers. Depending on the area of land they cultivate, and on the degree of self-sufficiency of the farming system, they need to buy additional food items to complement their diet or to increase their staple food stocks if these were to be depleted before the new harvest. Thus, access to food, even for farmers, may be closely related to income. On the one hand, increasing yields can help to reduce the amount of money needed to buy additional food, or increase the surplus, which may be sold. Furthermore, plant breeding can enhance farmers' access to food by developing varieties with which the farmers can generate a higher income i.e. improve their marketing possibilities.

There are very few studies that directly measure the effects of plant breeding or variety choices on farmers' income. Nevertheless, the acceptance and diffusion of varieties, combined with questionnaires on the reasoning behind those decisions, can provide some guidance. The abovementioned study from Honduras (Classen et al. 2008) shows that farmers who took part in a PPB research program could save more money due to improvements in their maize and bean production, compared to non-participating farmers (55 % of project participants compared to 11 % of non-participants achieved savings). .

For longer food value chains involving food processing, an interesting concept is to find ways of achieving improved varieties for industrial or local processing that would open up new sources of income for the farmers as well as the rest of the labor force. Examples of this can be found in the work of LI-BIRD in Nepal, where a sector for non-traditional products such as biscuits and pasta has emerged from local varieties.[7] There are also instances of processing criteria being included in breeding projects to produce chips or baby food from potatoes or sweet potatoes (Grüneberg et al. 2009). Such approaches could be very interesting for farmers in marginal regions, provided that solutions to transport and market access are also addressed, although actual studies on the income effect of such projects are yet to be published.

Another way to increase the income of poor farmers and thus their ability to purchase additional foodstuffs is cost-cutting for agricultural inputs, such as pesticides, fertilizer and seed. An example is provided by a study from the Philippines. MASIPAG is a network made up of farmers, scientists and NGOs in the Philippines that has, to some extent, improved the living conditions of the rural population through the spreading of organic farming practices and a wide range of training activities, including farmers' field schools. In the network are 67 rice breeders who have collaborated with participating farmers to develop a large number of new varieties. A recently published impact study examining the rice yields from organic-run farms, farms converting to organic practices, and conventional farms, found no significant differences in yield. This means that the organically run farms can attain the same yields without the usual inputs, something that is attributable to the newly developed varieties, among other factors (Bachmann et al. 2009). Net income per hectare was, for the organically operated farms, one and half times higher than the conventionally run farms. Unfortunately, the study does not allow one to separate the individual influencing factors: plant breeding together with a wider range of other measures on the MASIPAG farms is treated as part of one overall concept.

In this context, seed occupies a unique position among the means of agricultural production, because seed is the foundation of all food production and, in contrast to fertilizers or herbicides, is indispensable. In the past, access to seed was assured by the traditional farmers' systems and networks for seed care, storage and dissemination. Seed was and still is passed from person to person, sold or exchanged. Interestingly, disaster relief is familiar with such networks. Even during acute emergency situations, seed is nearly always available in sufficient quantities where a well-functioning, informal seed network is in place (Sperling and Cooper 2003). Studies from Mozambique and Mali show that the majority of all seed transactions between farmers there take the form of gifts. When seed is paid for, the price is generally in the range of normal grain prices or below (Rohrbach and Kiala 2007; Siart 2008). A report by the UN Special Rapporteur on the Right to Food, Olivier de Schutter, delivered at the UN plenary assembly on 23 July, 2009 (UNO 2009), underlines the importance of informal farmer seed systems for food security as well as for agro-biodiversity conservation. An important characteristic of informal seed systems is that there is no fundamental distinction made

---

[7] See, for example, http://www.farmersrights.org/bestpractices/success_benefit-sharing_5.html (30.1.2010)

between 'grain' and 'seed': grain from local markets can be used as seed, and stored seed can be consumed and replaced with grain, if necessary. This is important for food security, and plant breeding programs focusing on NSA should consider it by making sure that they develop variety types that allow farmers to use harvested grain as seed without taking large risks (i.e. of crop failure, as some variety types are not stable in subsequent generations). Furthermore, they could take targeted measure to improve the information flow on specific varieties and their nutritional properties.

For non-rural target groups, the issues of access to food and income can hardly be influenced directly by a plant-breeding program. Rather, it depends on food prices (which may to some degree be related to agricultural yields, but also other factors) and on the possibilities for the urban poor to obtain sufficient income. However, the development of food or agrobiodiversity-based value chain approaches can help generate employment for non-farmers, and thus (via additional income) improve their access to food. In order for benefits to reach vulnerable groups, the activities must follow an inclusive approach and need to be specifically targeted towards these groups (Will 2008).

Hence, the potential contributions of plant breeding to improving access to food are not restricted to improving individual traits that will perhaps result in higher market prices. An enhanced consideration of farming and seed systems and factors influencing access to both food and seed for vulnerable groups from the outset of a breeding initiative could improve nutrition-sensitive plant-breeding.

## Plant breeding and food utilization

After harvest, there are still many steps to consider before a crop turns into food and is consumed along with other products and ingredients. Conventional plant breeding programs very rarely consider post-harvest issues, such as local storage and processing quality, nutrient content or culinary quality, under the conditions of food insecure population groups. In order to do that in a systematic way, an activity analysis, revealing gender roles and responsibilities in the post-harvest process, would be a necessary prerequisite. On the other hand, quality criteria for industrial processing are often addressed, at least for those crops where a developed market exists. Furthermore, the issues of food diversity and food culture are usually not considered in conventional breeding programs, as they normally focus on a single crop.

In accordance with the new approach of NSA, a change can be observed in recent and forthcoming research projects (Hawkes et al. 2012). The biofortification approach is to be mentioned here, with important achievements regarding the micronutrient content of some staple food crops (see Sections Breeding approaches and their relevance for food and nutrition security and NSA and How could plant breeding programs align with NSA?), and research linking plant breeding and nutrition. However, the focus of these projects is rather narrow, with micronutrient content being defined as the main quality criterion to be addressed.

In PPB programs, variety evaluation has often included the whole chain from the field to post-harvest treatment and food, which means that the harvest from different test varieties is being stored and processed with the local means and facilities; food is being prepared and evaluated for processing quality, appearance, and taste. These aspects of food and nutrition quality are important criteria for farmers to favor or to reject varieties (cases were documented for example by Almekinders and Hardon 2006, and methods by Weltzien and Christinck 2005).

Grüneberg et al. (2009) describe advantages of decentralized and participatory breeding approaches for diverse tropical tubers, including cassava, potatoes, sweet potatoes, yam and taro. These plants show considerable genetic variability, particularly in their levels of iron, *ß*-carotene (as Vitamin A precursor), and zinc. A deficiency in any of these substances is associated with malnutrition or hidden hunger. Regional preferences for such tubers differ widely and are based on appearance (color), as well as cooking and processing qualities for the various regional dishes. The involvement of female and male farmers and consumers in the early stages of the breeding program, when variability of the material is still high, is described as a way of avoiding false selection decisions that can result in a variety being rejected for one or another reason in spite of the variety's nutritive benefits.

Some food crops are known to have additional medicinal properties, such as a positive influence on acute or chronic diseases, or preventive effects on human health. This can be due to their content of specific components, such as fructose, inulin, unsaturated fatty acids or secondary metabolites, such as flavonoids. Well-known examples are sweet potatoes (*Ipomea batatas*), topinambur (*Helianthus tuberosus*), spices such as curcuma (*Curcuma longa*) or natural stimulants such as green tea (*Camellia sinensis*). Omujal et al. (2010) describe the same for traditional African vegetables, including *Amaranthus*, *Solanum* and *Vigna* species.

For some cultivated plants, health effects have been studied and documented in the scientific literature, or they form part of traditional knowledge, as in the case of medicinal rice varieties, known in the ancient Ayurveda knowledge system (Leena Kumary 2007). Medicinal uses of cultivated, semi-wild or wild plants play an important role in local cultures, and often there is no sharp distinction made between food crops, spices and medicinal plants.

Even though some progress has been made with regard to nutritional quality evaluation in breeding programs, particularly those following the biofortification approach, the final link to assessing the impact on the nutritional and health status of human beings is commonly missing in most other breeding programs.

### Effects of plant breeding on the environment and human health

Plant breeding is an inherent part of the agri-food system, which forms a link to the environment with its natural resources on the one hand, and human nutrition and health on the other. Hammond and Dubé (2012) draw attention to the feedback loops that exist between these systems. In a nutrition-sensitive approach, the influence of technology innovations in agriculture on both the environment and human health should be considered. There are several ways in which plant breeding can exert an influence here, but these are in general weakly documented.

Certain breeding procedures or treatments applied in the course of a breeding process could affect human health negatively, if food made of these varieties is consumed. Concerns have been voiced particularly for genetically modified crop varieties, i.e. regarding allergenic properties (Pusztai and Bardocz 2009). Moreover, agricultural practices that may be associated with the cultivation of some varieties can affect both the environment and human health. For example, routine applications of herbicides (i.e. glyphosate) year after year have been claimed to result in residues in food items or accumulation in soil or drinking water in the longer term (Pusztai and Bardocz 2009).

Many farming practices, such as crop rotation and mixed cropping, can reduce production risks, improve or maintain soil fertility and reduce the incidence of pests, weeds and diseases. Plant breeders could actively support such practices by developing varieties that are adapted to such farming practices and are tolerant of biotic and abiotic stresses, which has indeed become a clear priority for many breeding programs. However, there is a risk that different breeding objectives (nutritional quality, processing quality, adaptation to specific stresses, such as drought, heat, flooding etc.) are treated separately, rather than in an integrated manner. The importance of understanding adaptation mechanisms to multiple stresses and the importance of agrobiodiversity in this context have been highlighted by Haussmann et al. (2012).

## How could plant breeding programs align with NSA?

### Examples of promising and/or successfully implemented approaches

In this section, we will present examples of projects that address several impact pathways and scales and include very different rationales on the links between agriculture and nutrition. The selection was based on the following considerations:

- The projects should have a stated objective of impact on nutrition, and should implicitly or explicitly address an impact pathway, as to how to reach this goal.
- Examples of both, technology-oriented and actor- or system-oriented approaches should be included, in order to point out the differences, strengths and weaknesses, i.e. with regard to the process-related quality criteria included in the overall NSA framework.

The three approaches are (1) a technology-based approach followed by HarvestPlus, (2) a community-based approach followed by the NGOs SEARICE and LI-BIRD, and (3) an integrated approach that combines elements of the aforementioned, followed by AMEDD and partners in Mali.

### Improving the micronutrient content of staple crops on a global scale

HarvestPlus, launched in 2004, is a large international research initiative that works on a global scale to reduce micronutrient deficiencies, mainly by using a biofortification approach. The second phase of research (2009–2013) was funded with 75 million US-Dollars, of which 45 million was contributed by the Bill and Melinda Gates Foundation; further funding was provided by the World Bank and USAID, among others.

HarvestPlus focuses on six staple crops (rice, wheat, maize, cassava, sweet potato, and common beans) that are consumed by the majority of the rural poor, and on three critical micronutrients that are recognized by the World Health Organization (WHO) as most limiting in diets: iron, zinc, and Vitamin A.

HarvestPlus envisages that in 15 years, millions of people suffering from micronutrient malnutrition will be eating the newly developed biofortified crop varieties.[8] As it does not seem to be realistic to grow one and the same variety of a crop worldwide, the solution is seen in backcrossing the newly bred HarvestPlus varieties with locally adapted or existing commercial varieties in the target regions. HarvestPlus thus relies on the breeding expertise of the CG centers and their partners in the national agriculture research programs (NARS), and allies with NGOs, government programs and the private sector to reach the target population groups. In order to avoid controversies as experienced with the 'Golden Rice' project,[9] the HarvestPlus Initiative bases its efforts on conventional breeding methods.

Whereas the nutritional impact of such breeding programs was limited initially, there has recently been progress in this regard, due to a more integrated approach taking into account the whole pathway from farming to nutrition. HarvestPlus projects divide the research area into breeding and delivery, the latter including the entire food chain, from farming to nutrition.

HarvestPlus projects thus follow a straightforward 'top-down' approach, in which nutritionists work with plant breeders to establish breeding targets for micronutrients. These targets are based on the food intakes of malnourished population groups.

---

[8] www.harvestplus.org →"Our vision" (accessed December 8, 2012)

[9] See for example https://www.foodwatch.nl/foodwatch/content/english/golden_rice/index_ger.html (accessed July 18, 2013)

Nutrient losses during storage and processing, as well as the bioavailability of nutrients, are being taken into account, and improved practices are being developed. The delivery chain further involves economic targeting and impact assessments, and professional communication and behavior change methodologies, including partnerships with many institutions and organizations to promote the biofortified crops (HarvestPlus 2011).

The most prominent outcome so far is orange-fleshed sweet potato containing higher levels of *ß*-carotene, compared to the white-fleshed varieties that are commonly grown in many African countries. The orange-fleshed sweet potatoes were introduced in Mozambique and Uganda in 2007, and 24,000 households were reached within the first 3 years of dissemination. There are no data available on the area cultivated per household. The adoption rate among the farmers targeted by the project was high, with 77 % of farmers continuing to grow OFSP in Mozambique and 65 % in Uganda. Children and women of the participating households consumed OFSP, and Vitamin A deficiencies were reduced with higher intake. For example, OFSP accounted for 78 % of the Vitamin A intake of children aged below 3 years in participating households in Mozambique, and 53 % in Uganda (HarvestPlus 2012). However, these data refer to the post-harvest period, when the sweet potatoes were present in the households. The amount harvested was still limited, so that the reported levels of intake could only be provided for 2–3 months in Mozambique and 5–6 months in Uganda in the participating households. Thus, scaling up the area cultivated with orange-fleshed sweet potatoes, as well as the overall outreach of the project will still be required in order to achieve a sustainable impact on nutrition (HarvestPlus 2012).

The OFSP could be a really promising option within a broader strategy to improve nutrition among the targeted population groups and particularly as it is a popular food also for child nutrition. However, the communication effort and amount of funds involved should not lead us to overestimate the real impact achieved so far, and that still other nutrition problems may exist that cannot be addressed in this way.

We can thus summarize that HarvestPlus stands for a technology-focused approach on hunger and malnutrition, with the underlying rationale that new crop varieties will substantially contribute to solving the problem. The projects are research-oriented and designed according to scientific understanding and standards. They clearly target vulnerable groups suffering from key micro-nutrient deficiencies and particularly mothers and young children. The impact is expected to be achieved by developing staple food crops with high contents of essential micro-nutrients, such as sweet potatoes with high *ß*-carotene content, thereby alleviating existing malnutrition for this micronutrient within the target group. The projects are thus focused on availability, access and utilization, primarily for rural population groups (i.e. farmers). They further involve high investments in awareness raising, behavior change and advocacy.

The impact pathway described on the HarvestPlus website[10] foresees the (passive) participation of farmers or consumers only shortly before release ("*study farmer adoption and consumer acceptance*"), so that the members of rural households do not seem to be actively involved in the process of technology development.

## Empowerment of small-scale farmers and rural communities: community agrobiodiversity management for improved food and nutrition security

SEARICE[11] is an NGO working in six countries of South-East Asia, the Philippines, Bhutan, Laos, Cambodia, Vietnam and Thailand. The organization works in the fields of advocacy, public awareness and policy development with the overall goal of improving rural livelihoods via empowerment of farmers. It is thus more a social movement than a classical research organization, though action research is part of the methodologies used. There is a strong focus on biodiversity, farmers' rights and community development, and within this context, SEARICE has joined the Community Biodiversity Development and Conservation Programme (CBDC), a coordinated NGO-driven initiative in 11 countries of Africa, Asia and Latin America. Starting from 1994, SEARICE has coordinated various PPB projects in the region as part of the CBDC Programme, the second phase of which ended in 2005 (CBDC 2006).

The approach taken on food and nutrition security is sharply contrasting to the aforementioned example, as any technology options proposed by external experts to achieve more food security are quite radically rejected: "*We all must bear in mind, that the hunger problem facing the world, is not brought about by the non-adoption of new technologies such as transgenic crops, but because there is insistence of increasing corporate profits, instead of empowering small farming families.*"[12]

Instead, people's empowerment for taking their own decisions is focused on farmers' own agrobiodiversity management as a key aspect, including breeding and seed diffusion activities. A practical example of community agrobiodiversity management following a similar rationale is pursued by the 'Community Biodiversity Management Programme'[13]

---

[10] http://www.harvestplus.org/content/harvestplus-impact-pathway (accessed December 8, 2012)

[11] South- East Asia Regional Initiatives for Community Empowerment, www.searice.org (accessed December 9, 2012)

[12] http://searice.org.ph/2012/10/18/empowerment-of-small-farming-families-is-a-basic-criterion-to-achieve-food-security (accessed December 9, 2012)

[13] www.cbmsouthasia.net (accessed December 9, 2012)

(CBM) in South Asia, coordinated by LI-BIRD (an NGO based in Nepal). The CBM approach is being implemented in 29 sites across four countries, with technical and organizational support from four partner organizations: LI-BIRD in Nepal, Anthra and Green Foundation in India, Green Movement in Sri Lanka and UBINIG in Bangladesh. Here, strengthening community capacities and local institutions relating to agrobiodiversity management are the main concerns. Consequently, communities develop their own priorities relating to agrobiodiversity, crop improvement and seed diffusion, generate funds and monitor and evaluate the outcomes of their activities. These activities include seed exchange, home gardens, PPB, value addition (post-harvest processing, e.g. juice production of a semi-wild plant with high Vitamin C content) and diversity fairs or blocks (Development Fund 2012).

Perhaps due to their focus on community activities, both projects lack accessible documentation of number and characteristics of varieties developed, and the nutritional outcomes, even though food security and livelihood improvement are major concerns. The approach is based on the conviction that smallholder farmers need diverse food and farming systems in order to produce sufficient and nutritious food on small landholdings, and to improve the resilience of food production against external drivers that may negatively affect those (Chaudhary and Sthapit 2013). As there will never be ‘enough’ plant breeders or formal breeding programs to take care of the diversity of food crops and varieties that rural communities need for achieving food and nutrition security, other forms of institutionalization are needed to take on the responsibility for agrobiodiversity management, breeding activities and seed diffusion, in which farming communities and individual farmers can take an active role – as they have been doing in the past. Following this argument, creating and strengthening these types of institutions that are complementary to formal breeding programs could be an effective way of addressing food and nutrition security in the longer term.

We can summarize that the projects focus on strengthening farming communities and their local institutions in order to address the problem of food and nutrition insecurity. Smallholder farmers are defined as a target group affected by food and nutrition insecurity, without further differentiating within this group. The measures taken to achieve these goals are based on community agrobiodiversity management and local crop improvement, with relatively little external support. The CBM Programme focuses particularly on creating and strengthening local institutions in the longer term. The implicit impact pathway for improving the nutritional status is by increasing the availability and access to food with higher nutritional value and as a result improving the level of dietary diversity and the resilience of local food systems. The projects are action-oriented rather than research-oriented and thus lack scientific documentation of impact; for example, there is no direct measuring of income effects or changes in the nutritional status of individuals. However, benefits to individuals and communities have been assessed by other (participatory) evaluation methods within the communities in one of the projects described (Development Fund 2012).

### Improving food and nutrition security of mothers and their children in Mali[14]

The Malian NGO AMEDD (Malian association of awakening on sustainable development) has recently started an action-research project, which targets women of reproductive age and malnourished children. In many parts of Africa, women work on their husbands’ fields and also farm plots on their own. Usually, different crops or varieties are grown in these different fields, and the growing conditions may also differ considerably. In Mali, for example, some women grow sorghum on small extra plots for the purpose of providing extra meals for their young children. Supporting this activity by targeting the specific nutritional needs and the production conditions in a breeding program could enhance access to quality food for children less than 5 years of age and their mothers – both of whom belong to the most vulnerable groups for food deficiencies in Mali.

The project is part of the research initiative AFRICA-RISING,[15] funded by USAID in relation to the ‘FEED the Future’ program of the US-Government. The project activities are developed in partnership with various international research centers, including IITA, ILRI, WVC, IFPRI and ICRISAT, each of which take responsibility for sub-projects, such as livestock integration, variety development or impact assessments. The research partnership further includes NGOs; besides AMEDD, the medical aid organization, Médécins sans Frontières (MSF) in particular.

The main target is to move those children, who were malnourished at the beginning of the project activities, out of this status, besides improving the knowledge and practical options available to women, men and community leaders. The nutritional impact will be measured on three groups: (a) children 0–5 years of age, (b) pregnant and (c) breast feeding women. As the project activities were started only recently (2012), the nutritional impacts are not yet documented.

Measures include teaching and practical community action on food utilization and dietary needs, including developing cooking recipes based on ingredients that can be accessed by the target group; another focus is on increasing the availability of nutritionally valuable food, such as vegetables, goat’s milk and meat, and increasing the nutritional value of staple food, such as sorghum. The project activities focusing on breeding include participatory variety evaluation, i.e. of sorghum

---

[14] www.ameddmali.org

[15] www.africa-rising.net, accessed December 4, 2012

varieties. A further field of action is awareness building among men and community leaders, including the issue of access to land for women (Sogoba et al. 2012). The project thus includes a clear gender perspective by addressing both women and men and exploring their respective options for action in view of the targeted outcomes.

We summarize that the project focuses on improving the nutritional status of clearly defined vulnerable groups, including an assessment of the nutritional outcomes on individuals. It addresses a defined impact pathway, including various aspects of food and nutrition security (increasing the availability and improving access to nutritionally valuable food, whilst also improving its utilization, i.e. by improving the target group's knowledge on dietary needs and food preparation). It explores various options for improvements in an integrated approach (improved sorghum varieties, improved access to animal products and vegetables for dietary diversification), thus overcoming the 'biofortification versus food diversification' debate.

It further addresses other related factors that may be beyond the target group's influence by taking on a gender perspective; the project addresses men and community leaders in order to raising awareness on nutritional problems, particularly in relation to women's access to land, and through this contribute to addressing actual root causes for gender inequality. It is based on action-research and community action, and builds on active participation of the target group as well as other community members.

## Challenges for breeding programs to align with NSA

The three aforementioned examples show how nutrition-sensitive breeding is approached very differently, based on underlying rationales on the causes of malnutrition. The HarvestPlus approach bases its interventions on the concept that new varieties are the key to overcome malnutrition, whereas the community-empowerment approach sees the main need for action in institutional and social development at the local level. The example of AMEDD shows a multidimensional approach, that addresses simultaneously various aspects of food and nutrition security, including gender inequality, i.e. lack of access to land (food), improved varieties and enhanced nutrition knowledge.

All three approaches show, however, an important shift, as they are targeted towards people and their (nutritional) needs. In the past, a successful outcome of a breeding program was a released variety, which means a variety that had been successfully tested in officially coordinated trials, mainly for yield performance across a range of test environments and in some cases for other agronomic traits, e.g. resistance to important fungal diseases. Developing varieties was seen as a more or less user-neutral technology, from which all farmers would benefit, though on different productivity levels. Thus, in most cases, little consideration has been given to targeting specific user groups and their nutritional needs, or aligning breeding activities with overarching policy and development goals, such as gender and equity considerations.

Badstue et al. (2012) have drawn attention to the fact that most formal breeding programs continue to be based on an implicit and largely unreflected concept of technology diffusion, which regards farmers as more or less passive 'adopters' of these technologies. However, contemporary research into technology diffusion regards individuals as social actors whose strategies and interactions contribute to shaping the outcome (see for example Long 2001). Badstue et al. (2012), therefore, state that participatory crop improvement must be re-conceptualized in order to make the outcomes of scientific plant breeding and knowledge production more effective, accessible and relevant to those smallholders who hitherto have been unable to benefit fully from the advances in formal crop improvement. Whereas the HarvestPlus approach is based on the 'transfer-of-technology' paradigm and involves users only in the final stage in a mere passive role ('adoption'), the other examples focus on active participation of the target groups in the innovation process (AMEDD), or even aim at institutionalizing this process within the local communities in the longer run (SEARICE, CBM).

Even though it is well-known that plant breeding and the persisting models of agricultural intensification and rural development have been the main driving factors for agrobiodiversity loss, there is little evidence so far of a new emerging concept really aiming at harmonizing breeding and agrobiodiversity conservation on a large scale. This is largely due to a lack of overall policy concepts that align agriculture and nutrition more strongly with relevant international agreements relating to agrobiodiversity, conservation and use. The International Seed Treaty (ITPRGFA) refers explicitly to farmer participation in Article 6, and indeed with the aim of developing varieties that are adapted to their social, economic and ecological circumstances. Article 9 refers to farmers' rights: the protection of traditional knowledge, the right to be involved in decision-making pertaining to the use of genetic diversity, and the right to share in any benefits arising from the use of the genetic resources. In relation to these issues, we find strong differences between the three examples given; the NGO-promoted approaches of community agrobiodiversity management clearly have strengths here, as they aim at creating innovative community-led institutions to manage and develop agrobiodiversity in a sustainable manner, whereas HarvestPlus focuses on a few varieties of staple food crops and aims at a wide diffusion of these. AMEDD, on the other hand, emphasizes the nutritional needs of vulnerable groups, with agrobiodiversity conservation not being addressed as such. It further includes a true gender perspective in the way that it addresses its activities to both women and men, focusing on their respective possibilities to improve the situation of vulnerable groups.

## Conclusions

We conclude that the potential for improving crops and varieties in line with the concept of NSA are far from being tapped; very often it is not the breeding technology itself but an improved understanding of the surrounding factors, which result in remarkable selection gains achieved within a few years. In order to produce relevant results, modern plant breeding technologies need a thorough assessment of the context in which and for which improvements are to be developed. Thus, the predominant focus on plants (or varieties) which is inherent in most breeding programs needs to be complemented by a focus on the people and their needs. The promises of 'high-tech' breeding methodologies to deliver solutions for food and nutrition insecurity should be reflected on against this background.

Plant breeding for NSA requires innovative forms of institutional cooperation. A productive and critical dialogue is required between plant breeders, agriculturalists, economists, nutrition specialists, societal change and agrobiodiversity activists on the one hand, and farmers, consumers and other stakeholders involved in food value chains on the other. Plant breeding institutions often focus on improvement of single crops. However, this high degree of specialization is needed for technical breeding operations only; in order to better target and serve NSA, the focus should be broadened and institutions be complemented by other professionals covering topics relating to food and nutrition security, and also including social and economic aspects of agricultural and food systems.

Within and between research institutions, technology-oriented research approaches often stand in opposition to the more actor or system-oriented approaches. A lot of progress could be achieved if this divide was increasingly overcome: Neither does any technology alone alleviate poverty and eradicate hunger and malnutrition, nor is it a disadvantage to more system-oriented approaches to include innovative technological options where appropriate. Therefore, in order to achieve systematic progress towards a more nutrition-sensitive agricultural system, any technological interventions should take into account and that these technologies have societal impacts that need to be carefully assessed and balanced early in the process. The guidelines and incentives provided by donors and funding agencies will be of great importance to overcome this gap in the future, and to promote more integrated approaches.

At present, seed legislation, as well as variety registration and release regulations, are strongly shaped by the interests of large commercial players. The policies relating to variety registration, release and seed diffusion should, therefore, be revised in order to remove obstacles that presently impede a broader implementation of decentralized breeding and seed diffusion of nutrition-relevant crops and varieties. Seed production and distribution needs to become much better linked to breeding programs, and should be included in the design of the breeding strategy and specific output planning; access to seed of newly developed varieties needs to be secured for vulnerable groups.

In order to align plant breeding with NSA, any efforts to further harmonize agricultural, nutrition, health, environmental, and educational policies, also with international policy frameworks and obligations, could help to create an enabling policy environment. Policies relating to agriculture, agrobiodiversity conservation, nutrition and health should be increasingly integrated and active steps should be taken to fully implement existing policy agreements at all levels; for plant breeding, this concerns specifically the CBD, ITPGRFA, and the Cartagena Protocol on Biosafety. The focus on gender which is an inherent part of these agreements (e.g. the CBD and the related Global Plan for Action) should be specifically addressed. Furthermore, the human right to adequate food should be given serious consideration in this context, and any policies affecting nutrition should routinely be subjected to human rights assessments prior to, as well as after, their implementation.

In general, it should be broadly acknowledged that the legitimate commercial interests of private breeding and seed companies do not fully converge with public or societal interests in the fields of agriculture and nutrition and that they thus need to be complemented by other initiatives. Their role should be regarded as an important complementary element within the agri-food system, and they should be publicly funded for their contributions to developing nutrition-sensitive approaches to breeding and seed systems. Conservation, use and further development of agrobiodiversity as a basis for food and nutrition security worldwide are issues that should increasingly come into the responsibility of society as a whole. It is not an issue to be left to a few specialists and private companies. Therefore, broadly implemented and coordinated public awareness schemes should stimulate and support local or regional initiatives that are active in this field. Capacity building should target the links between agriculture, agrobiodiversity and food and nutrition security, and also include collective learning and action approaches involving stakeholders operating at all levels.

**Acknowledgments** Funding provided by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, for a comprehensive study on NSA, coordinated by the Food Security Center, University of Hohenheim, is gratefully acknowledged. We further thank for funding received for previous work on plant breeding and food security from the *fiat panis* Foundation, Ulm/Germany, and the EU Food Facility for WCA coordinated by IFAD, via the PROMISO 2 project, and the INSTAPA project via the EU 7th Framework program, the AnbeJigi project funded by the McKnight Foundation, and the HOPE project funded by the Bill and Melinda Gates Foundation.

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

Abay, F., & Bjørnstad, A. (2009). Specific adaptation of barley varieties in different locations in Ethiopia. *Euphytica, 167*(2), 181–195.

Almekinders, C., & Hardon, J. (2006). *Bringing farmers back into breeding. Experiences with participatory plant breeding and challenges for institutionalization. Agromisa Special No. 5*. Wageningen: Agromisa Foundation.

Annicchiarico, P., Royo, C., Bellah, F., & Moragues, M. (2009). Relationships among adaptation patterns, morphophysiological traits and molecular markers in durum wheat. *Plant Breeding, 128*, 164–171.

Bachmann, L., Cruzada, E., & Wright, S. (2009). *Food security and farmer empowerment. A study of the impacts of farmer-led sustainable agriculture in the Philippines*. Los Baños: MASIPAG.

Badstue, L. B., Hellin, J., & Berthaud, J. (2012). Re-orienting participatory plant breeding for wider impact. *African Journal of Agricultural Research, 7*(4), 523–533.

Beuchelt, T., & Badstue, L. (2013). Gender, nutrition- and climate-smart food production: opportunities and trade-offs. doi: 10.1007/s12571-013-0290-8.

CBDC. (2006). *Pathways to participatory farmer plant breeding: Stories and reflections of the community biodiversity development and conservation programme*. Manila: SEARICE.

Ceccarelli, S., Grando, S., Tutwiler, J., Baha, J., Martini, A. M., Salahieh, H., et al. (2000). A methodological study on participatory breeding. 1. Selectionphase. *Euphytica, 111*, 91–104.

CFS (2012). Coming to Terms with Terminology. Food Security, Nutrition Security, Food Security and Nutrition, Food and Nutrition Security. Revised draft, July 25, 2012. Rome: Committee on World Food Security (FAO).

Chaudhary, P., & Sthapit, B. (2013). Agricultural biodiversity conservation and food security for small-scale farmers. In A. Christinck & M. Padmanabhan (Eds.), *Cultivating Diversity. A handbook on transdisciplinary approaches to agrobiodiversity research*. Weikersheim: Margraf Publishers.

Christinck, A., vom Brocke, K., & Weltzien, E. (2000). What is a variety? Investigating farmers‘concepts as a base for participatory plant breeding in Rajasthan, India. In: *International Agricultural Research: A contribution to crisis prevention.* Proceedings of Deutscher Tropentag, 11–12 October 2000, University of Hohenheim, Stuttgart.

Classen, L., Humphries, S., Fitzsimons, J., Kaaria, S., Jímenez, J., Siera, F., et al. (2008). Opening participatory spaces for the most marginal: learning from collective action in the Honduran Hillsides. *World Development, 36*(11), 2402–2420.

Conroy, C., Witcombe, J. R., Virk, D. S., Basu, M., Buchy, M., & Dey, A. (2009). *New upland rice varieties for India. Rainfed Agriculture Impact Study No. 1*. London: DFID.

Davis, D. R. (2009). Declining fruit and vegetable nutrient composition: what is the evidence? *HortScience, 44*(1), 15–19.

Dawson, J. C., Murphy, K. M., & Jones, S. S. (2008). Decentralized selection and participatory approaches in plant breeding for low-input systems. *Euphytica, 160*, 143–154.

Development Fund. (2012). *Community-based biodiversity management – South Asia Programme (CBM-SA). Evaluation report*. Oslo: The Development Fund.

Gari, J. A. (2004). *Plant diversity, sustainable rural livelihoods and the HIV/Aids crisis*. Rome: FAO, & Bangkok: UNDP.

Gilding, E. K., Frere, C. H., Cruikshank, A., Rada, A. K., Prentis, P. J., Mudge, A. M., et al. (2013). Alleleic variation at a single gene increases food value in a drought-tolerant staple cereal. *Nature Communications, 4*, 1483. doi:10.1038/ncomms2450.

Grüneberg, W. J., Mwanga, R., Andrade, M., & Espinoza, J. (2009). Breeding clonally propagated crops. In S. Ceccarelli et al. (Eds.), *Plant breeding and farmer participation* (pp. 275–322). Rome: FAO.

GTZ. (2006). *Agrobiodiversity: The key to food security. GTZ Issue Paper series People, Food and Biodiversity*. Eschborn: GTZ.

Hama, F., Icard-Verniere, C., Guyot, J. P., Picq, C., Diawara, B., & Mouquet-Rivier, C. (2011). Changes in micro- and macronutrient composition of pearl millet and white sorghum during field versus laboratory decortication. *Journal of Cereal Science, 54*, 425–433.

Hammond, R. A., & Dubé, L. (2012). A systems science perspective and transdisciplinary models for food and nutrition security. *Proceedings of the National Academy of Science of the United States of America, 109*(31), 12356–12363.

HarvestPlus. (2011). *From research to delivery*. Washington DC: HarvestPlus.

HarvestPlus. (2012). *Disseminating orange-fleshed sweet potato: findings from a HarvestPlus project in Mozambique and Uganda*. Washington DC: HarvestPlus.

Haussmann, B. I. G., Rattunde, H. F., Weltzien-Rattunde, E., Traoré, P. S. C., vom Brocke, K., & Parzies, H. (2012). Breeding strategies for adaptation of pearl millet and sorghum to climate variability and change in West Africa. *Journal of Agronomy and Crop Science, 198*(5), 327–339.

Hawkes, C., Turner, R., & Waage, J. (2012). *Current and planned research on agriculture for improved nutrition: A mapping and gap analysis. Report for DFID, 21st August 2012*. London: DFID.

Hotz, C., Loechl, C., Lubowa, A., Tumwine, J.K., Ndeezi, G., Masawi, A.N. et al. (2012). Introduction of β-Carotene-Rich Orange Sweet Potato in Rural Uganda Results in Increased Vitamin A Intakes among Children and Women and Improved Vitamin A Status among Children. *The Journal of Nutrition:* 111.151829.

ICRISAT. (2012). *Research Highlights ICRISAT West and Central Africa: Biofortification of staple crops. Increased nutrients from women's farms for improved child nutrition*. Bamako: ICRISAT.

Jaenicke, H., & Virchow, D. (2013). Entry points into a nutrition-sensitive agriculture. doi: 10.1007/s12571-013-0293-5.

Kriesemer, S. (2013). Nutrition-sensitive agriculture: the conceptual framework underlying a new approach. In: D. Virchow, (Ed.) Nutrition-sensitive agriculture: a pillar of improved nutrition and better health. Food Security Center, Stuttgart, Germany.

Leena Kumary, S. (2007). Conservation to commercialization: Sustaining Kerala's rural livelihoods through utilization of the medicinal rice diversity. In V. Arunachalam (Ed.), *Participatory plant breeding and knowledge management for strengthening rural livelihoods* (pp. 48–55). Chennai: MSSRF.

Long, N. (2001). *Development sociology: Actor perspectives*. London: Routledge.

Meenakshi, J. V., Johnson, N., Manyong, V. M., De Groote, H., Javelosa, J., Yanggen, D., et al. (2007). *How cost-effective is biofortification in combating micronutrient malnutrition? An ex-ante assessment. HarvestPlus Working Paper No. 2*. Washington DC: IFPRI.

MSSRF. (2005). *UN millenium development goals – five years later. Agricultural biodiversity and the elimination of hunger and poverty. The Chennai platform for action*. Chennai: MSSRF.

Murphy, K., Reeves, P. R., & Jones, S. S. (2008). Relationship between yield and mineral nutrient concentration in historical and modern spring wheat cultivars. *Euphytica, 163*, 381–390.

Mwanga, R.O.M., Niringiye, C., Alajo, A., Mpembe, I., Kigozi, B., Kapinga, R. et al. (2009). Participatory Breeding Experience and Implications for Sweetpotato Breeding in Uganda. In: *Proceedings of the 15th ISTRC Symposium, November 2–6, 2009 in Lima, Peru* (pp. 29–34). Lima: CIP.

Omujal, F., Nnambwayo, J., Agwaya, M. S., Tumusiime, R. H., Engeu, P. O., Katuura, E., et al. (2010). Bioactive non-nutrient components in indigenous African vegetables. In B. Burlingame & S. Dernini (Eds.), *Sustainable diets and biodiversity. Directions and solutions for policy, research and action* (pp. 206–213). Rome: FAO.

Pusztai, A. & Bardocz, S. (2009). *Sicherheitsrisiko Gentechnik.* Stuttgart: Gentechnikfreies Europa e.V.

Rohrbach, D. & Kiala, D. (2007). Development options for local seed systems in Mozambique. SAT e-Journal 3(1), ICRISAT. http://ejournal.icrisat.org/mpii/v3i1/impi2.pdf. Accessed 7 June, 2013.

Siart, S. (2008). *Strengthening local seed systems: Options for enhancing diffusion of varietal diversity of sorghum in Southern Mali. Kommunikation und Beratung Series (85)*. Weikersheim: Margraf Publishers.

Sogoba, B., Lugutuah, V., Coulibali, P., Seydou Kone, F., Diarra, H., Tangara, A., et al. (2012). *Evaluation and planning report for the project: "Intensification durable de l'agriculture pour l'amélioration de la sécurité alimentaire et nutritionnelle dans le cercle Koutiala, Mali"*. Ibadan: IITA.

Sperling, L., & Christinck, A. (2005). Developing strategies for seed production and distribution. In A. Christinck et al. (Eds.), *Setting breeding objectives and developing seed systems with farmers* (pp. 153–176). Weikersheim: Margraf Publishers and Wageningen: CTA.

Sperling, L. & Cooper, D. (2003). Understanding seed systems and strengthening seed security: a background paper. In: *Effective and Sustainable Seed Relief: A Stakeholder Workshop, 26–28 May 2003*. Rome: FAO. http://www.fao.org/docrep/007/y5703e/y5703e06.htm#bm06.1. Accessed 7 June 2013.

Sperling, L., Loevinsohn, M., & Ntavombura, B. (1993). Rethinking the farmers' role in plant breeding: local bean experts and on-station selection in Rwanda. *Experimental Agriculture, 29*, 509–519.

Tumwegamire, S. (2011). *Genetic variation, diversity and genotype by environment interactions of nutritional quality traits in East African sweetpotato*. Thesis. Department of Agricultural Production. Kampala: Makerere University. http://sweetpotatoknowledge.org/germplasm/breeding/Genetic%20varition%20and%20diversity%20-%20Thesis.PDF . Accessed 7 June 2013.

UNO. (2009). *Seed policies and the right to food: Enhancing agrobiodiversity and encouraging innovation. Report of the Special Rapporteur on the Right to Food to the General Assembly of the United Nations, July 23, 2009*. New York: UNO.

Van Oosterom, E. J., Bidinger, F. R., & Weltzien, E. R. (2003). A yield architecture framework to explain adaptation of pearl millet to environmental stress. *Field Crops Research, 80*, 33–56.

vom Brocke, K., Christinck, A., Weltzien, R. E., Presterl, T., & Geiger, H. H. (2003). Effects of farmers'seed management on performance and adaptation of pearl millet in Rajasthan, India. *Euphytica, 130*, 267–280.

Welch, R. M. (2002). The impact of mineral nutrients in food crops on global human health. *Plant and Soil, 247*, 83–90.

Welch, R. M., & Graham, R. D. (2002). Breeding crops for enhanced micronutrient content. *Plant and Soil, 245*, 205–214.

Weltzien, E., & Christinck, A. (2005). Identifying farmers'preferences and needs for varieties and specific traits. In A. Christinck et al. (Eds.), *Setting breeding objectives and developing seed systems with farmers* (pp. 83–104). Weikersheim: Margraf Publishers and Wageningen: CTA.

Will, M. (2008). *Promoting value chains of neglected and underutilized species for pro-poor growth and biodiversity conservation. Guidelines and good practices*. Rome: GFU.

Witcombe, J. R., Joshi, K. D., Virk, D. S., & Sthapit, B. R. (2011). Impact of introduction of modern varieties on crop diversity. In J. M. Lenné & D. Wood (Eds.), *Agrobiodiversity management for food security* (pp. 87–98). Wallingford: CAB International.

Yadav, O. P., & Weltzien, E. R. (2000). Differential response of landrace-based populations and high-yielding varieties of pearl millet in contrasting environments. *Annals of Arid Zone, 39*, 19–45.

**Anja Christinck (PhD)** is an Agricultural Social Scientist with specialization in Communication and Extension. She has worked as an independent consultant, trainer and researcher for about 15 years. The main focus of her work is on methodologies for dialogue and joint learning of scientists and non-academic stakeholders in research projects on plant breeding, seed systems and agrobiodiversity , and more generally food and nutrition security and sustainable rural development.

**Eva Weltzien (PhD)** has worked on the improvement of dryland cereals in tropical and subtropical regions over the past 32 years, focussing on the effective use of Sorghum, Pearl Millet and Barley genetic resources for variety development and seed systems that best meet farmers' needs, in Syria, North West India and Mali. Appropriately targeting plant breeding research to priority production systems by building multi-disciplinary and multi-institutional teams to create new technologies for farmers has been a focus for her. Her projects have involved research and development organizations, farmers and other end-users in a range of roles.