Participatory non-GM cotton breeding to safeguard organic cotton production in India

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Key words: cotton, breeding, local adaptation, genetic diversity, farmer participation

Abstract

Due to fast spread of genetically modified (GM) Bt-cotton, organic farmers in India were suddenly exposed to a severe shortage of non-GM seed threatening the organic cotton production. Therefore, organic cotton grower organisations got engaged in decentralized participatory cotton breeding to develop their own locally adapted cultivars and to reintroduce the traditional more robust Desi cotton species. By engaging and training advisors and farmers using participatory methods, they became researchers and breeders. The close collaboration with the textile industry ensures that the market demand is also met. Training of male and female farmers in cultivar selection and seed propagation made them independent from global seed companies. Participatory breeding is an important tool to get prepared for future challenges like climate change and at the same time strengthens the relationship along the value chain. The project can serve as a successful model for other organisations and crops.

Acknowledgments

This project is supported by Mercator Foundation Switzerland, bioRe Foundation Switzerland, Corymbo Foundation, Coop Sustainability Fund, and C&A foundation.

Introduction

Up to 80% of world's organic cotton has been produced in India in 2010, but dropped dramatically due to shortage on non-GM cotton seed. Genetically modified F1 hybrids of the tetraploid upland cotton (*Gossypium hirsutum*) carrying a gene from Bacillus thuringiensis (Bt cotton) account for more than 95% of the cotton area in India. The non-GM cotton seed market became completely eroded (Nemes, 2010; Marty 2013) and locally adapted diploid Desi cotton (*G. arboreum, G. herbaceum*) almost disappeared. Fast action was needed to re-establish non-GM cotton seed supply chains and breeding programs to support organic and low input cotton farmers in India. Participatory plant breeding (PPB) offers a great opportunity for developing locally adapted cultivars as well as for maintaining and increasing genetic diversity (Lancon et al. 2004; Ceccarelli et al. 2009). The main aim of the project was to (i) foster collaboration among stakeholders, (ii) introduce participatory breeding approaches for organic cotton, (iii) evaluate improved cotton cultivars in smallholders' organic cotton fields, and (iv) gain information about the suitability of different types of cotton species and cultivars for organic and low input farming in India.

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Material and methods

The participatory cotton breeding project was initiated in 2011 and has been driven by two local organic cotton producer organisations bioRe Association in Madhya Pradesh and Chetna Organic in Odisha. Cotton germplasm and guidance on cotton breeding was provided by Prof. S.S. Patil heading the cotton breeding department of the University of Agricultural Science (UAS) Dharwad, Karnataka. FiBL coordinated the transdisciplinary project and provided training in participatory methods. To initiate the process a two day national workshop was organized to develop a common vision and roadmap towards safeguarding the heritage of Indian Desi cotton, maintaining genetic diversity, avoiding GM contamination and supporting the organic farmers with suitable cultivars (Dharwad declaration 2011). Based on the commitment of the stakeholders to join forces for re-establishing the seed supply chain we started cotton cultivar evaluation and participatory cotton breeding in 2011 and 2013, respectively. Five activity strains were followed in parallel or sequential: (i) replicated on-station field trials (mother trials) and replicated multi location trials (year 4-6), (ii) unreplicated on-farm trials (baby trials) in year 1 to 6, (iii) pilot cultivation in year 4 to 6, (iv) new crosses in year 3, and (v) single plant selection in segregating populations in year 4-6. This was accompanied by capacity building at local level including training of trainers, farmer workshops on cultivar ideotypes, farmers’ trainings for cultivar evaluation, crossings, single plant selection and seed multiplication. Networking and awareness rising was done on local level in India, and Switzerland as well as on international level.

Based on the workshop with farmers we identified the most distinct cotton farming systems per region: (i) summer sown (May-June) cotton on fertile soil with irrigation and (ii) monsoon sown (June – July) cotton on shallow or light soils in Madhya Pradesh and (iii) shallow red soil and (iv) black fertile soil and both under rainfed conditions in Odisha. Black soil is characterized by deep soil with high clay content (>40%), whereas light or red soils are shallow soils with high sand content (>50%) and low water holding capacity. Annual precipitation (mainly during monsoon: June till September) at field sites in Khargone district in Madhya Pradesh and at sites in Kalahandi district in Odisha, ranged between 760 and 937mm and between 1372 till 1855mm, respectively, during project years (2013-2016). Highest average temperature was reached in May with 38°C in Madhya Pradesh and 33°C in Odisha. On-station trials: each year 50 to 90 non-GM cultivars and breeding lines of different cultivar types (*G. hirsutum* hybrids, *G. hirsutum* varietal lines, *G. arboreum* varietal lines) were tested against commercial F1 hybrids under the different growing conditions with two replications in a randomized complete block design. Promising cultivars were selected for further testing, while the others were discarded and replaced by new entries. Plant spacing was first 1 x 1 m and later reduced to 1 x 0.3 m for summer sown cotton and 0.6 x 0.3 m for rainfed conditions for varietal lines and 1 x 0.6 m or 0.6 x 06 m for F1 hybrids, respectively. The 4 row plots (4 x 7 m) were always separated by other species (millet) or by morphologically distinct *G. arboreum* lines to avoid any mixture during picking time. Cotton was picked two up to three times (October till January) depending on soil fertility and irrigation. The best 10 cultivars based on two years data were tested with three replication under 2-4 organically managed farms (multi location trials). Germination, vegetative growth, plant morphology, susceptibility to bollworm, sucking pests and diseases as well as seed cotton yield per plant and hectar were assessed for the different pickings. Male and female farmers visited the on-station trials and make a ranking of cultivars during picking period, independent from the rating of the breeder and the research team. Ginning output and fiber quality parameters (fibre length as Upper half mean Length UhmL (mm), fibre finesse (micronaire), fibre strength (g/tex), Maturity Index (MI), Uniformity Index (UI) and Short Fibre Index (SFI)) were assessed for the bulk of the first two picking and the last picking.

In addition, on-farm cultivar evaluation trials were conducted with a set of the five most promising cultivars and one common standard (in two replications) by farmers in their own fields after training by the research team. In total 4 sets of cultivars were tested on either heavy or light soil aiming for 6 farmers per set, resulting in total of 24 on-farm trials per region and year. Due to small fields only 100 plants per cultivar were tested, allowing the farmer to identify the different characteristics of the cultivars. Seed cotton was picked per cultivar by colour coding and sent for fiber quality analysis. Farmers made a ranking of the genotypes with detailed explanations. After 3 year successful testing in on-station and on-farm trials, seed of candidate cultivars were distributed among farmer for pilot cultivation to be grown on 400 to 1000 m2 next to their standard cultivar. Yield and fiber quality of both cultivars was assessed.

In 2013 we started with new crosses of tetraploid *G. hirsutum* lines and diploid *G. arboreum* lines to start participatory selection under organic production in the target environment (heavy soil and light soil) at both regions. The homogeneous F1 generation was multiplied and the obtained F2 progenies were provided to the two organic cotton growers organisations. The F2 plants were independently selected by the breeder, research team and farmer at each location. Phenotypic selection by farmers was compared with selection by researchers and experienced cotton breeders. Selected single plants (5 – 10%) were harvested to determine seed cotton yield, fiber length and micronair. Only those plants with satisfying fibre quality were selected and grown as one-row plot in the F3 generation. This process was repeated till F5 or F6 generation, afterwards the lines will enter the cultivar evaluation trials. In parallel the farmers have been continuously trained in all aspects of plant breeding, seed multiplication and GM testing to obtain a "farmer's breeder curriculum". Female farmers are especially encouraged to participate together with their husbands or in separate groups. Local partners have organized or attended national meetings and workshops to exchange with other organic cotton growers, breeders, seed companies, and stakeholders of the value chain. The importance of securing non-GM cotton seed was also forwarded to the international Organic Cotton Round Table of Textile Exchange, organizing yearly meetings of the Seed & Soil Task Force, to obtain attention and engagement of the textile brands.

Results

Summer sowing in fertile soil with irrigation resulted in much higher yield (2.0 t ha-1) than monsoon sowing in sandy soil (1.2 t ha-1) and we obtained different rankings of the cultivars for heavy soil and light soil trials. Delayed sowing can cause further yield reduction. Pest attack of bollworms was very severe under fertile conditions (67%) with two crops per season compared to the low bollworm pressure under rainfed conditions (7%) with only one major crop per year. While *G. arboreum* is more tolerant against sucking pests, the susceptibility against bollworm is similar to F1 *G. hirsutum* hybrids. *G. hirsutum* varietal lines show higher susceptibility to bollworm which might be attributed to their delayed fruiting compared to F1 hybrids. *G. arboreum* showed high yield potential and yield stability both on light and heavy soil in Madhya Pradesh, however the fiber length is often not fitting the textile industry (fiber length > 28mm). A few *G. arboreum* introgression lines had consistently long fiber, while others show strong environmental effects. In Odisha the performance of existing *G. arboreum* cultivars was not satisfactory, due to late boll opening. Here early genotypes need to be selected. For female farmers boll opening and easy picking is of great importance, while male farmers are interested in boll size, plant height and germination. In general, cotton growth under rainfed conditions is reduced and therefore, a higher plant density should be implemented to increase productivity per ha. Under less fertile conditions *G. hirsutum* varietal lines can outperform F1 hybrids, which cannot realize their yield potential under rainfed conditions. We observed on average higher yield level in on-station trials compared to on-farm trials. However, there is a huge variation for yield between the different farmers, indicating the great scope for yield improvement if the cotton management is done properly. Yield potential of the best cultivars can only be reached if the crop management is also optimized with respect to fertilization, timely weed control, and preventive pest control. Single plant selection under organic conditions was very successful, as new developed lines showed high yield potential under fertile and less fertile management. Final data will be presented at the conference. It was possible to set up cotton cultivar evaluation trials under organic conditions to identify and multiply cultivars that are suited for organic cotton farmers and meet the demand of the textile industry to close the seed gap in the short term (4-6 years). We could identify in Madhya Pradesh and Odisha ten and three promising non-GM cotton cultivars that have a high yield potential and yield stability and meet the expectation of the textile industry. Comparing the different cultivar types it became obvious that F1 hybrids can outyield varietal lines only under very favourable growing conditions, and that *G. arboreum* were very resilient against various stresses like water logging, drought or sucking pests.

Discussion

The organic sector has to take responsibility for its own seed supply and breeding, which need to be done under organic conditions. Priorities for optimal traits are quite different between breeders, farmers, also between female vs. male farmers, and the textile industry. To be successful all aspects must be considered. Under low fertility and rainfed conditions traditional G. arboreum have much higher yield than *G. hirsutum*. A limited number of *G. arboreum* show good fiber quality, but picking time is increased. Inbred lines can outyield hybrids under less favorable conditions. A broad range of genotypes is needed to cover the different growing systems, soil types and demands of textile industry. Continuous breeding is indispensable to cope with climate change and new pest & diseases evolving. Cultivation (e.g. plant density) need to be adjusted to each cultivar, therefore breeding must go hand in hand with improvement of plant management and anticipated future trends like mechanical harvest.

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