Sorghum in Africa: research opportunities and priorities.

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Introduction

Sorghum (*Sorghum bicolor*), a crop of African origin, remains an important staple crop for millions of Africans – mostly smallholder farmers and their families. It has also been identified as one of the priority commodities by regional economic blocks and lead continental organisations for value chain development as part of the agricultural transformation process that is taking place in Africa under the Comprehensive Africa Agriculture Development Programme (CAADP). Sorghum is cultivated across diverse agro-ecologies; from higher altitudes to dry lowlands, from the Sudan Savannah to residual moisture regimes on the Sahara Desert's fringes, on degraded acidic soils with toxic levels of aluminium to highly intensified irrigated systems. It traditionally produces very hard grains (the crystalline type), facilitating easy storage and is consumed in diverse forms and used for multiple purposes including animal fodder, construction material and energy.

Sorghum is a drought-tolerant crop: adapted to high temperatures; low soil fertility, especially low phosphorus conditions; low soil pH; aluminium toxicity; and water logging on the one hand to growing entirely on residual moisture stored lower in the soil profile on the other, in either deep sandy soils or deep black cotton soils (vertisols). Some sorghum varieties reach maturity 75 days after sowing, while others may take six months or more. Similarly, sorghum grain characteristics are very diverse: some can be stored easily for several years without losing viability. Thus sorghum has potential for further development in Africa in a future that is being shaped by climate change, and requires more efficient use of available resources. It could become a crop of choice in new areas, because of its low input requirements, and yield stability under adverse conditions. Beyond Africa, sorghum is also gaining notice as an important cereal for the future.

Cultivated sorghum diversity is classified into five major races, mostly based on grain shape and floret characteristics. These races have rather distinct distribution patterns across Africa. Genetic diversity analyses (Morris *et al.*, 2013) using genetic markers largely confirm the significant genetic distances between races. While all five races and their intermediate forms continue to be cultivated in Africa, sorghum breeding worldwide has primarily focused on two races, caudatum and kafir, providing the basis for exploiting hybrid vigour in the USA, India and Australia.

Opportunities for improving sorghum productivity in Africa

Sorghum breeders in several countries have recently succeeded in various ways to improve and stabilise sorghum productivity in specific production contexts in Africa.

1. **Guinea-race sorghum hybrids for the Sudan Savannah of West Africa**
   The first sorghum hybrids based on the West African Guinea-race derived parents were created to enhance farmers' food security and income through increased yields. Eight hybrids, six experimental open-pollinated varieties, and a highly-adapted landrace check variety were evaluated in 27 farmer-managed and 2 on-station yield trials in Mali, West Africa (WA) (2009-2011). The hybrids have similar photoperiod sensitivity to the well-adapted Guinea Landrace check variety. Differences among entries for grain yield were highly significant and larger than the genotype-by-environment interaction component of variance. The yield superiorities of individual hybrids, relative to the landrace check, ranged from 14 to 38% when averaged over all environments. The top three yielding hybrids showed more than 30% yield advantages across productivity levels, with absolute yield advantages averaging 450 kg ha^{-1} under lower- (1.0 -1.5 t ha^{-1}) and 700 kg ha^{-1} under higher- (2.0-3.5 t ha^{-1}) productivity conditions. As these hybrids involved low-intensity selection using a limited number of parents, even greater yield superiorities may result from scaled-up hybrid breeding (Rattunde et al. 2013).

2. **Transfer of *Striga* resistance QTLs (Quantitative trait locus) into locally preferred but susceptible varieties in Sudan**
   Recently, Sudanese scientists succeeded in making local varieties of sorghum, Tabat and Wad Ahmed, and breeding line AG8, *Striga*-resistant, by introgressing them with 5 small genomic regions associated with improved Striga resistance derived from N13, a line from the Durra race of sorghum. These are first products of marker-assisted selection to be created in Africa, for African farmers (Abdallah H. Mohamed, Rasha Ali *et al*., unpublished).

3. **Selection strategy for adaptation to low phosphorus conditions in the soil**
   Sorghum in WA is generally cultivated with limited or no fertilisation on soils of low phosphorus availability. Grain yield assessments of 70 diverse sorghum genotypes under −P (no phosphorus P fertilisation) and +P conditions at two locations in Mali over a 5 years' period provided detailed insights: Genetic variation for grain yield under –P conditions and the feasibility and necessity of sorghum varietal testing for grain yield under −P conditions were evaluated. Under low P conditions, heading dates were delayed by 0–9.8 d and reductions of grain yield (2–59%) and plant height (13–107 cm) were observed in −P relative to the +P trials. High estimates of genetic variance and broad-sense heritabilities were found for grain yield across both −P (h^2 = 0.93) and +P (h^2 =0.92) environments. The genetic correlation for grain yield performance between −P and +P conditions was high (r_G = 0.89), suggesting that WA sorghum varieties generally possess good adaptation to low-P conditions. However, genotype × phosphorus crossover interaction was observed between some of the highest yielding genotypes from the −P and +P selected sets, with the variety IS 15401 showing specific adaptation to −P. Direct selection for grain yield in −P conditions was predicted to be 12% more efficient than indirect selection in +P conditions. Thus, selection under −P conditions should be useful for sorghum improvement in WA, allowing varieties specifically adapted to be recommended to farmers. Women farmers in WA tend to farm the lowest fertility fields (Leiser *et al*., 2012).

4. **Recurrent selection for population improvement**
   In an effort to combine the conservation of cultivated diversity of sorghum, while creating the basis for developing new and improved varieties of

sorghum, teams of scientists in Mali and Burkina Faso created several so-called random-mating populations, constituted mainly of local varieties of sorghum from WA. These populations outcross more frequently than sorghum would normally, because a single gene is segregating in them that renders homozygous plants male-sterile, creating new combinations of traits every growth cycle. Farmers have helped choose parental lines and local varieties. Four populations were developed in Burkina Faso, and two in Mali, each derived from eight to fifteen local varieties and three to four improved sorghum lines. Each population was sown for two to three subsequent generations in the target region. Farmers managed the populations in their fields, identified male-sterile plants during flowering and harvest, and conducted evaluation and preference classification of male-sterile panicles. (vom Brocke *et al*., 2010).

5. **Reintroduction of landraces into areas where they had been abandoned**
   Sorghum is a major staple crop in Burkina Faso, where farmers continue to cultivate photoperiod-sensitive Guinea landraces as part of the strategy to minimise risk and ensure yield stability. In the Boucle du Mouhoun region, however, sorghum farmers appear to have insufficient varietal choice given that cropping systems have shifted towards more intensive cultivation of cotton and maize, and rainfall patterns have decreased over the past decade. In search for new varietal options for this changing context, researchers decided to give farmers access to *ex-situ* national collections along with the opportunity to evaluate recently improved varieties. From 2002 to 2007, researchers and farmers worked closely together to implement on-farm testing, including varietal selection trials, crop management and multi-locational trials. Farmers' choices tend to differ among groups, villages and years, with the exception of four particular landraces: two collected in the Mouhoun region more than 30 years earlier, and two from dissimilar agro-ecological zones of Burkina Faso. Farmers' selection criteria were focused on adaptation to agro-climatic conditions as well as specific grain qualities for processing and consumption. The potential usefulness of each variety was verified via multi-locational trials. Wide dissemination of experimental seed at a national scale was largely achieved through collaboration with a strong farmer organisation together with farmer training programmes focused on the on-farm seed production and commercialisation (vom Brocke *et al.,* 2013).

6. **Farmer participatory variety testing for local adaptation and productivity**
   Variety development for sorghum requires multi-location testing for adaptation and yielding ability. In WA, adaptation to specific zones of rainfall distribution is crucial, but most countries lack sufficient research station capacity for such testing. We developed a trial design and experimented with sharing roles and responsibilities between farmers, NGOs and researchers, allowing for effective varietal differentiation in the target environment, across a wide range of production conditions within a zone. Early-stage farmer participation means they evaluated many other characteristics that are essential for success of a variety. With this approach, several varieties and five hybrids have been released in Mali (Weltzien *et al.*, 2008).

7. **Harnessing photoperiod sensitivity for improved yield stability**
   In WA, sorghum landraces flower 60-180 days after sowing. The growth duration is always related to the length of the rainy season. Photoperiod-sensitivity determines the triggering of the flowering time and modifies the rates of development. Under natural sunlight, the photoperiod influences both the apical rate of leaf initiation and the beginning of the flowering process.

The stable apical rate of leaf initiation, at plant emergence or at the onset of jointing in response to environmental conditions, including lighting, also determines the rate of growth of the panicle (Clerget *et al.*, 2007).

8. **Farmers and the diffusion of seed of jointly created varieties**
Diffusion of seed of improved varieties tends to be done through the formal seed sector, i.e., usually private seed producers sell to farmers, or when the private seed sector is poorly established, parastatal companies fill this gap. However, in most African countries the private seed industry is poorly developed, and focuses its activities on cash crops suitable for hybrid breeding.

Around 80-90% of all seeds worldwide are produced by farmers themselves, or acquired through the informal seed sector (Almekinders and Louwaars, 2002). The absence of seed of newly bred varieties contributes to the low adoption rates of new varieties of sorghum for many countries.

Farmer participation in breeding can also trigger innovations in approaches in seed distribution and diffusion. Experiences with Participatory Variety Selection (PVS) programmes suggest the mere involvement of farmers in variety trials is not sufficient to create conditions for rapid seed diffusion of these varieties. Diffusion through informal channels tends to be rather slow, especially if associated with slow diffusion of information about the new varieties.

Thus Participatory Plant Breeding (PPB) programmes tend to plan specific activities for rapid diffusion of seed to the target group of farmers. PPB programmes that have components targeting farmer empowerment may aim at creating local institutions, or organisations which can sustain these activities possibly without project support, e.g. farmer seed cooperatives, or local seed enterprises. However, to achieve rapid adoption and widespread impact from use of the newly identified varieties, PPB programmes often partner with NGOs, community-based organisations, or extension services to rapidly diffuse small packs of seed widely among the target group of farmers (Christinck *et al.,* 2005).

9. **Fighting *Striga*: a series of Farmer to Farmer Videos**

Striga is a parasitic weed that attacks most cereals, especially in poor soil fertility fields. It multiplies readily, producing thousands of very small seeds that survive for many years in the soil, only germinating when cereal roots grow in their vicinity. Farmers used the Farmer Field School experience of developing effective and profitable integrated *Striga* Control packages to produce ten 10-12 min videos that explain the advantages of individual *Striga* control techniques, and options for their integration, from a sorghum or pearl millet farmers' perspective. These videos are available from http://www.accessagriculture.org/ in many African languages.

Setting research priorities for sorghum improvement

Priority traits for future research and development of sorghum are central to establishing the selection criteria. The germplasm base must be well known and understood and particular varieties chosen appropriately, using partners' knowledge of the possible options. This implies the need for proper consultation with local stakeholders, appropriate discussions with farmers as to what varieties might be most suitable and giving due recognition of the local knowledge which guides the final selection. The extent of intra-varietal diversity is critical.

What is often left until activities are planned is the identification of key roles and responsibilities of partners. When considering a participatory approach to plant breeding, it should be borne in mind that the options for sharing responsibilities can have major impacts on the outcomes and the goals, e.g. capacity building or diversity conservation should guide the choice (Christinck *et al.*, 2005).

Conclusions

New sorghum varieties can be developed to meet a range of specific demands by farmers, e.g. improving yield, while maintaining the preferred grain type; or improving yield under poor soil fertility conditions. Future market demand; both regionally and internationally should also guide the research and development agenda for sorghum and consultations should go beyond discussions with farmers to include agro-processors and other agri-entrepreneurs involved in the sorghum value chain. Other factors that should drive the R&D agenda include climatic variability, food and nutrient needs and availability of resources. Farmers can contribute by working with scientists on clearly identifying priorities for improvements and using their skills for panicle selection and variety evaluations. Farmers who are organised and can collaborate could also become seed entrepreneurs and become bigger players in other segments of the sorghum value chain.

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