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Chapter 2

The Bean – Naturally Bridging Agriculture and Human Wellbeing

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Additional information is available at the end of the chapter

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1. Introduction

Human existence requires a steady supply of food containing a multitude of vitamins, minerals, trace elements, amino acids, essential fatty acids and obviously starch. Advances in crop production have mostly occurred in cereals like rice, wheat and maize, whereas grain legumes like bean and lentils only have experienced a quarter of these advances [1]. The shift have had consequences on the human wellbeing [2] as cereals after polishing or dehusking only contain small amounts of protein and micronutrients.

The plant family *Leguminosae* is particular interesting as it is protein rich and possesses the capability to fix atmospheric N_2, which makes it independent off fuel-driven supplies of nitrogen fertilizers. Common bean (*Phaseolus vulgaris* L.) is without comparison eaten more than any other grain legume [3]. Because of its importance it is often considered the 'poor man's meat' although this comparison may not give full justice to the bean. Beans are rich in the amino acids lysine and methionine, making beans complementary to cereals. In addition, they are rich in dietary fibre and low in oil content. Beans are genetically very diverse, adapted to local conditions and dietary preferences. An evaluation of the various collections by in particular CIAT and USDA Plant Germ System for useful traits has started but sophisticated plant breeding of the bean is sparse [e.g. 4, 5].

Beans are consumed as mature grain and immature seeds as well as green pods and leaves taken as vegetables [6]. As early as 1958, the UN organisation FAO organised a conference where the production and consumption of bean were discussed. In this context, [7] noted that data on production and consumption on grain legumes generally were incomplete. It seems plausible that this condition prevails till today given that a large proportion of the

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bean crops are produced for home consumption in backyards and small gardens and frequently it is also intercropped with maize by smallholders as a secondary crop. Consequently, reliable statistics may be difficult to obtain regarding production.

Bridging agriculture and human wellbeing is the answer to major challenges like world hunger, diminishing natural resources, and climate changes. The bridging can be done in two ways, either by enhancing the content of nutrients in the starch-rich stable food or by enhancing the accessibility of nutrient-dense food in the diet. Acknowledging beans importance in the diet of large segments of the world population, we will in this chapter explore possibilities to bridge the production side with the consumption side. This we will do by focussing on enhancing the amounts of important nutrients in our dominant diets.

Enhancing the content of nutrient in the available food can be done via traditional fortification through the processing of diet elements. Or it can be done via the so-called 'biofortification', which aims at improving the genetic basis for making plant foods more nutritious as the plants are.

Improving our access to nutrient dense food elements requires a different look as such food elements already may be part of the traditional diet. Such a look requires that local production and productivity is our vantage point and that peoples' specific preferences and cultures may influence their preferences for cultivating particular cultivars. Such a vantage point requires that people are involved in the process [8] and this chapter will pursue this using the *Phaseolus* bean as a model for one nutrient-dense element of the diet.

2. The bean

Improving the content in the starch-rich food elements like wheat, rice and maize is obviously possibly but the starting point is very low (Table 1). The grain legumes, on the contrary, have a high starting point from where to seek improvements. Beans are superior to cereals in their macro- and micronutrient content as demonstrated in Table 1, in agreement with [9] although trials with other pulses under farmers' conditions have demonstrated that genetic potential are not always expressed under more marginal conditions. Furthermore, the legumes holds a potential for entering the diet in a diversity of ways, ranging from the dry mature seeds, to green seeds and pods as well as leaves used as vegetables, see also [10]. An efficient bridge to human wellbeing can thus be established by enhancing the access to and intake of the beans with their high nutrient density.

The production and the uses of legumes decrease in some regions while it increases in others. Brazil and Argentina have become major producers and exporters of soya bean due to its value in the feed industry, while the production of grain legumes for home consumption decreases steadily in a country like Bangladesh [12]. A historical view since 1970 show however a consistent decline in the average annual consumption of grain legumes per capita from 9 to 7 kg per person [6].

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	Protein (%)	Mg (%)	P (%)	S (%)	K (%)	Ca (%)	B (ppm)	Na (ppm)	Cr (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Mo (ppm)
Bean	25.0	0.171	0.396	0.178	1.450	0.177	11.0	23.0	0.00	18.0	65.0	1.00	3.00	38.0	28.0
Pigeonpea	23.6	0.157	0.370	0.126	1.710	0.110	11.4	10.1	0.14	14.0	29.9	3.69	11.8	23.2	1.22
Maize	8.4	0.122	0.380	0.206	0.430	0.005	-	-	-	7.9	33.2	0.43	2.84	29.0	0.34
Maize dehusked	1.1	0.002	0.024	0.113	0.015	0.011	0	96.3	0.40	0.15	3.58	0.29	0.18	0.9	0.02
Potato flour	0.7	0.005	0.009	0.097	0.121	0.017	0	41.0	0.37	0.5	7.5	0.10	0.09	0.6	0.01
Wheat flour	15.1	0.010	0.030	0.162	0.398	0.030	0	11.6	0.31	14.7	29.6	0.12	3.37	21.7	0.81
Basmati ris	4.2	0.030	0.012	0.162	0.132	0.043	0	9.0	0.36	12.9	5.2	0.25	2.05	23.5	0.55

Table 1. Nutrient content of two grain legumes (Cajanus cajan: pigeonpea and Phaseolus vulgaris L.: bean) and maize (with or without husk) cultivated under farmers' conditions in eastern and southern Africa. Included is also the content of rice, wheat and potato flour sampled from various shops. After [11] and Høgh-Jensen, unpublished data).

In a trial with approx. 100 bean genotypes grown under relatively fertile one-site conditions in Malawi, an unexpected small variation was observed in terms of iron and zinc content of the grain. Mean contents of iron in the bean grains were 67.7 (± a SE of 0.95) and zinc were 33.6 (± a SE of 0.54) ppm (Høgh-Jensen and Chirwa, unpublished data). This demonstrated that genetic diversity may not be fully expressed when conditions are the same. However, seven of the best performing varieties were selected for subsequent trialling under varying local conditions in Malawi and Tanzania in the dry season of 2005 utilizing residual moisture. This trialling expressed on average over 230 plots selected for variation a content of 90 and 37 ppm iron and zinc, respectively (Table 2). The promising varieties consequently performed above expectations and certainly above average - even under fairly harsh conditions and less welcoming soils.

What varied the most was actually the yield between farmers. Consequently, the low hanging fruit is to focus on trialling and selecting the highest yielding varieties and to work with farmers to optimize the cultivation of beans (Table 3). Breeders have had some success by simply selecting for yields under conditions with semi-controlled drought periods [13,14] or across environments [15]. This approach does not disregard the more sophisticated breeding efforts like marker-assisted selection [e.g. 5]. However, the diversity seems yet only partly tapped, which means that local conditions to a large extent can be accommodated in a simpler trialling approach. The effect of this localness is expressed in the yield differences shown in a trialling of 6-8 bean varieties in Tanzania and Malawi, ranging from 100 kg grain per hectare to almost 3 tonnes (Table 3).

Variety per country	Grain yield (kg DM ha^{-1})	Grain weight (g 1000 grains^{-1})	Iron (ppm)	Zinc (ppm)
Malawi				
101	1671	516	88	39
102	1410	444	88	39
103	1131	442	114	46
104	1470	478	88	38
108	1262	419	110	41
109	1749	503	91	39
Napilira	1280	408	104	42
Tanzania				
Jesca	782	324	61	33
Lyamungo85	860	358	81	32
Lyamungo90	1015	393	77	31
Selian94	1010	314	88	36
Selian97	1121	346	82	34
Uyole84	710	259	70	33
Uyole96	746	404	87	40
Wanja	924	385	78	34

Table 2. Mean grain yield, individual grain weight, and iron and zinc content in dry matter for tested varieties in Malawi and Tanzania in the dry season of 2005.

Farmer	Country	Grain yield (kg ha^{-1})	Country	Grain yield (kg ha^{-1})
1	Tanzania	296	Malawi	1129
2		740		1146
3		146		2006
4		634		1508
5		432		1696
6		155		1602
7		189		1600
8		99		1415
9		1924		844
10		1475		1068
11		2829		648
12		704		1518
13		1534		1241
14		1336		876
15		716		1573

Table 3. Average bean grain yield per farmer, who tested 6-8 varieties.

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3. Innovation in a value chain that also accommodate human well-being

Documented trialling efforts have so far been dominated by the researchers and only including the farmers, processers, traders, etc. to a limited extend. This does not mean that actors of change like innovative farmers, NGO, etc., have not had such activities. Our experiences tell us however that many of these data are difficult to get access to as they appear in reports, notebooks, newsletters, and similar documents that are found on shelves and stores. It appears logical that such trialling efforts must be linked to a learning process. The localness must however not hinder that the conclusions from such learning processes to be made available to others. The increasing using of open online repositories of research documents, which often is termed "grey literature", is an important step to share knowledge. The increasing publication rate in open access literature is another that will bring actors of change into the knowledge stream and to our common building of joint research capacity [see e.g. 16].

Since the Second World War, the innovation model in science has been linear, although a new model – less linear – emerged in the 1990s, called the 'Triple-Helix model', based on interactions between policy, science and society [17]. Increasingly, this model is being seen as also having a fourth leg, namely that of business. The fairly sequential linear innovation approach where production >> processing >> retailing may be adequate when talking about industrialized agricultural commodities. However, when quality requirements are less standard, the development of the requested traits at the commodities at various steps along the chain may require quite different orchestrated processes [16].

Such a process have been depicted by [18], drawing on experiences from working with small and market-inexperienced farmers, small processers with limited financial and processing capacity, and more fragmented retailers where market requirements are only partly known. Due to the limited experiences and capacities along the chain, a number of learning loops are included where the various stakeholders interact. These interactions are centred on value chain forums and actions related to each transforming step in the chain. Such value chain forums are found very important to enable the adjustment and enabling of mutual learning. Included in the model are also the feedback loops and the transformation of the intelligence regarding market requirements (Figure 1).

The value chain forums can be regarded as the places that prototyping is taking place. Prototyping is an important step in the innovation process as this is where ideas are being presented, discussed and validated – or maybe even more importantly discharged. Prototyping is a very important mode of action to avoid mistakes that will be very expensive in the longer run, if the solutions are allowed to travel further up the value chain. Clearly such learning processes are a challenge to researchers as management is becoming management of the process and not management of the variables.

Prototypes are designed to answer questions. The prototypes need not to be sophisticated but should best be as simple as possible. Simplicity is important to keep costs down and to enable the question-solution discussion. At a moment where management wisdom insists that speed to market is the key to competitiveness, the maintenance of the learning loop is

important – the cycle should be kept running to produce different ideas. Simplicity and differentiation is the two carrying principles here! But the circle MUST be stimulated by feeding in intelligence from the other actors along the chain, e.g. retailers and sellers, among others, to maintain chain agility. Consequently, innovation is not solely about technology. Innovation in this context is more about means to obtain, consolidate, translate and manage knowledge, means to transform knowledge, and organisational learning. In that sense, innovation becomes a culture of prototyping [see e.g. 20,21]. The possibilities of including dietary requirements in the first learning loop (Figure 1) are good as long as these requirements can be quantified and described and as long as they are causal.

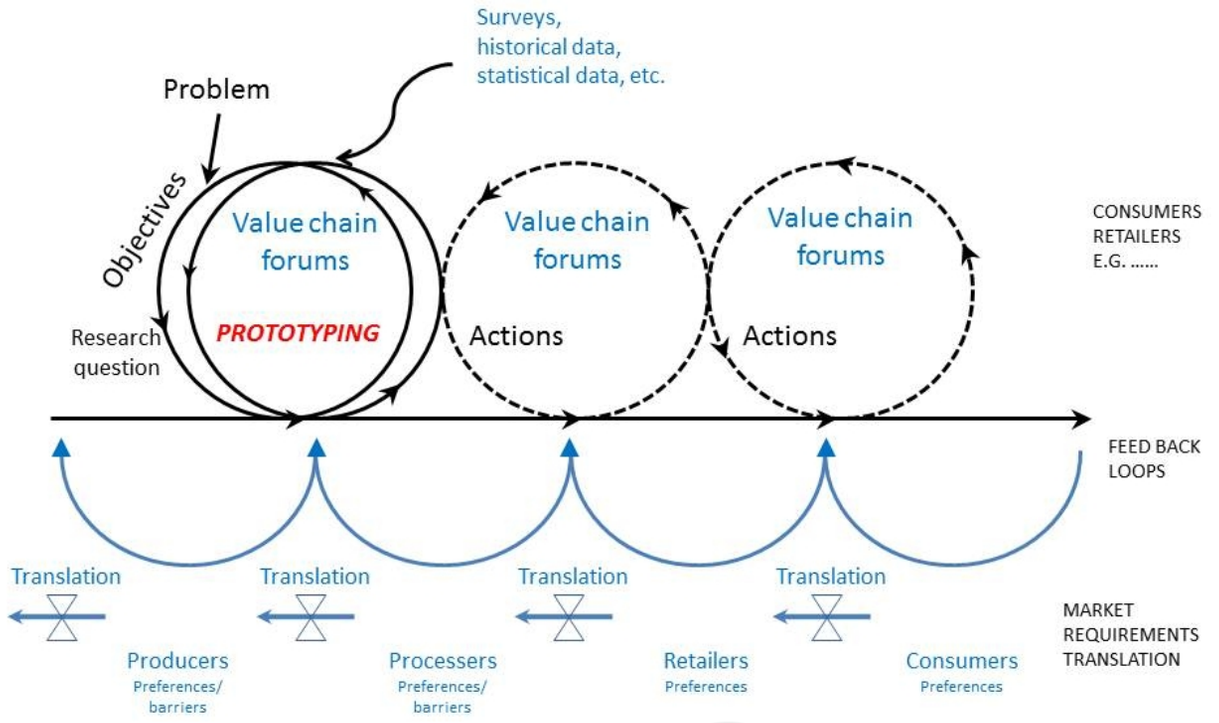


Figure 1. Prototyping in value chains innovation and development [modified after 19].

Nutrient dense diets can be sought in two ways. One is to find variation within one element of the diet that can form the basis for selecting the most promising in order to enhance the content. Or to seek a better production and/or access to the part of the diet that is particularly contributing with the nutrients. The later may be done by enhancing the production potential of bean varieties. It may however also be by promoting the use of the leaves for vegetable stews. [22] documented that the iron contents of the leaves compared to the mature grains could be 5-10 times higher on a dry matter basis. Leafy vegetables are indeed good sources of iron but they are mostly eaten for their vitamin-A and vitamin-C content. On a volume basis, the leafy vegetable and the boiled beans may provide similar amounts of iron. The boiled mature grain may however be a much better source of zinc [22].

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4. Naturally bridging agriculture and human wellbeing

To maintain productivity in agroecosystems, before the era of the fertilizer industry, humans traditionally have included animals in the systems and used their manures as fertilizers to drive the cereal production [23] in combination with grassland legumes to enhance the supply of nitrogen via symbiotic fixation [24]. Depending on locality, up to an average of 4-5 tonnes of manure could be applied per hectare in the UK [23] or as low as 1.5 tonnes per hectare in extensive mid-USA or north Spain [25].

The tropics have few examples where livestock is integrated in the agroecosystems in the same manner as frequently found under Northern temperate conditions [26). As fertilizer use in Africa is still a very modest proportion of worlds fertilizer use [27], the cereal yields per area unit has remained low (Figure 2).

The response of data like those of low yield levels (depicted in Figure 2) follows a paradigm development [26], which also is referred by [8]. During the 1960s and 1970s, an external input paradigm was driving the research and development agenda which later has been known as the 'Green Revolution'. In the early 1980s, the balance shifted from mineral inputs only, to low external input sustainable agriculture (LEISA) where organic resources were believed to enable sustainable agricultural production. During the 1990s, the Integrated Natural Resource Management research approach and ultimately the Integrated Soil Fertility Management paradigm emerged. Still it was however argued that Sub-Saharan African farmers must use more fertilizer, improved germplasm, etc. to achieve a so-called "Second Green Revolution" [see e.g. 29].

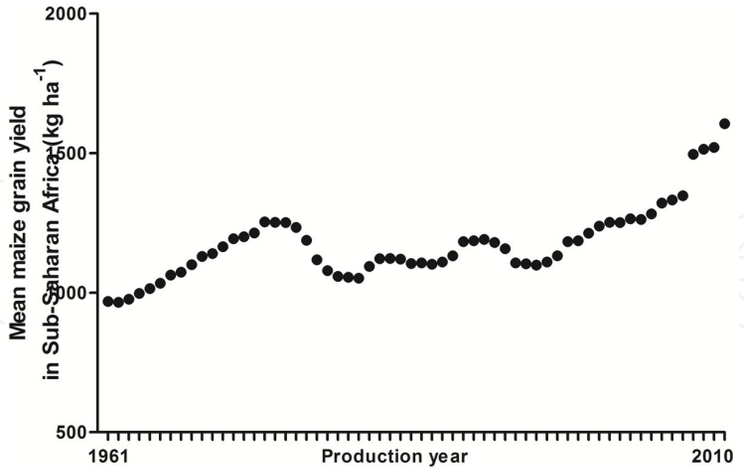


Figure 2. Official UN 5-year running average maize yield in the Sub Saharan African region between 1961 and 2010 [30].

A critical lesson from all this work is that a highly context-specific approach is required which takes into account the fertility status of the soil, the availability of organic inputs and the ability to access and pay for mineral fertilizers [28,31].

The response further assumes that the markets are perfect and that all agricultural commodities are entering a market. On one hand, large proportions of the diet of Africans are produced and consumed locally and may not enter the market. The part that enters the market may ignore the markets needs and preferences as it is sold as surplus on a local market. One commonly used model of innovation is the so-called value-chain model developed by Kline and Rosenberg, which emerged from studies of technological innovation. Modern innovation models must thus see many reverse processes and feedback loops in the incremental changes along the value chain, which further often has to include local conditions, cultural preferences, etc.

Elements in the bridge between agriculture and human wellbeing would thus be to trial for locally adapted bean varieties and to form a network among researchers that can promote a legume-based agriculture in these regions, in their particular social context. This approach would also recognize that a large proportion of the bean production occurs under conditions of significant drought stress [32], where agricultural inputs may not be an economically viable option. To overcome these particular stress conditions in combination with a vulnerable crop establishment phase, [10]) suggested investing in semi-perennial leguminous crops that has capacity to cope with short term weather variations. However, given the dominant role that beans have in nutrition in Africa and Latin America, robustness to environmental stress must be sought (Table 3) and combined with proper seed availability programmes [33].

The traditional plant-based diet is quite voluminous, i.e. it has high moisture content, with a limited protein and fat content. This is a particular challenge to children who require a diet of higher nutrient density than adults [34,35]. Some studies suggest that supplementary intake of animal protein, especially milk and fish, may stimulate childhood growth [e.g. 36]. However, some population segments may not have access to animal protein or cultural reasons limit their use of animal protein. Furthermore, dietary compositions vary over season in rural Africa and there may be temporal windows with surplus, adequate or lack of particular nutrients. Such windows may be influenced by reproduction cycles, health issues, harvest time and storage capacity, climate variability, household composition, among others [e.g. 37,38,39]. There is thus every reason to seek a higher density of nutrients in plant-based diets.

Cereals typical have a positive correlation between the nitrogen supply of the crop, thus the nitrogen content of the grain and the iron and zinc content [40]. Legumes are self-reliant on nitrogen through the biological fixation process. Consequently, correlations between nitrogen, iron and/or zinc content cannot be expected.

5. Seeking the nutrient dense diet – An adaptability analysis

It has frequently been assumed that farmers management and local growth conditions are fairly homogeneous and recommendations based on information generated on experimental stations dominate the extension services [e.g. 22]. However, homogeneity may be an illusion [e.g. 11]. Methods must thus be applied that allows for evaluation of performance under varying conditions.

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Differentiating farmers are thus the approach in the so-called adaptability analysis [41]. This is an analysis that depicts the performance of the individual genotype across a wide range of environments versus the mean performance of the tested varieties can indicate if some varieties perform better or worse.

In terms of dry matter grain yield (Figure 3), there were no significant difference between the regression lines fitted to the observations in Malawi whereas the lines differed significantly ($p<0.05$) in Tanzania. In Tanzania, the slopes of the lines (Figure 3, right) had the following order in decreasing order: Selian97 > Selian94 > Lyamungo90 > Wanja > Lyamungo85 > Uyole96 > Jesca > Uyole84.

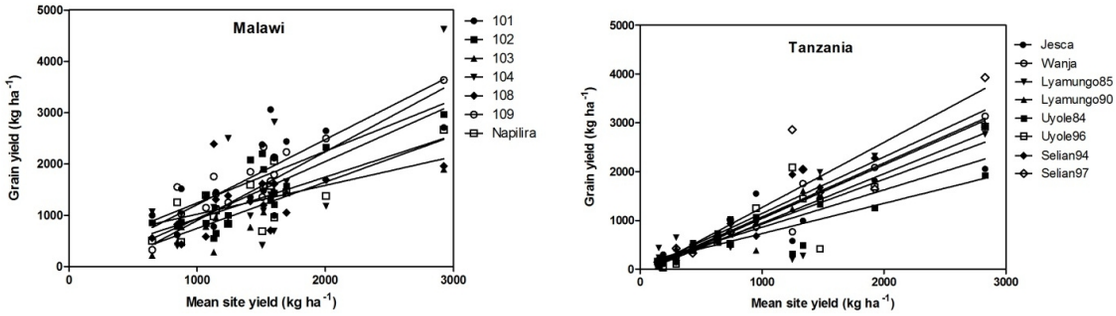


Figure 3. Individual observations and regression lines of grain dry matter yield of individual genotypes versus the mean site yield.

Phosphorus content in the grain follows pretty much a 1:1 ratio – so there is no effect of environment here as the slopes of the fitted regression lines did not differ ($p>0.05$). This is surprizing as the environment generally is considered P-scarce. The two environments clearly gave different proportions of phosphorus in the grain (Figure 4). And most observations from Malawi indicate that phosphorus in no way could be viewed as a limiting factor for beans at the current site with a mean site phosphorus proportion of 0.5% in the grain. Further, there seems no reason to believe that the individual genotypes could maintain a higher proportion of phosphorus in the gain across a phosphorus limiting environments as it appears to be the case in Tanzania.

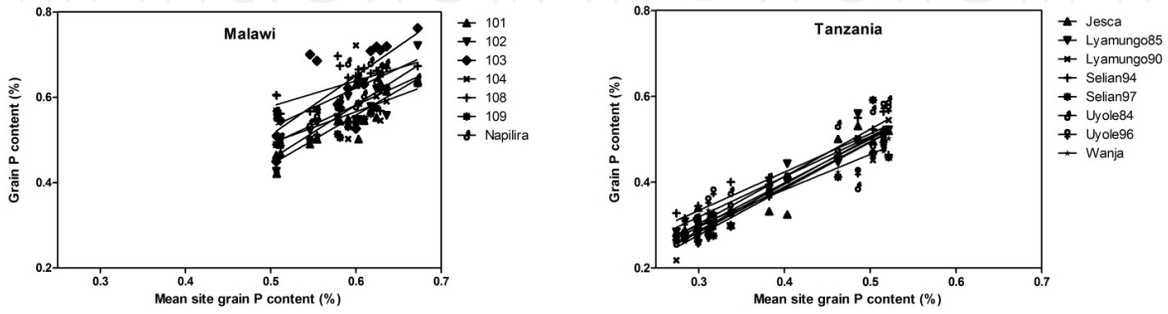


Figure 4. Individual observations and regression lines of the proportion (%) of phosphorus in the grain dry matter of individual genotypes versus the mean site yield.

A picture similar to phosphorus emerge (Figure 4) when plotting the proportions of iron in the grain (Figure 5). Obviously the two sites gave a different proportion of iron in the grain and there were tendencies to believe that some genotypes could be richer or poorer in iron than others. The 3 varieties with the highest proportion of grain iron content in Malawi were 103, 108 and Napilira while they in Tanzania were Selian94, Uyole96 and Selian97. In the Tanzanian case, the righest in iron thus seems to be the highest yielding across environments. An almost identical picture emerged regarding the proportion of zinc in the grain (Figure 6). The 3 varieties with the highest proportion of grain zinc content in Malawi were 103, 108 and Napilira while the 2 varieties with the richest zinc content in Tanzania were Selian94 and Uyole96.

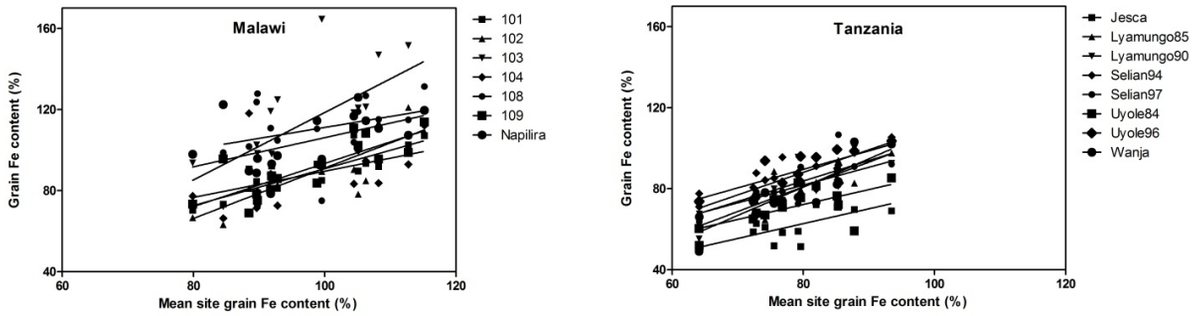


Figure 5. Individual observations and regression lines of the proportion (%) of iron in the grain dry matter of individual genotypes versus the mean site yield.

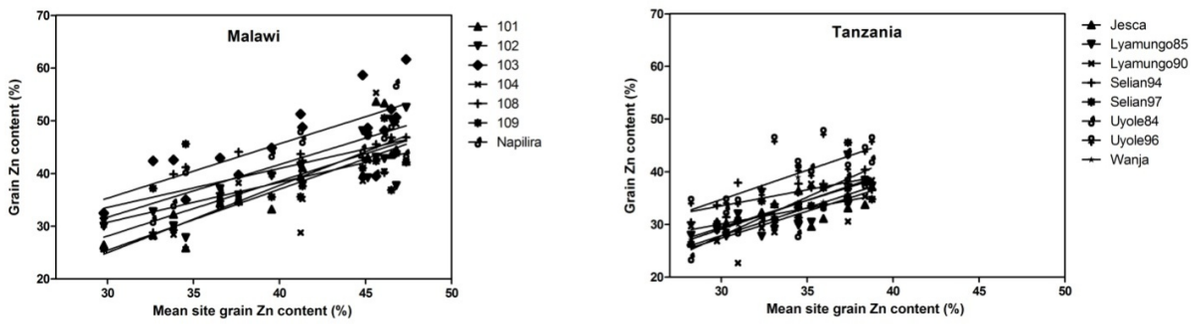


Figure 6. Individual observations and regression lines of the proportion (%) of zinc in the grain dry matter of individual genotypes versus the mean site yield.

Interestingly, however, is the fact that grain size did not appear to explain the differences between the element concentration as Malawi tended to have varieties that had individually larger grains (Table 2) and the grains with the highest proportion of phosphorus, iron and zinc in the grain dry matter. That eliminates a theory of element dilution at the end of the grain filling period which is often observed in bread wheat [42] but not always in other

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crops [40]. In other words, bean appears to continue to fill in elements in to the grain together with carbon while maturing.

The current data (Figures 4-5) demonstrate that efforts to find the genetic material that tend to accumulate elements, which are important for human wellbeing, in higher concentrations in the grains are justified. Naturally we may - from an evolutionary point of view - wonder what benefit the plant gets from this. But it should not stop us from utilizing this variation in modern plant breeding efforts.

However, we are in a situation where we rely on small scale farmers to increase their production substantially. This production is both for home or local consumption but even more also for industrial purposes because of the rapid urbanisation of Africa and Asia. Building on farmers' capability and knowledge of their own environments may be the best way to enhance output from agriculture. That requires innovative approaches at farm level to test and select the best suited genetic material (Figure 2) to that particular environment. This will further require new approaches to seed supply systems as "one type fits all" approach will not do the job. On the contrary, seed supply systems must build on an approach of "multiple types to fit any environment", which obviously is a major challenge to extension and research.

6. A bowl of beans

The complementarity in the amino acid composition among beans and maize has been recognized for long [7, and references herein]. Grain legumes are characterised by being markedly deficient in the essential amino acids of methionine and tryptophan but rich on lysine. Cereals normally hold more methionine than the grain legumes so a high complementarity and higher combined nutritional value could be expected. Indian scientists were front runners in documenting such efforts [e.g. 43,44]. In recent years there has been a change in the consumption of grain legumes in developed countries were they increasingly are viewed as "health foods".

The traditional plant-based diet in part of Africa and Asia can be quite voluminous, i.e. it have a high moisture content, and the protein and fat content may also be limited [35,44]. This pose a particular challenges to population segments that cannot ingest sufficient food to cover their needs, in shorter or longer periods of their lives [e.g. 35,36,37].

Dietary diversity is important for the wellbeing of humans [45,46]. An inexpensive bowl of beans or other grain legumes would benefit many people. Agriculture has the potential to supply this bowl. Here we argue that by accepting that conditions vary much locally, we will have to adapt a learning approach to selecting bean varieties based on local productivity of the various genotypes given the local pest and disease pressures, soil fertilities and soil fertility management practices, on local preferences for processing and eating the beans, on the beans role in the local cropping systems, on differentiated population and resource groups.

From the industry's point of view, improved yields will be favourable as intensification will support a profitable production. This is clearly illustrated with the case of soybean production in South America [47]. Such cases highlight the expected situation in the future where the industrial focus on particular functional traits [48] will enhance the focus on the combination of yields and particular quality requirements. In a future, where production must be increased to meet the needs of additional 2 billion world inhabitants, quality traits of importance for human health and wellbeing may come into focus. Such traits must include iron and zinc.

Beans are to a large extent multiplied and reseeded from previous crops. Thus, the localness is already expressed in communities' planting preferences. To distribute new improved seed types are by experience very difficult when these types of crops are in question. The best the food industry can do to secure abundant supplies of beans when working with a multiple of smallholders are thus to contract on particular quality traits. Such outlet and market preferences have previously been found to have strong impacts on farmers' behaviours.

In the time of writing these lines, the food prices seem permanently to have left the relatively low levels of post-2007-2008 price peak [49]. Bean is a crop that is largely controlled by smallholders and the crop thus has a potential to contribute to the food security of the households. We have in this paper argued that bean holds the potential to bridge agriculture and human wellbeing because of its nutritional value, because it's genetic diversity and because it is controlled by local communities. The presented data suggest that farmers and change actors may improve the quality of the diet by simply going for the varieties that performs the best.

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