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Why not beans?

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Abstract. Changes in climate and urbanisation rapidly affecting human livelihood are particularly threatening to developing nations in tropical regions. Food production crises have focused the global development agenda on agricultural research, a proven approach for increasing crop yield. A few crops benefit from private investment, but improvement of most crops will rely on limited public funding that must be deployed strategically, pushing forward both proven approaches and new ideas. Why not invest in beans? More than 300 million people rely on this crop, considered to be the most important grain legume for human consumption. Yet the yield of beans, especially in poor regions or marginal soils, is reduced by abiotic stresses such as phosphorus deficiency, aluminum toxicity and especially drought. Is it possible to assemble resources, including genetic diversity in beans, breeding expertise, genomic information and tools, and physiological insight to generate rapid progress in developing new lines of beans more tolerant to abiotic stress? A workshop to address this question was held in November 2010 at the International Center for Tropical Agriculture (CIAT) in Colombia. The resulting 'call to action' is presented in this issue which also includes research papers focused on tolerance of beans to stress.

Why not beans?

Our planet faces significant challenges to provide adequate food and nutrition for human consumption in the face of population increases, urbanisation, changing diets and climate change (World-Bank 2008; Ainsworth and Ort 2010; Godfray *et al*. 2010). Reducing poverty and improving the lot of poor farmers while feeding an increasingly urbanised population, a challenge in the best of times, is becoming more so in the light of global change factors. After 20 years of neglect, governments, donors and multilateral organisations are once again focusing on the risks of ignoring agricultural production and nutrition.

Since 2007, spikes in food prices have contributed to the level of alarm regarding food production and availability (Von Braun and Torero 2009). Opportunities to increase food production and improve nutrition by increasing land area under cultivation are becoming more limited, as suitable agricultural land is less available. Additionally, use of irrigation and synthetic fertilisers is increasingly scrutinised due to diminishing availability and processing costs of these resources. Combined effects of climate change, urbanisation and an increasing population will put more pressure on existing centres of production. Such effects will be exacerbated in parts of Africa and South Asia where higher temperatures, reduced rainfall and population growth rates are predicted to be highest.

Attention to these problems is coming to the fore of the global development agenda (La Franchi 2011) and while this acknowledges the need for action, it raises the question of how to address needs in the most cost-effective manner. Agreement on improving production by improving yield through 'sustainable intensification' is a popular solution for which research and development (R&D) will continue to play an important role (Godfray *et al*. 2010). Agricultural R&D is a proven approach with a high return on funds invested (Alston *et al*. 2009); however, in light of recent global economic crises, the extent of public spending is under renewed pressure. It is also well known that basic R&D is largely wasted without meaningful funding for dissemination and delivery of products and approaches to the food security supply chain.

Many opportunities exist for R&D to sustainably intensify crop production, including new varieties and hybrids, more efficient and sustainable farming systems, more effective fertiliser use and more efficient irrigation. Research to improve crop production and nutrition can also offer new approaches for increasing the quality of people's livelihoods. Development funding needs to be balanced between proven approaches and new ideas that allow farmers in developing countries to adopt new technologies and management techniques. In some cases, this may involve 'skipping' existing technology in much the same way that cell phones allowed developing countries to overcome the problems associated with building a land line based system. Combined with the potential impacts of more effective policies at various levels of government, many analysts believe it is possible to meet global food demands in the coming decades (Fedoroff *et al*. 2010; Godfray *et al*. 2010).

So where should we spend scarce development and research funds? The revolution in biology since the early 1970s has resulted in tools for crop improvement that have been employed to increase the investment in, and rate of improvement of, some crops, particularly those of interest to the private sector seed industry. It is, however, important to recognise that companies will only invest in improving crops where they can receive a financial return. For example, private seed companies have employed sophisticated approaches for those crops that provide a return on private investment. To ensure this return, some form of protection for the intellectual property must be realised. This can take the form of patents, plant variety protection, trade secrets or biological forms of protection, such as hybrid and transgenic crops. Hybrids provide a level of 'natural' intellectual property protection, as hybrid vigour is lost in the F_2 generation. The requirement that farmers buy seed every year to realise the benefits of heterosis provides a pricing opportunity as well as a predictable market for products.

Introduction of transgenic traits in markets with strong intellectual property rights has resulted in private investment for research into some varietal crops (e.g. transgenic, herbicide-resistant soybeans), but this remains limited in scope. Even varietal lines of wheat, the world's most widely planted crop, have received limited attention from the private sector to overcome problems of low heterosis and problematic seed production systems. Combined public and private spending on wheat improvement is below US$250 million per year while investment by the private sector alone in research spending for maize improvement exceeds US$1.5 billion annually. What factors underpin such a significant imbalance of investment?

The importance of beans

The importance of common bean (*Phaseolus vulgaris* L.) as a subsistence and cash crop is well established with more than 300 million people relying on the crop for protein, micronutrients and calories and 1 million farmers using beans as an important source of income (International Center for Tropical Agriculture (CIAT)). Common beans are critical components of many peoples' diet (both rural and urban) providing much needed protein and nutrients and hence are regarded as the most important grain legume for direct human consumption (McClean *et al*. 2004). For example, beans are a primary source of dietary protein for 70 million people in sub-Saharan Africa. In 2009, the global bean harvest was 18 million tons primarily in Latin America and Africa (Food and Agriculture Organization CIAT).

Despite the critical importance of common bean in diets of impoverished people and to the livelihood of farmers throughout the world, research funding to improve this grain legume crop is comparatively minor to that of 'mainstream' crops. The considerable interest from private and public sectors in soybean has not extended to its close relatives, such as common bean. Support for research and breeding on common bean languishes at US$5–10 million per year globally, an amount dispersed among national programs, universities and a few international crop improvement centres. This level of global investment clearly lacks the size, consistency and integration to realise the benefits of advances in genetics and biology.

In addition to their status as a (almost) perfect food, common beans play an important role in societal organisation. In Africa, common beans are often referred to as a 'woman's crop' reflecting a social dimension to the cultivation practices, which are usually subsistence or small scale. Across the world, common beans are often cultivated on steep erosion-prone hillsides in soils characterised by low fertility. More than 50% of bean area suffers from phosphorus deficiency; 40% may experience aluminum (Al) toxicity and 73% is affected by drought (Beebe *et al*. 2010).

It is not enough that common beans are an important source of nutrition and income for a large number of farmers in the developing world. In order to justify additional resources for common bean improvement it is necessary to make the case for the technical feasibility of improving the crop. The gap between what could be done to improve the bean yield and adaptation and what is being done is substantial. Why is this? The lack of private sector interest results from difficulty in obtaining a reasonable return on investment with a varietal crop grown by poor farmers with little cash to devote to improved genetics along with the difficulty in reaching poor farmers with small acreages in developing countries with poor infrastructure. Consequently, bean improvement will continue to be a mostly public sector activity, dependent on government and donor support, for the foreseeable future.

The workshop

In light of limited funding allocated to R&D on *Phaseolus* and its importance for global food security, careful consideration should be made to ensure the fundamentals are in place to justify public investment. To explore these possibilities, a workshop was convened at CIAT in November 2010 (http://www.wun.ac.uk/research/plant-systems-bean-yield) under the broad banner of improving tolerance of beans to stress. A brief review of the meeting is presented in McClean *et al*. (2011) who also put forward a work plan developed at the workshop for pushing forward the tolerance of common beans to abiotic stresses.

It is widely recognised that many promising technical approaches can be applied to improve common beans largely derived from commonalities with closely related crops, such as soybeans where research investments have been more substantial. These approaches leverage advances made in molecular genetics, genomics and phenomics combined with a strong literature on the basic physiology and biochemistry of common bean, forming a platform for improving beans when tied to several small but solid breeding and molecular biology programs. Below we consider some of the main points related to the areas underlying bean improvement.

Common beans have exceptionally wide genetic variation among four gene pools and many races (Tohme *et al*. 1996; Beebe *et al*. 2001) two of which form the focus of sequencing work performed by Mamidi *et al*. (2011). Reflecting this diversity, the CIAT maintains a primary gene bank with more than 36 000 accessions providing raw material for improving the crop using traditional breeding and molecular marker approaches. Genes for many important traits, disease resistance, abiotic stress tolerance and nutritional variants are identified in the collection. Importantly, common beans are the closest relative to cowpeas and pidgeonpea in 'mainstream' food production and represent a model system for the more complex polyploidy of its close relative soybean. Common beans are diploid and represent a model system for the more complex, polyploidy of its close relatives (e.g. soybean).

Physiological approaches to breeding for abiotic stress tolerance have resulted in improved levels of drought tolerance, aluminium toxicity tolerance and performance under low phosphorus conditions. Phosphorus is immobile in the soil, and is frequently limiting. Reductions in phosphorus levels immediately around roots stimulate root development, deploying new roots into un-mined soil. Under dense plantings, this root behaviour can be interpreted as neighbour detection (competition) but is instead a direct response to low phosphorus. Roots will however change their morphology in response to competition, and selection for flexibility in root architecture may provide more adaptable lines for poor soils (Nord *et al*. 2011).

Climate change in Africa and Latin America will result in environments requiring improved heat tolerance and will make drought, flooding and salinity tolerance more essential. Interaction of stresses, and especially the influence of abiotic stress on susceptibility to disease, needs to be addressed in selection protocols. For example, You *et al*. (2011) show that salinity enhances damage caused by the fungus *Macrophomina phaseolina* on common beans. The mechanism for the interaction results in an imbalance in cytoplasmic K : Na suggesting selection for plants able to maintain K, and exclude Na. Efficiently breeding for these traits will ideally leverage approaches in other crops and require molecular marker and genomics based approaches for selection. Breeding for iron biofortification (as part of the Harvest Plus program) has resulted in bean varieties with iron levels adequate to improve diets of poor people (Beebe *et al*. 2010).

Plant phenotyping is critical for selection of improved lines, and the more precise the phenotype the better (Beebe *et al*. 2010). Linking phenotypes to underlying physiological mechanisms is useful, especially when the genetic components of the mechanisms are also partly known. Phenotyping is rapidly developing into a field of its own, with more elegant tools becoming available. Rascher *et al*. (2011) present a state-of-the-art menu of non-invasive approaches for phenotyping function and performance traits in bean. At the Forschungszentrum Julich, high precision measurements are made to investigate shoots, roots, and transport and allocation processes. Allocation of nutrients within a plant, in particular partitioning and transport of reduced carbons, is the basis for biomass accumulation, and arguably is the limiting process for plant growth and yield. Merchant and Richter (2011) have developed means for assaying the polyol content in phloem, and then analogously to humans' blood tests, they explore the possibility of using polyols as biomarkers for stress and tolerance mechanisms.

Biotechnology, in the form of molecular breeding approaches (e.g. Chia and Ware 2011) and transgenics has rapidly changed programs to improve several economically important crops in developed and increasingly in developing countries. Molecular marker approaches have provided tools to select for root architecture and virus resistance. However, application of these tools has not yet become central to breeding programs. High throughput marker platforms are not currently in use and are a clear opportunity to improve common bean across a range of objectives.

Association genetics and genome selection, approaches to crop improvement, reduce the need for field testing and predict the performance of new crosses (Heffner *et al*. 2009). Mamidi *et al*. (2011) have used multilocus sequence data to test models for domestication of common beans. Their data support a single domestication event in each of the MesoAmerican and Andean gene pools, and provide needed information for more precise association mapping and selection. The ability to use genomic selection would speed the breeding process and result in considerable reduction in cost and time of creating new varieties. These technologies are readily available for application to beans.

Molecular marker development boosted by the soon-to-be-completed sequencing of the common bean genome will undoubtedly aid in comparative candidate gene discovery among closely related legume species and identification of useful genes in *Phaseolae*. Transgenic crops with genes for drought tolerance and other abiotic stress tolerance traits could have significant benefits for crop production particularly in changing climates. Commercialisation of these traits will occur in maize in the next 2–3 years in developed countries (Monsanto-company 2011). Additional sources of drought tolerance would be valuable in common bean as well (Beebe *et al*. 2010). Meaningful efforts to use transgenic approaches to improve drought and heat tolerance of beans have not occurred. It is possible to use genes developed for other crops and to adapt transformation technologies from soybeans and other dicots in common bean. Successful regulatory approval for a transgenic virus resistant common bean cultivar was recently announced in Brazil but, in general, little investment in using transgenic approaches has occurred. Public–private partnerships like the 'Water Efficient Maize for Africa' project aim to use privately developed drought tolerance genes to improve maize for poor farmers in Africa. Unfortunately, no similar projects exist for common bean despite the value of such a trait to bean growers in impoverished locales.

Common beans have often been used as an experimental system for basic physiological and biochemical research. Despite this, for reasons outlined above, the likelihood that common bean research will be integrated across disciplines within large well-funded research organisations, such as the multinational seed companies, is extremely low. More likely, any coordinated initiative will need to leverage work from many public research organisations to realise significant advances. Consequently, scientific research organisations, donors and governments will need to identify and fund well-designed cross-disciplinary, cross-organisational bean improvement programs appropriate to the importance of the crop and the opportunity to apply well understood approaches for improvement. Building on the results of this workshop, the Common Bean Network and other mechanisms for coordinating research efforts, initiatives can meaningfully increase the yield and adaptation of common beans and develop delivery mechanisms that will allow smallholders ways to realise the benefits of the research for development efforts.

Investment in common bean improvement using the broad genetic diversity, deep physiological and biochemical understanding and leveraging genomic and genetic technologies could result in rapid improvement of this important crop. The tools exist to make a significant difference with relatively modest funding. A coherent, well-funded long-term program across the centres of bean improvement, working through existing networks and combined with complete sequencing of the bean genome would undoubtedly result in meaningful improvement of the yield and nutritional value of this crop. Integrating the appropriate scientific disciplines from more basic physiological, genetic and biochemical approaches to breeding and biotechnology should allow rapid progress at a reasonable cost (Passioura 2010). Such a program could also be tied to capacity-building efforts in Africa and Latin America where breeders and other scientists could be engaged in improving the crops. The current piecemeal approaches are unlikely to realise the full benefits of the available science.

The research front papers in this issue advance the case of using a basic understanding of common bean biology to design and execute effective crop improvement programs. As Passioura (1979) explained; basic science has an obligation to both make ‘profound discoveries’ and ‘useful’ ones. For *Phaseolus* there is ample scope to deliver on both of these objectives.

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