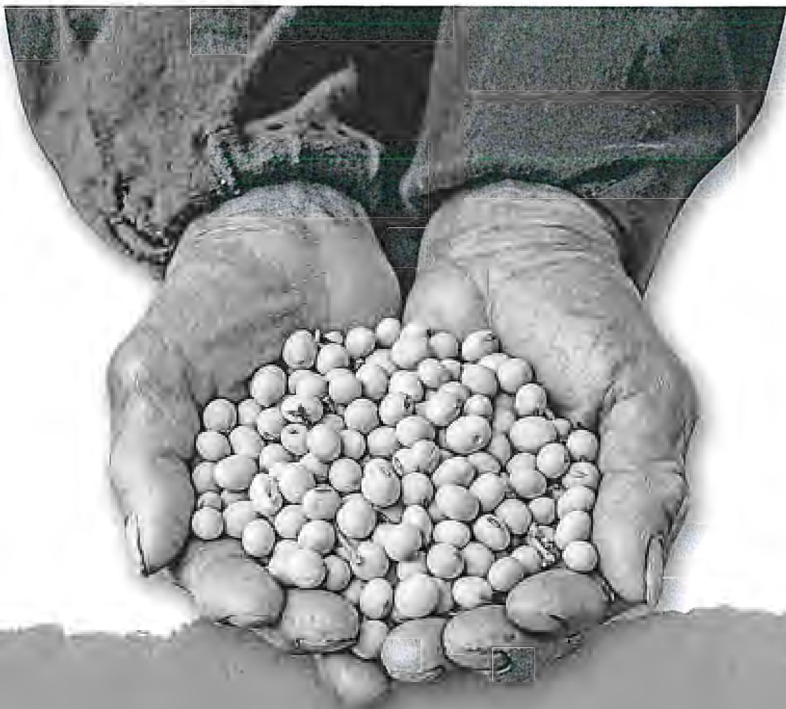

Seeds that give *revisited*

Participatory plant breeding and rural revitalization

Yiching Song, Ronnie Vernooy ◎ Editors-in-chief
Lanqiu Qin, Linxiu Zhang ◎ Associate editors-in-chief

CHINA AGRICULTURE PRESS · BEIJING

Farmer – plant breeder collaboration: The case of sorghum breeding in West Africa

Eva Weltzien, Fred Rattunde, Mamourou Sidibe,
Kirsten vom Brocke, Abdoulaye Diallo, Bettina Haussmann,
Bocar Diallo, Baloua Nebie, Aboubacar Toure, Anja Christinck

1 Introduction

Sorghum (*sorghum bicolor*) is widely cultivated across West Africa, in a broad range of agro-ecological conditions and contrasting production objectives of individual farmers, women and men. These farmers use and manage varietal diversity of sorghum to optimize their household's productivity and minimize risks (Haussmann, et al., 2012). The intimate knowledge of West African farmers of these varieties calls for collaboration among farmers and researchers for variety development. Our plant breeding activities included collaborative setting of priorities, generation of new diversity, identification and testing of experimental varieties, and developing seed system activities with farmer organizations, like the "Cooperative des Producteurs Semenciers du Mandé" (Seed producers coop of Coprosem, Mali), the "Union Locale de Producteurs de Cereales" (Union of cereal producers, ULPC) in Mali and others in Burkina Faso (vom Brocke, et al., 2010).

The participating sorghum breeders came from the national agricultural research organizations in Mali (Institut d' Économie Rurale, IER; Institute of Rural Economy) and Burkina Faso (Institut de l'Environnement et Recherches Agricole, INERA; Institute of the Environment and Agricultural Research), the French Agricultural Research Centre for International Development (CIRAD), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The collaborative activities are described here for each step in the breeding process, followed by a brief section on policy impact, and conclusions.

2 Setting priorities for the breeding program

The priority setting included efforts to predict farmers' production system constraints and understand trait preferences, taking gender roles into account. The priorities for sorghum breeding in Mali were to develop new open-pollinated varieties with higher grain yield and better adaptation to the predominant growing conditions (Siart, 2008; Clerget, et al., 2008; Leiser, et al., 2012; Rattunde, et al., 2018). Grain quality should be appropriate for storage, processing, and food uses (Isaacs, et al., 2018; Weltzien, et al., 2018). In addition, the concentration of iron (Fe) in the whole grain should be maintained at or above the threshold of the local control variety named Tieblé (initially registered as CSM 335), derived from a Malian landrace.

3 Generating new diversity as a basis for breeding

The sorghum team emphasized use of local germplasm of the guinea-race of sorghum to provide a strong foundation for the diverse adaptation and grain quality traits demanded by farmers (Weltzien, et al., 2018). Exotic germplasm (mostly the caudatum race of sorghum) was introgressed at approx. 12% to increase variability for productivity. We used introgression with a single backcross generation and recurrent selection for population improvement in collaboration with farmers for this purpose.

We created backcrosses using a farmer-preferred guinea-race variety as recurrent parent. Several exotic donor parents were used, based on experiences in Australia (Jordan, et al., 2011). Farmers were very interested to select in these BC1-sub-populations, because of the acceptable levels of key farmer-preferred panicle, grain and glume traits, combined with useful diversity.

Recurrent selection for the improvement of populations, created by crossing multiple parents, is a cyclical process that results in novel gene combinations from the repeated recombination of the diverse parents, using a genic male-sterility system. In each cycle, the more promising progenies are selected and then inter-crossed to form the next population bulk. This is expected to increase the frequency of progenies with superior performance for the targeted traits while retaining genetic variation for further selection.

Farmer' collaboration with breeders to improve populations evolved over time (Table 1). Farmers engaged in deriving new progenies from the population bulk by growing plots of the population bulk selecting single plants, which then entered the breeders' program for either variety development, or the next cycle of recurrent selection. The farmers frequently detected differences not seen by the breeders. They thus helped to increase the population size of the breeding programs, and to focus the limited resources on plant types that were more acceptable. The farmers kept half of the seed of each selected panicle and gave the other half to the plant breeders.

Farmers also evaluated progenies in on-station and on-farm trials. Farmers with special expertise in observing panicles scored hundreds of progeny plots prior to harvest for critical traits, such as traits related to threshing. Women farmers judged grain quality of progenies by visually scoring grain desirability and grain hardness after harvest. These farmers were paid for contributing their special expertise. Farmers also volunteered to evaluate population progeny trials by attaching labels to more desirable progenies and afterwards discussed the strengths and weaknesses of the new materials they observed.

Table 1 Recurrent selection schemes used for sorghum in Mali (Weltzien, et al., 2019)

Year	Material sown and main step	Farmer Activity	Breeder Activity
1	Random-mated S0 population bulk (3-10,000 plants/field) to derive new progenies	Sow bulk in isolated fields, thin to single plants, label male-fertile plants at flowering, select desirable male-fertile panicles to derive S_1 lines	
2	S_1 progenies (500-750) for evaluation	On-station scoring of grain desirability, panicle appreciation, and threshability in S_1 trial; contribute to selection of panicles to derive S_2 lines. Experienced women farmers score grain quality	Manage S_1 progeny trials, evaluate for maturity, disease resistances, grain yield and overall appreciation, chose progenies for further testing based on index of farmer and breeder observations; conduct S_1 nursery to derive S_2 lines

continued

Year	Material sown and main step	Farmer Activity	Breeder Activity
3	S_2 progenies (approx. 125) for S_2 testing and selection	Score grain and panicle desirability, threshability, label desired progenies in S_2 trial; contribute to selection of panicles to derive S_3 lines for on-farm testing	Manage S_2 progeny trials, evaluate for maturity, disease resistances, grain yield and overall appreciation, create selection index to choose best progenies to recombine; conduct S_2 nursery to derive S_3 lines for line/variety development Plant remnant S_1-seed of the selected progenies in isolation for an initial random mating and increasing the frequency of the male sterility gene. Only seed from sterile plants will be harvested
4	S_1 progenies derived in S_0 (approx. 30) for random mating	Contribute to selection of desirable panicles based on form, grain and glume characteristics	Sow remnant S_1-seed of selected progenies in isolation, in alternating rows with seed harvested from sterile plants from the first random mating, label male-sterile and male-fertile plants, select panicles of desirable sterile-plants and bulk to create next cycle

4 Selecting in segregating materials

Selection over several generations in this phase operates like a funnel in reducing the total genetic diversity, attempting to focus on a more limited number of progenies/sub-populations of greatest interest for achieving the breeding objectives. The breeding programs strived to apply their evolving understanding of farmers' needs and preferences to define the breeding strategy for the following stages of selection.

Farmers' evaluation of progenies, as described for the population improvement activities, became an integral part of the breeding program and contributed to final selection of progenies to use for developing experimental varieties. Farmers sowed nurseries of between 30 to 50 early generation progenies to select within these segregating materials using their own criteria and growing conditions.

Selection for grain yield in early generations

Selection for grain yield only based on on-station testing was of questionable utility for achieving yield gains in farmers' fields under low-input, conditions (Bänzinger, Cooper, 2001). The sorghum team with 34 farmers tested the feasibility of early-generation yield testing on-farm, using a set of 150 progenies (S_2/S_3) and a trial design with sub-sets of 50 progenies and two common repeated check varieties tested per farmer. The farmers grew single-row plots to make sowing of the trials easy for farmers. Progenies were selected using either combined on-farm or on-station results and their on-farm yield performance was tested in subsequent years in a series of replicated on-farm trials. Despite the farmers' management practices and field conditions differing greatly among the various on-farm selection trials, early generation on-farm yield testing was found to be effective (Rattunde, et al., 2016).

5 Testing experimental varieties

5.1 Evaluation of grain yield performance and adaptation traits

The farmer-researcher collaboration in the testing stage addressed two main objectives: i) arriving at a joint assessment of varieties and their advantages and disadvantages; and ii) evaluating grain yield and its stability across a wide range of growing conditions within the priority target zone for the new varieties (Rattunde, et al., 2013; Weltzien, et al., 2006a, 2008).

The team developed a system for farmers (sometimes assisted by a village facilitator) to score a standard set of priority traits identified by farmers (crop duration, adaptation to the local conditions, panicle appreciation, overall appreciation) (Weltzien, et al., 2006a). Researchers assisted the farmers with grain yield and yield component measurements. The field book with all observations was kept by the farmers who conducted the trial, with researchers keeping a photocopy, for use for data analysis.

In each trial village, farmer visits were organized to evaluate the trials before harvest (Weltzien, et al., 2006a). The farmers chose the three most important criteria for which they scored varietal differences in small groups (vom Brocke, et al., 2010). The technicians recording the scores also noted reasons mentioned for scoring certain varieties especially high or low. Two separate trials were conducted, each with 16 entries (tall and short varieties separately) with two replications each. We used an alpha-lattice design with sub-blocks of four plots. A common landrace check variety (Tieblé) was used in all trials. Both trials were conducted in each of 10 to 12 villages by two farmers each, and in 2 to 3 research stations. Each set of experimental varieties were tested for two years, based on the farmers' and researchers' desire to see varietal performance over years. All experimental varieties were given short vernacular names that could easily be remembered, but without any suggestive meaning to facilitate farmers' discussions and feedback. The breeders conducted the analysis of individual and combined farmers' trials. The results were presented to the farmers for discussion and selection of entries for post-harvest grain quality tests, including village level sensory evaluations, and second stage, fully farmer-managed, on-farm testing. Robust data on grain yield performance and farmer appreciation of the experimental varieties over many diverse environments could thus be collected (Kante, et al., 2017; Rattunde, et al., 2013).

5.2 Post-harvest quality evaluations

Grain processing traits and culinary evaluations of experimental varieties were conducted in each of the participating villages after harvest, because grain quality, grain storage and food-processing attributes are critical for variety adoption. The farmers choose four of the experimental varieties for this evaluation based on the results from the field trials. For these post-harvest evaluations, teams of women provided quantitative and qualitative measurements of varietal differences for the ease and time taken for various processes, decortication losses, flour-to-grit ratios, and the swelling potential (i.e., the capacity to absorb water) of the stiff porridge (known as tô), one of the main local dishes (Isaacs, et al., 2018). A village-based panel of men and women taste testers evaluated the color, taste and consistency of the prepared food.

These grain quality evaluations provided the entry-point for evaluating nutritional qualities as a possible selection criterion, specifically iron concentration (Fe). The team initially tested approaches for assessing Fe concentrations in the food products consumed by farm-families, as obtained and measured during the culinary trial evaluations. As farm families consume only decorticated sorghum grain, we focused on iron analysis of decorticated grains, initially. We identified significant genetic variation for iron concentrations in decorticated grains (grain from which the pericarp had been removed, using a mortar and pestle). These variations could not completely be explained by decortication yields (the amount of dry matter removed from the grain during the decortication process). In addition, we observed that approx. 50% of the total iron contained in the whole grain was removed during the decortication process.

The nutritionists on the team then tested procedures for producing acceptable flour and food products from flour prepared from whole sorghum grains, in collaboration with the women groups conducting the culinary tests and variety trials. A process that combined soaking the grains overnight and milling them by machine resulted in a highly acceptable product. Based on these results, the team limited their breeding effort for high iron concentrations to a monitoring activity to ensure that new varieties were not causing reduced iron concentration. The team also focused on the identification of those varieties that provided significantly higher levels of iron than a local control. More effort was invested in developing a training program for women, and to work with women groups to learn about the nutritional advantages of whole grain flour, as well as other options for providing their children with adequate nutrition, using local ingredients (Bauchspies, et al., 2017).

5.3 Testing varieties under fully farmer-managed conditions

The second stage trials were conducted to provide a larger number of farmers the opportunity to evaluate varieties under their own field and management conditions (Weltzien, et al., 2006a). The testing procedure evolved to include an option to split the plots with one half fertilized, so that farmers could assess each variety's performance with and without fertilizer. Adaptation trials were conducted in villages with four or more farmers interested to conduct this type of trial. The farmers needed to agree on the specific objective for their trials, e.g., finding varieties with good performance (even if they were having Striga infestation), late or early sowing, more or less weeding, or in a specific intercropping situation. As demand for these trials was very high, for several years, trials were only given to those villages where a group of at least four women conducted a variety trial in their own fields. The trials were designed with three, four, five or sometimes six varieties, always including a common local check widely grown in the village. Farmers recorded their observations directly or with help of village facilitators, and each group of farmers jointly discussed and documented their varietal choices. Researchers visited some of the trials and assisted some groups, particularly women's groups, with harvest and weighing of plot yields. Yield data from these trials, extracted from the above-mentioned field books, permitted broad assessments of the relative performance, profitability, and risks of not recouping investments in seed of improved open-pollinated varieties and hybrid varieties and fertilizer relative to the farmers' local varieties over diverse environments for men and women farmers (Weltzien, et al., 2018).

6 Developing seed system activities with farmer organizations

Although several varieties were identified through the above-described process and registered in the national variety catalogue, the spread of seed of newly identified varieties was very slow within villages conducting the on-farm trials, and even slower to surrounding villages. A commercial seed system for staple food crops, such as sorghum, does practically not exist in Mali; in addition, cultural norms make it largely unacceptable for individual farmers to buy or sell seed to others on a regular basis. Seed dissemination was further hampered by the introduction of the regional seed legislation of the Economic Community of West African States (ECOWAS) in 2008, to which Mali as a member state is committed. According to this law, variety registration and seed certification are mandatory requirements. In practice, there was widespread insecurity regarding future modes of implementation at the national and regional levels and prospects for farmer seed marketing.

However, there was interest among certain farmers and farmer organizations collaborating in the participatory trials to start larger scale seed production, compliant with the emerging seed marketing rules. With training and support by the breeders and technicians from the research stations, several groups of farmers launched formal seed production of the preferred varieties identified in the trials. These groups included the (initially) very small cooperative Coprosem, which was started by just 8 farmers and less than 10 hm^2 of seed production per year (Dalohoun, et al., 2011) and a very large union of farmer cooperatives (Union Locale de Producteur Cereales, ULPC) engaged in collective marketing of their grain and interested in new higher yielding varieties for their members. The choice of which varieties to produce was made by the individual farmers and seed-producer groups. The prior season test-results and discussions at the Annual Feedback and Planning Meetings were used to formulate their list of varieties for seed production. IER and ICRISAT sorghum breeding program jointly conducted training in commercial seed production and certification for farmer groups involved in seed production.

The number of farmer-seed producer cooperatives as well as the amount of seed produced and marketed by them has constantly increased since then, making these cooperatives important "new players" in the seed systems of several West African countries (Christinck, et al., 2014). Since each cooperative can make their own decision on which varieties from the breeding program to produce, based on their members' preferences and needs, this system is responsive to diverse agroecological and socioeconomic conditions. Seed production and marketing is embedded in the collective activities of the cooperatives, thus serving "the common good" . For this reason, it has become much more acceptable for individual farmers to engage in seed production and marketing, or to buy seed of specific varieties.

7 Policy impact

The collaborative breeding program of ICRISAT, national research and farmer organizations contributes to several overarching goals that form part of international, regional and national policies addressing food security and nutrition as well as resilience of farming and food systems and adaptation to climate variability and change. It shows exemplarily how agronomic, post-harvest and nutrition-related traits can be addressed simultaneously in a breeding program. The program's approach to facilitating participation of women and men turned out to be a key success factor in this regard, enabling nutritional benefits for vulnerable groups, such as women and young children.

The approach can also serve as one example for the realization of farmers' rights as set out in Article 9 of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). Through manifold group-based and knowledge-exchange activities, farmers' traditional knowledge has been strengthened and put to active use. They participate in the sharing of benefits arising from the use of plant genetic resources by having access to a broader range of varieties that meet their preferences and needs as well as through income-generating activities relating to the production, processing, and marketing of seed. Through formal involvement as cooperation partners, farmers and their organizations also participate in decision-making at national level, e.g., by contributing to priority setting of national breeding programs. Farmers maintain far-reaching rights to save, use, exchange and sell seed, based on their enhanced capacity to produce and sell seed on a legal basis. Since seed of varieties developed by national and international breeding programs is not covered by intellectual property rights, farmers can continue to save farm-produced seed of newly developed varieties for their own use without any legal restrictions.

8 Conclusion

Capacities and skills of farmers as well as breeders contributed to achieving genetic gains for the objectives targeted. Certainly, every joint interaction and project with farmer-researcher collaboration advanced joint learning and effective farmer-oriented breeding. Important advantages of long-term farmer-breeder collaboration for achieving changes include:

- The possibility of systematic follow-up from understanding of farmer needs and conditions to changing the design and activities in the breeding program;

• Establishing synergetic roles and sharing responsibilities for breeding at larger scales;

• The decentralized design of the breeding programs helped achieve sizeable genetic gains despite the limited resources and the complex environmental and socio-economic contexts;

• The sustained collaboration of farmers and breeders resulted in detectable contributions to overarching goals, such as:

– Enhanced food security, with understanding of and breeding for traits required for reduced risk to climate variability (Haussmann, et al., 2012; Weltzien, et al., 2006b) and yield improvements expressed under poor soil-fertility and farmers' low-input management systems (Kante, et al., 2017; Leiser, et al., 2015, 2012; Rattunde, et al., 2013). This helped to reduce the share of sorghum grain that farmers purchased for food while increasing the portion of harvest they sell (Smale, et al., 2018);

– Improved nutrition, particularly in view of micronutrient deficiencies that are widespread among women and children in West Africa (Bauchspies, et al., 2017; Christinck, Weltzien, 2013). This included understanding the women's practice of preparing separate meals for children with the grain they produce, along with selecting for vitreous grain and reducing micronutrient losses during decortication. It provided a pathway by which the benefits of bio-fortified varieties reach vulnerable groups, especially children;

– Empowerment of farmers: women and men initiated their own variety and cropping-system experimentation as well as methods of marketing seed and facilitating communication about seed among farmers and farmer cooperatives based on their learning and access to novel types of varieties (Weltzien, et al., 2018). They became co-owners of the variety development and dissemination process;

- Conservation and sustainable use of agro-biodiversity: our approach makes extensive use of local germplasm in breeding programs to produce a wider range of variety types that are made available to farmers through a decentralized system for variety development, seed production and delivery. This approach involves and responds to different types of farmers within and across contrasting agro-ecological zones (Weltzien, et al., 2018).

9 Acknowledgements

It is with profound gratitude that we acknowledge the commitment, curiosity, hospitality and many frank and open discussions with members of the different farmer organizations, the village-level farmer facilitators, as well as technical staff associated in the districts. We also wish to thank the donors who supported this research, the McKnight Foundation Collaborative Crop Research Program, BMZ/GIZ, IFAD, EU, the Rockefeller Foundation, the Bill and Melinda Gates Foundation and USAID.

References

Access to Seeds Foundation, 2018. The rise of the seed-producing cooperative in Western and Central Africa[R]. Access to Seeds Foundation, Amsterdam, The Netherlands.

Ashby J A, 1990. Evaluating technology with farmers a handbook[R]. CIAT, Cali, Colombia.

Atlin G N, Cooper, M, Bjornstad A, 2001. A comparison of formal and participatory breeding approaches using selection theory[J]. Euphytica, 122: 463-475.

Bänzinger M, Cooper M, 2001. Breeding for low input conditions and consequences for particpatory plant breeding: Examples from tropical maize and wheat[J]. Euphytica, 122: 503-519.

Bauchspies W K, Diarra F, Rattunde F, Weltzien E, 2017. "An Be Jigi": Collective cooking, whole grains, and technology transfer in Mali[J]. FACETS, 2: 955-968.

Christinck A, Diarra M, Horneber G, 2014. Innovations in seed systems: Lessons from the CCRP-funded project "Sustaining Farmer-managed Seed Initiatives in Mali, Niger and Burkina Faso" [EB/OL]. http://www.ccrp.org/wp-contednt/uploads/2020/06/CCRP_SeedSystems_Nov 2014.pdf.

Christinck A, Weltzien E, 2013. Plant breeding for nutrition-sensitive agriculture: An appraisal of developments in plant breeding[J/OL]. Food Security, 5:693-707. https://doi.org/10.1007/s12571-013-0288-2.

Christinck A, Weltzien E, Hoffmann V, 2005. Setting breeding objectives and developing seed systems with farmers. A handbook for practical use in participatory plant breeding projects[M]. Magraf Publishers and CTA, Weikersheim, Germany and Wageningen, The Netherlands.

Clerget B, Dingkuhn M, Goze E, Rattunde H F W, Ney B, 2008. Variability of phyllochron, plastochron and rate of increase in height in photoperiod-sensitive sorghum varieties[J]. Annals of Botany, 101: 579–594. https://doi.org/10.1093/aob/mcm327.

Coulibaly H, Didier B, Sidibé A, Abrami G, 2008. Les systèmes d'approvisionnement en semences de mils et sorghos au Mali: Production, diffusion et conservation des variétés en milieu paysan[J]. Cahiers Agricultures, 17: 199–209.

Dalohoun D N, van Mele P, Weltzien E, Diallo D, Guinda H, vom Brocke K, 2011. Mali : When government gives entrepreneurs room to grow[M]// Paul van Mele, Jeffery W Bentley, Robert G Guéi. African seed enterprises. Sowing the seeds of food security. FAO and Africa Rice, 56-88.

Haussmann B I G, Rattunde F, Weltzien-Rattunde E, Traoré P S C, vom Brocke K, Parzies H K, 2012. Breeding strategies for adaptation of pearl millet and sorghum to climate variability and change in West Africa[J]. Journal of Agronomy and Crop Science, 198: 327-339. https://doi.org/10.1111/j.1439-037X.2012.00526.x.

Isaacs K, Weltzien E, Diallo C, Sidibé M, Diallo B, Rattunde F, 2018. Farmer engagement in culinary testing and grain-quality evaluations provides crucial information for sorghum breeding strategies in Mali[M]// Tufan H A, Grando S, Meola C. State of the knowledge for gender in breeding: Case studies for Practitioners. Lima, Peru, 74-85. CGIAR Gender and Breeding Initiative. Working Paper. No. 3. http://hdl.handle.net/10568/92819.

Jordan D R, Mace E S, Cruickshank A W, Hunt C H, Henzell R G, 2011. Exploring and exploiting genetic variation from unadapted sorghum germplasm in a breeding program[J]. Crop Science, 51: 1444. https://doi.org/10.2135/cropsci2010.06.0326.

Kante. M, Oboko, R, Chepken, C, 2017.Influence of perception and quality of ICT-based agricultural input information on use of ICTs by farmers in developing countries: Case of Sikasso in Mali[J/OL]. The Electronic Journal of Information Systems in Developing Countries, 83: 1-21.https://doi.org/10.1002/j.1681-4835.2017.tb00617.x.

Kountche B A, Hash C T, Dodo H, Laoualy O, Sanogo M D, Timbeli A, Vigourou Y, This D, Nijkamp R, Haussmann B I G, 2013. Development of a pearl millet Striga-resistant genepool: Response to five cycles of recurrent selection under Striga-infested field conditions in West Africa[J]. Field Crops Research, 154: 82-

90. http://dx.doi.org/10.1016/j.fcr.2013.07.008.

Leiser W L, Rattunde H F W, Piepho H P, Weltzien E, Diallo A, Melchinger A E, Parzies H K, Haussmann B I G, 2012. Selection strategy for sorghum targeting phosphorus-limited environments in West Africa: Analysis of multi-environment experiments[J]. Crop Science, 52: 2517-2527. https://doi.org/10.2135/cropsci2012.02.0139.

Leiser W L, Rattunde H F W, Weltzien E, Haussmann B I G, 2014. Phosphorus uptake and use efficiency of diverse West and Central African sorghum genotypes under field conditions in Mali[J]. Plant and Soil, 377: 383-394. https://doi.org/10.1007/s11104-013-1978-4.

Leiser W L, Weltzien-Rattunde H F, Weltzien-Rattunde E, Haussmann B I G, 2018. Sorghum tolerance to low-phosphorus soil conditions[M]// Achieving sustainable cultivation of sorghum: Genetics, breeding and production techniques. Burleigh Dodds Series in Agricultural Science. Burleigh Dodds Science Publishing, 247-272. https://doi.org/10.19103/AS.2017.0015.30.

Leiser W, Rattunde F, Piepho H P, Weltzien E, Diallo A, Touré A, Haussmann B, 2015. Phosphorous efficiency and tolerance traits for selection of sorghum for performance in phosphorous-limited environments[J]. Crop Science, 55: 1-11. https://doi.org/10.2135/cropsci2014.05.0392.

Quirós C A, Gracia T, Ashby J A, 1991. Farmer evaluations of technology: Methodology for open-ended evaluation[R]. IPRA : CIAT, Cali, Colombia.

Ragot M, Bonierbale M, Weltzien E, 2018. From market demand to breeding decisions: A framework[R]. CGIAR Gender and Breeding Initiative Working Paper 2. Lima (Peru): CGIAR Gender and Breeding Initiative. http://hdl.handle.net/10568/91275.

Rattunde F, Sidibé M, Diallo B, van den Broek E, Somé H, vom Brocke K, Diallo A, Nebie B, Touré A, Isaacs K, Weltzien E, 2018. Involving women farmers in variety evaluations of a "men's crop": Consequences for the sorghum breeding strategy and farmer empowerment in Mali[M]// Tufan H A, Grando S, Meola C. State of the knowledge for gender in breeding: Case studies for practitioners. Lima, Peru, 95-107. CGIAR Gender and Breeding Initiative. Working Paper. No. 3. http://hdl.handle.net/10568/92819.

Rattunde H F W, Michel S, Leiser W L, Piepho H P, Diallo C, vom Brocke K, Haussmann B I G, Weltzien E, 2016. Farmer participatory early-generation yield testing of sorghum in West Africa: Possibilities to optimize genetic gains for yield in farmers' fields[J]. Crop Science, 56: 1-13. https://doi.org/10.2135/cropsci2015.12.0758.

Rattunde H F W, Weltzien E, Bramel-Cox P J, Kofoid K, Hash C T, Schipprack W, Stenhouse J W, Presterl T, 1997. Population improvement of pearl millet and sorghum: Current research, impact and issues for implementation[R]. Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet. Lubbock, Texas USA, 188-212.

Siart S, 2008. Strengthening local seed systems: Options for enhancing diffusion of varietal diversity of sorghum in Southern Mali[R]. University of Hohenheim, Stuttgart, Germany.

Smale M, Assima A, Kergna A, Thériault V, Weltzien E, 2018. Farm family effects of adopting improved and hybrid sorghum seed in the Sudan Savanna of West Africa[J]. Food Policy, 74: 162-171. https://doi.org/10.1016/j.foodpol.2018.01.001.

Smale M, Kernga A, Assima A, Weltzien E, Rattunde F, 2014. An overview and economic assessment of sorghum improvement in Mali[R]. Michigan State University International Development Working Paper.

vom Brocke K, Trouche G, Weltzien E, Barro-Kondombo C P, Gozé E, Chantereau J, 2010. Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria[J]. Field Crops Research, 119: 183-194. https://doi.org/10.1016/j.fcr.2010.07.005.

vom Brocke K, Trouche G, Weltzien E, Kondombo-Barro C P, Sidibé A, Zougmoré R, Gozé E, 2014. Helping farmers adapt to climate and cropping system change through increased access to sorghum genetic resources adapted to prevalent sorghum cropping systems in Burkina Faso[J]. Experimental Agriculture, 50: 284–305. https://doi.org/10.1017/S0014479713000616.

Weltzien E, Christinck A, 2008. Participatory plant breeding: Developing improved and relevant crop varieties with farmers[M]// Snapp S, Pound B. Agricultural systems: Agroecology and rural innovation for development. Academic Press, Burlingont, M A, USA and London UK, 211–251.

Weltzien E, Christinck A, Touré A, Rattunde F, Diarra M, Sangare A, Coulibaly M, 2006a. Enhancing farmers' access to sorghum varieties through scaling-up participatory plant breeding in Mali, West Africa[M]// Almekinders C, Hardon J. Bringing farmers back into breeding. Experiences with participatory plant breding and challenges for institutionalisation, Agromisa. Agromisa Foundation, Wageningen, Netherlands, 58-69.

Weltzien E, Kanouté M, Toure A, Rattunde F, Diallo B, Sissoko I, Sangaré A, Siart S, 2008. Sélection participative des variétés de sorgho à l'aide d'essais multilocaux dans deux zones cibles[J]. Cahiers Agricultures, 17: 134-139.

Weltzien E, Rattunde H F W, Clerget B, Siart S, Touré A, Sagnard F, 2006b. Sorghum diversity and adaptation to drought in West Africa[M]// Jarvis D, Mar I, Sears L. Enhancing the use of crop genetic diversity to manage abiotic stress in agricultural production systems. IPGRI, Rome, Italy, Budapest, Hungary, 31-38.

Weltzien E, Rattunde H F W, Sidibe M, vom Borcke K, Diallo A, Haussmann B, Diallo B, Nebie B, Toure A, Christinck A, 2019. Long-term collaboration between farmer organizations and plant breeding programs: Cases of sorghum and pearl millet in West Africa[M]// Westengen O W Tone. State of the art of participatory plant breeding. Routlegde, Oxon, UK, 29-48.

Weltzien E, Rattunde H F W, van Mourik T A, Ajeigbe H A, 2018. Sorghum cultivation and improvement in West and Central Africa[M]// Achieving sustainable cultivation of sorghum: Sorghum utilization around the world. Burleigh Dodds Science Publishing, Cambridge, UK, 380.

Yapi A M, Kergna A O, Debrah S K, Sidibe A, Sanogo O, 2000. Analysis of the economic impact of sorghum and millet research in Mali, Impact Series[R]. International Crops Research Institute for the Semi-arid Tropics, Patancheru, Andhra Pradesh, India.