Institution: Aberystwyth and Bangor Universities - Biosciences, Environment and Agriculture Alliance (BEAA)

Unit of Assessment: 6: Agriculture, Veterinary and Food Science

Title of case study: Novel genetic marker-assisted breeding produced a pearl millet hybrid grown on 700,000 ha of drought-prone areas in Northern India which has improved food security of three million people

1. Summary of the impact

Research using novel techniques of genetic marker-aided selection enabled the development of new high yield, disease- and drought-resistant pearl millet hybrids, of which *HHB67-Improved* was released throughout India. *HHB67-Improved* is the first product of marker-assisted breeding to reach cereal producers in India and has spread rapidly since its release, preventing yield losses to downy mildew of up to 30% (valued at £7.8M) per year, and providing £2.6M additional annual grain yield. By 2011, it was grown on over 700,000 ha and currently three million people have improved food security as a direct result of this international development focused work.

2. Underpinning research

Pearl millet is grown for grain and stover in some of the harshest environments of Africa and South Asia. In India, where 40% (9M ha) of the world's millet is grown, at least 70% consists of genetically uniform hybrids, particularly vulnerable to downy mildew, the single most destructive pearl millet disease. Epidemics can cause reductions in total harvests of 30% or more. As the crop is rain-fed, scant and unreliable rainfall can further drastically reduce yield. Grown by the poorest farmers cultivating the least favourable land, pearl millet stands between famine and food sufficiency for many families, and improving downy mildew resistance and yield in a widely grown drought tolerant variety such as *HHB67* has had a major impact on improving food security.

Collaborative research by the Centre for Arid Zone Studies (now Centre for Advanced Research in International Agricultural Development, CARIAD) at Bangor University, the Institute of Grassland and Environmental Research (now Institute of Biological, Environmental and Rural Sciences, IBERS) at Aberystwyth, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the John Innes Centre used a combination of traditional techniques and the novel method of genetic marker-assisted backcrossing selection to develop improved hybrids of pearl millet, as part of the DFID-funded Plant Sciences Research Programme. This collaborative research since 1993 by Professor Witcombe (1990-present), Dr Yadav (researcher 1996-present), Dr Howarth (researcher 1985-present) and Dr Breese (researcher 1996-2006) in BEAA produced a number of new genetic resources, including the first ever molecular marker map in pearl millet [3.1], and maps of the genetic basis of specific traits such as disease resistance [3.2, 3.3], and yield. These were a prerequisite for the subsequent marker-assisted breeding in millet [3.4].

This research enabled the subsequent transfer of downy mildew resistance into the popular millet variety *HHB67* [3.5] using marker-assisted backcrossing [3.6], a new model for hybrid breeding combining traditional techniques and the high-tech method of genetic marker-assisted selection to introduce the mapped downy mildew traits into a new cross. *HHB67* was widely grown (about 550,000 ha) by resource-poor farmers in Northern India but was becoming very susceptible to downy mildew. The aim of our research was to retain the advantageous traits of *HHB67* (high yield and drought escape through very early maturity) whilst improving downy mildew resistance.

Genetic markers for downy mildew resistance identified by BEAA from the ICMP451 parent were used to backcross a downy mildew resistance quantitative trait locus (QTL) into the male-parent of *HHB67*. Subsequent screening to confirm downy mildew resistance in the backcross progeny was done by BEAA and ICRISAT by 2000. Using marker-assisted backcrossing allowed quick identification of resistance traits in the laboratory through analysis of the plant's DNA, a much faster and more reliable process than field trials. Conventional backcross transfer of downy mildew

resistance to a parental donor plant of *HHB67* took nearly nine years (1991-1999), while novel marker-assisted backcross transfer was completed in just over three years (1997-2000), once the markers had been developed and marker-trait associations established.

Field screening of the best backcross products at ICRISAT and downy mildew screening at BEAA was followed by field testing of the best of these in Northern India in 2001-2004. From these trials, the best line not only had improved downy mildew resistance but, through beneficial non-target contributions from ICMP451, 5-10 % more grain and stover yield than the original *HHB67* [3.5]. *HHB67-Improved* constitutes a technological milestone in unconventional plant improvements, marking the era of DNA marker-assisted breeding.

3. References to the research

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3.5. Hash, C.T., Sharma, A., Kolesnikova-Allen, M.A., Singh, S.D., Thakur, R.P., Bhasker Raj, A.G., Ratnaji Rao, M.N.V., Nijhawan, D.C., Beniwal, C.R., Sagar, P., Yadav, H.P., **Yadav**, Y.P., Srikant, Bhatnagar, S.K., Khairwal, I.S., **Howarth, C.J., Cavan, G.P.,** Gale, M.D., Liu, C., Devos, K.M., **Breese, W.A., Witcombe, J.R**. 2006. Teamwork delivers biotechnology products to Indian small-holder crop-livestock producers: Pearl millet hybrid "HHB67-Improved" enters seed delivery pipeline. *SAT e-Journal* **2:** 3 pp. Available at: http://www.icrisat.org/Journal/bioinformatics/v2i1/v2i1teamwork.pdf

3.6. **Witcombe, J.R**., Hash, C.T. 2000. Resistance gene deployment strategies in cereal hybrids using marker-assisted selection: gene pyramiding, three-way hybrids, and synthetic parent populations. *Euphytica* **112**: 175-186. Doi 10.1023/A:1003836132603. 45 citations.

4. Details of the impact

HHB67-Improved was the first pearl millet variety produced by DNA marker-assisted-selection to reach farmers in India. In 2005, it was officially approved for cultivation in Haryana state, followed by approval of its All-India release later that year. Large quantities of Breeder Seed of the parental lines of *HHB67-Improved* were distributed by ICRISAT and Haryana Agricultural University in 2005-06 to public and private seed agencies, sufficient to sow more than 50,000 ha with Certified Hybrid Seed of *HHB67-Improved* during the 2006 rainy season. Provision of this initially free Breeder Seed to the seed industry resulted in its widespread adoption in drier parts of Rajasthan and Haryana, replacing the original *HHB67* variety [5.1].

In 2008, large-scale seed production of affordable *HHB67-Improved* was taken up in Nizamabad and Kurnool districts of Andhra Pradesh. Seed production has continuously increased, reaching 3491 t in 2010/11. Over 1.1M packets of seed were produced that year and over 900,000 sold in

Rajasthan alone, demonstrating its growing, phenomenal rate of adoption by the seed industry and farmers across North-Western India. This replaced the original *HHB67* variety, the seed production of which had risen from 81 t in 1991 to a peak production of 2835 t in 1999, but by 2008 was no longer in the production chain because of increased susceptibility to downy mildew [5.2]. By this time it had been effectively replaced by the downy mildew resistant and higher yielding *HHB67-Improved*, allowing farmers to continue to grow this unique very early maturing hybrid.

Impact on measures of improved international food security, increased production and economic value to farmers and their families

In Rajasthan and Haryana states, the area of *HHB67-Improved* cultivation increased from 47,000 ha in 2006, to 875,000 ha in 2011, an increase from 0.2% to 4.4% of the total Indian pearl millet area in just 3 years [5.1]. Such vast expansions of growth reflect the popularity of the new variety.

Based on an average farm size of 2 ha, supporting a family of eight [5.3], *HHB67-Improved* has brought greater food security to approximately 3 million people in North-West India, in particular resource-poor farmers whose cultivation of the original variety *HHB67* left their food security highly vulnerable to downy mildew. Compared with the original *HHB67*, *HHB67-Improved* provides larger grain yields (about 10%), worth £2.6M per year in central and western parts of Rajasthan. Its improved downy mildew resistance has prevented losses of over £7M: the expected costs in the first year of a major downy mildew outbreak (assuming 30% loss in harvest from 550,000 ha, yielding 700 kg/ha and a grain price of Rs 5/kg) [5.2, 5.4]. Compared with *HHB67* and other local varieties in Rajasthan and Haryana, *HHB67-Improved* gave a net benefit of Rs 544M (£6.5M) in 2011 alone [5.1]. The higher yield and early maturity of this staple also released land for crop diversification with sesame and food legumes. Furthermore, *HHB67-Improved* enabled farmers to continue with the advantageous practice of the cultivation of a second crop, like wheat or chickpea, during the post-rainy season, thus effectively transforming single-crop lands into two-season multicrop fields. This doubled cropping intensity provides resilient farming systems, substantially increased income and improved nutrition compared with systems based on the previously grown pearl millet landraces [5.1, 5.4].

Commercial impact for those involved in seed production and improved measures of gender equality

In addition to direct benefits to grain farmers, the production of hybrid seed benefits a whole industry of irrigated seed producing farmers who, on average, see 12 times higher net returns than rainfed grain and stover farms. In 2011, the production of *HHB67-Improved* seed gave a net income of Rs 300M (£3.6M) to the seed producers in Andhra Pradesh [5.1] and further generated 186 person days per ha of employment, resulting in a total of 900,000 person days of employment in 2011 alone, of which 45% comprised women labourers [5.1, 5.4]. Women hired in seed production account for twice the total labour days of men, demonstrating the improved gender equality and significant increase in employment opportunities for women in seed production regions and villages resulting from the improved hybrid availability [5.1]. As seed production takes place at times and in regions different to the main millet harvest, these benefits reach additional households [5.3].

5. Sources to corroborate the impact

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