Cost-effective breeding for disease resistance in pearl millet

Validated RNRRS Output.

A cost-effective method of breeding millet resistant to disease is now available. This new technique has already been used to insert genes resistant to downy mildew—the most devastating of all the pearl millet diseases—into top hybrid varieties. Poor farmers in Haryana and Rajasthan now grow these hybrids over 150,000 hectares, both as food grain and for animal feed. Government and international laboratories in India use these methods. Millet resistant to mildew could have a huge impact in India where 40% of the world's millet is grown and over half of world's poorest people live. Now, the techniques are spreading to the private sector and research organisations in Africa, South Asia, and the Americas.

Project Ref: **PSP24:**
Topic: **1. Improving Farmers Livelihoods: Better Crops, Systems & Pest Management**
Lead Organisation: **ICRISAT**
Source: **Plant Sciences Programme**

Document Contents:

Description, Validation, Current Situation, Current Promotion, Impacts On Poverty, Environmental Impact,

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Research into Use
NR International
Park House
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Geographical regions included:

India,

Target Audiences for this content:

Crop farmers,

Description

PSP24

A. Description of the research output(s)

1. Working title of output or cluster of outputs: In addition, you are free to suggest a shorter more imaginative working title/acronym of 20 words or less:

Marker development, QTL mapping and marker-assisted breeding for improvement of downy mildew resistance of popular pearl millet hybrids for India

Marker-assisted breeding of disease-resistant versions of farmer-preferred pearl millet hybrids

2. Name of relevant RNRRS Programme(s) commissioning supporting research and also indicate other funding sources, if applicable:

Plant Sciences Research Programme.

CGIAR core funding support to ICRISAT,
Australian Centre for International Agricultural Research grants to ICRISAT and ILRI for marker-assisted improvement of pearl millet stover quality,
USAID-supported Cereals Comparative Genomics Initiative projects on marker development and broad-spectrum disease resistance.
Generation Challenge Programme commissioned grants for pearl millet marker-assisted selection and for pearl millet marker development.

3. Provide relevant R numbers (and/or programme development/dissemination reference numbers covering supporting research) along with the institutional partners (with individual contact persons (if appropriate)) involved in the project activities. As with the question above, this is primarily to allow for the legacy of the RNRRS to be acknowledged during the RiUP activities.

R8183 and its predecessors; (R7979, R7382, R7379, R6951, R6667)

RNRRS partners included the
John Innes (MD Gale, CJ Liu, KM Devos, C Busso, X Qi, and others); University);
University of Wales, Bangor (D Shaw, ES Jones, WA Breese, JR Witcombe); Institute of Grassland and Environmental Research, Aberystwyth (CJ Howarth, G Cavan, RS Yadav);
CCS Haryana Agricultural University, Hisar, Haryana, India (DC Nijhawan, CR Beniwal, PS Kakar, YP Yadav);

4. Describe the RNRRS output or cluster of outputs being proposed and when was it produced? ***(max. 400 words)****. This requires a clear and concise description of the output(s) and the problem the output(s) aimed to address. Please incorporate and highlight (in bold) key words that would/could be used to select your output when held in a database.*

The main output is an improved method of plant breeding, **marker-assisted breeding,** for **disease resistance** in **pearl millet.** It allows breeders, for the first time to cost-effectively identify the location of disease resistance genes and introduce them in known combinations to the parental lines of hybrids (and eventually to open-pollinated populations) of pearl millet.

The application of this new technique allowed the breeding of resistance to downy mildew disease, the most devastating of all the pearl millet diseases that causes catastrophic losses for pearl millet farmers when it occurs in epidemic proportions. The application of this new approach when **integrated** with **conventional methods** resulted in the production of an **improved pearl millet hybrid cultivar** "**HHB 67 Improved**", which was tested, released, and fed into the seed multiplication pipeline for delivery to farmers.

This achievement was the result of a cluster of outputs including the pearl millet **molecular markers** developed at JIC and ICRISAT, **genetic linkage maps** for pearl millet (both for individual mapping populations and regularly updated consensus maps). This was used to identify **quantitative trait loci** (**QTLs)** for:

- **downy mildew resistance**,
- **phenology** (flowering time and plant height),
- **grain and stover yield potential**,
- grain and stover **yield components**,
- **salinity tolerance**, and
- **ruminant nutritional value** of residues following grain harvest from dual-purpose pearl millet hybrid cultivars.

Further, a series of **publications and presentations** were delivered related to development and application of molecular genetic tools to assist pearl millet breeders in developing countries. Finally, human resource development in the course of this series of projects included training not only for public-sector and private-sector pearl millet scientists in India, but also degree training for a large number of **post-graduate students** both in the UK and in India.

5. What is the type of output(s) being described here?
Please tick one or more of the following options.

Product	***Technology***	***Service***	***Process or Methodology***	***Policy***	***Other Please specify***
X Improved hybrid parental lines; better characterized sources of disease resistance	***X Markers, linkage maps, and QTL information***	***X Publications and presentations***	***X Marker-assisted breeding and its integration with conventional hybrid breeding***		***X Training***

6. What is the main commodity (ies) upon which the output(s) focussed? Could this output be applied to other commodities, if so, please comment:

Pearl millet (*Pennisetum glaucum*). While largely applicable to pearl millet, thanks to close genomic relationships among the grasses, much of the information generated is potentially applicable in other cereals and forage grasses. Further, the training provided is applicable across any seed-propagated plant species that reproduces sexually.

7. What production system(s) does/could the output(s) focus upon?
Please tick one or more of the following options. Leave blank if not applicable

Semi-Arid	***High potential***	***Hillsides***	***Forest-Agriculture***	***Peri-urban***	***Land water***	***Tropical moist forest***	***Cross-cutting***
X							

8. What farming system(s) does the output(s) focus upon?
Please tick one or more of the following options (see Annex B for definitions).
Leave blank if not applicable

Smallholder rainfed humid	***Irrigated***	***Wetland rice based***	***Smallholder rainfed highland***	***Smallholder rainfed dry/cold***	***Dualistic***	***Coastal artisanal fishing***
				X		

*9. How could value be added to the output or additional constraints faced by poor people addressed by clustering this output with research outputs from other sources (RNRRS and non RNRRS)? (****max. 300 words****). Please specify what other outputs your output(s) could be clustered. At this point you should make reference to the circulated list of RNRRS outputs for which proformas are currently being prepared.*

QTLs detected for downy mildew resistance to specific pathogen populations can continue to be introgressed into a range of economically important, agronomically elite pearl millet hybrid parental lines. Downy mildew resistance QTLs can be pyramided with QTLs for increased grain and/or stover

yield potential, improved tolerance to salinity stress and/or terminal drought stress (see PSP dossier 23), and improved ruminant nutritional value of crop residues, in elite hybrid parental line backgrounds. Products of these marker-assisted QTL pyramiding programs can be evaluated for hybrid performance in multi-locational field trials.

The technology can be applied to other target traits, such as the ability to acquire phosphorus from poorly soluble sources (e.g., rock phosphate or soil-fixed P) and foliar disease (rust and blast), and to other breeding systems that can lead to improved open-pollinated (rather than hybrid varieties).

Large-scale SSR-marker-based diversity assessment of elite hybrid parental lines and using this information, combined with appropriately designed field testing of their hybrid combinations, can be used to identify/create combining ability groups to improve the efficiency of conventional pearl millet hybrid breeding.

Validation

B. Validation of the research output(s)

***10. How** were the output(s) validated and **who** validated them?*
*Please provide brief description of method(s) used and consider application, replication, adaptation and/or adoption in the context of any partner organisation and user groups involved. In addressing the "who" component detail which group(s) did the validation e.g. end users, intermediary organisation, government department, aid organisation, private company etc... This section should also be used to detail, if applicable, to which social group, gender, income category the validation was applied and any increases in productivity observed during validation **(max. 500 words)**.*

HHB 67 Improved was validated by ICRISAT, All India Coordinated Pearl Millet Improvement Project (AICPMIP) and CCS Haryana Agricultural University (CCS HAU). *HHB 67 Improved* is much more resistant to downy mildew disease and also yields more grain and fodder. *HHB 67 Improved* is liked for its combination of high yield (2.0 t ha^{-1} compared to 1.79 tha^{-1} for the original hybrid 'HHB) with extreme earliness (62-65 days) that allows it to escape end-of-season droughts.

*11. **Where and when** have the output(s) been validated? Please indicate the places(s) and country(ies), any particular social group targeted and also indicate in which production system and farming system, using the options provided in questions 7 and 8 respectively, above **(max 300 words)**.*

Evaluation trials were conducted on-station at the CCS HAU research farms at Hisar and Bawal, Haryana in 2003 and 2004 and on-farm at several locations in Haryana during 2003 and 2004 as part of the All India Coordinated Pearl Millet Improvement Project.

Current Situation

C. Current situation

*12. **How and by whom** are the outputs currently being used? Please give a brief description **(max. 250 words**).*

Hybrid cultivar HHB 67 Improved: This is being used by resource-poor farmers in the semi-arid tropics in India in the states of Haryana and Rajasthan. Farmers grow the hybrid for grain and stover. The grain is used as a staple food and is also sold for cash.

Markers and processes: These are being used by several public-sector research laboratories in India (including that at the Central Arid Zone Research Institute in Jodhpur, Rajasthan, India, which serves the hottest, driest, most marginal pearl millet production environments in India, and at the International Crops Research Institute for the Semi-Arid Tropics). ICRISAT has recently been contracted by a major private-sector seed company to perform marker-assisted backcrossing to further strengthen the disease resistance (and therefore economic life) of the male parent of its most popular pearl millet hybrid. Further, ICRISAT is now being approached on a regular basis by other private sector seed companies for information on how to most appropriately begin to apply marker-assisted breeding methods in their proprietary pearl millet and sorghum hybrid breeding programs.

*13. **Where** are the outputs currently being used? As with Question 11 please indicate place(s) and countries where the outputs are being used **(max. 250 words).***

The outputs are primarily being used in India, where about 40% of the global pearl millet area and over half of the world's poorest people are found. Several of the persons trained in the course of this research programme are now employed with private seed companies, public-sector research programs, or in academia in Africa, south Asia, or the Americas.

*14. What is the scale of current use? Indicating how quickly use was established and whether usage is still spreading **(max 250 words).***

Different outputs are in different stages of use. The most applied product of this research programme, pearl millet hybrid "HHB 67 Improved" was grown on approximately 30,000 ha during the 2006 rainy season. It is expected to spread rapidly next year following more widespread multiplication of seed of

this hybrid during the 2006/07 post-rainy season, and could be cultivated on as much as 150,000 ha in the Indian states of Haryana and Rajasthan during the 2007 rainy season. The impact could be higher than this since the deployment of the downy mildew resistant 'HHB 67 Improved' will reduce the risk of epidemics on the original HHB 67 by reducing the extent of disease foci.

15. In your experience what programmes, platforms, policy, institutional structures exist that have assisted with the promotion and/or adoption of the output(s) proposed here and in terms of capacity strengthening what do you see as the key facts of success? ***(max 350 words).***

The public- and private-sectors of the Indian pearl millet improvement programme, in combination with the applied pearl millet hybrid parents breeding programme at ICRISAT-Patancheru, provide the institutional platform from which the promotion, application, and adoption of outputs from R8183 and its predecessors must be made for south Asia. The MS Swaminathan Applied Genomics Laboratory, and its Centre of Excellence for high-throughput marker data generation (being established with funding from the Government of India's Department of Biotechnology), can provide service lab facilities for marker data generation for all applied plant breeding in India. A DArT marker platform will soon be established at ICRISAT-Patancheru as part of this Centre of Excellence, and application of this to high-throughput marker genotyping for pearl millet has the potential to completely revolutionize breeding of pearl millet hybrids for this region. The BecA facility, hosted by ILRI in Nairobi, Kenya, is expected to play a similar role for crop and livestock improvement programmes (both public and private) in eastern and central Africa, and similar facilities are under development in southern Africa and in western Africa. A Syngenta Foundation-sponsored project to develop marker-assisted breeding tools for pearl millet and sorghum in sub-Saharan Africa should also be considered as an important mechanism to be supported to broaden the scope of application of R8183 outputs to poverty alleviation and livelihood enhancement in developing countries.

Organisations that assisted in the promotion of outputs were:

All-India Coordinated Pearl Millet Improvement Project, ARS Mandor, Jodhpur, Rajasthan, India (OP Govila, SK Bhatnagar, OP Yadav, IS Khairwal); Indian Agricultural Research Institute, New Delhi, India (OP Govila); Central Arid Zone Research Institute, Jodhpur, Rajasthan, India (OP Yadav, M Singh); Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India (N Jayaraman, AK Fazlullah Khan, V Muralidharan); Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India (P Rangasamy); University of Mysore, Mysore, Karnataka, India (HS Shetty); ANG Ranga Agricultural University, Hyderabad, Andhra Pradesh, India (S Sivaramakrishnan); Osmania University, Hyderabad, Andhra Pradesh, India (P Kavi Kishor); Central University of Hyderabad, Hyderabad, Andhra Pradesh, India (Arjula R Reddy); International Center for Genetic Engineering and Biotechnology, New Delhi, India (MK Reddy); International Livestock Research Institute, c/o ICRISAT, Patancheru, Andhra Pradesh, India (E Zerbini, M Blummel); Pro-Agro Seed Co. Pvt. Ltd., Hyderabad, Andhra Pradesh, India (SK Gupta); PHI-Biogene Pvt. Ltd., Hyderabad, Andhra Pradesh, India (RS Mahala); and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India (JR Witcombe, SB King, CT Hash, FR Bidinger, SD Singh, RP Thakur, S Chandra, P Bramel-Cox, C Busso, R Serraj, V Vadez, M Kolesnikova-Allen, A Sharma, P Azhaguvel, R Bhattacharjee, T Nepolean, SK Gulia, P Sathish Kumar, N Sridevi, V Rajaram, SMH Rizvi, and others).

Current Promotion

D. Current promotion/uptake pathways

16. ***Where*** *is promotion currently taking place? Please indicate for each country specified detail what promotion is taking place, by whom and indicate the scale of current promotion* ***(max 200 words).***

Hybrid cultivar HHB 67 Improved: The new hybrid is being promoted in Haryana by private and public-sector seed producers. An advantage for the promotion of this hybrid lies in the name 'HHB 67 Improved' since HHB 667 is a well known product and farmers have grown it for many years. When farmers buy seed of HHB 67 Improved they expect that the hybrid will be of similar phenotype and maturity to HHB 67 but with some improved traits – and that is exactly what they get.

Processes. Limited promotion is taking place in India. The Indian Council of Agricultural Research is providing ICRISAT with US$100K during fiscal year 2006/07 for application of marker-assisted breeding for improvement of pearl millet hybrids for downy mildew resistance and terminal drought tolerance. In addition, the Government of India's Department of Biotechnology is supporting a Millets Biotechnology Network Project that includes funding to support staff training and limited marker lab development at the Central Arid Zone Research Institute and Project Coordination Unit of the All-India Coordinated Pearl Millet Improvement Project. Finally, ICRISAT is actively seeking further support (from the Government of India's Department of Biotechnology, from USAID, from the Generation Challenge Programme, from the System-wide Livestock Programme, and other potential donors including the Gates Foundation, the Syngenta Foundation, BMZ, and DFID) for development and application of marker-assisted breeding methods as tools to more efficiently improve pearl millet.

17. What are the current barriers preventing or slowing the adoption of the output(s)? Cover here institutional issues, those relating to policy, marketing, infrastructure, social exclusion etc. ***(max 200 words)****.*

Hybrid cultivar HHB 67 Improved: A major barrier has been that the new versions of HHB 67 could not enter public-sector seed multiplication without official release and this process is lengthy and difficult. Now that *HHB 67 Improved* is released then it has entered the seed multiplication chain from breeder seed of the new parental lines. Hybrid seed production can take off quickly once official release is obtained as seed multiplication rates are high and seed can be produced in two seasons each year.

Processes. A major barrier (now becoming less important) has been the understandable feeling among both public- and private-sector pearl millet breeding programmes that the technology is too expensive to apply to a relatively low-value commodity like pearl millet. Our success with development, testing, release, multiplication, and dissemination of pearl millet hybrid "HHB 67 Improved" has gone a long way to overcoming the hesitation of the public- and private-sector in south Asia to invest in this area. The development of DArT markers for pearl millet, and establishment of networks for rapidly and reliably moving pearl millet DNA samples to regional service labs that can provide DArT marker (and other marker data types) in a timely and cost-effective manner, and move marker data from these labs back to the breeding programmes, will permit application of the technology even in much of sub-Saharan Africa where improved open-pollinated varieties may remain the preferred pearl millet cultivar type for many years to come.

18. What changes are needed to remove/reduce these barriers to adoption? This section could be used to identify perceived capacity related issues ***(max 200 words).***

Large-scale training of pearl millet breeding teams is needed in the application of markers to their breeding programme objectives. This needs to be supported by investment in DArT marker facilities in regional service laboratories in eastern and central, southern, and western Africa, once these have been established and demonstrated to be effective in south Asia,

19. What lessons have you learnt about the best ways to get the outputs used by the largest number of poor people? ***(max 300 words).***

The breeding approach has been client-oriented by building on cultivars that are already popular and have traits that are greatly liked by farmers. The next step has been to identify their weaknesses (potential breakdown to downy mildew disease) and to identify potential sources of genes that can be used in crossing programmes to address these weaknesses. In addition combining ability trials in the breeding programme have allowed progress in the non-targeted traits of grain and stover yield. A key has been to involve local breeding teams. It has been essential to be able to intervene in the seed delivery chain. We also found that the private sector were more flexible in the adoption of new, downy mildew resistant lines before official release.

Impacts On Poverty

E. Impacts on poverty to date

20. Where have impact studies on poverty in relation to this output or cluster of outputs taken place? This should include any formal poverty impact studies (and it is appreciated that these will not be commonplace) and any less formal studies including any poverty mapping-type or monitoring work which allow for some analysis on impact on poverty to be made. Details of any cost-benefit analyses may also be detailed at this point. Please list studies here.

No formal studies have yet been completed because on-farm adoption of the first finished products of the technology has just begun. However, it is estimated that: by rapidly adopting *HHB 67 Improved*, farmers in Haryana and Rajasthan can avoid grain production losses of Rs 36 crores (US$8 million), which would be expected in the first year of a major downy mildew (DM) outbreak on the original HHB 67. In years of severe DM attack, up to 30% of the pearl millet grain and straw harvest can be lost. Income losses in a severe DM outbreak on HHB 67 can be estimated conservatively assuming an average grain yield of 0.8 t ha^{-1} (most of the HHB 67 area is in Haryana, which has recently had state average pearl millet grain yields in excess of 1 t ha^{-1}), and a minimum selling price of Rs 3 per kg (prices range from Rs 2 to Rs 6 per kg). The value of these potential grain yield losses—in the first year of a major DM epidemic on the original HHB 67—exceeds the total research funding support provided by the UK Department for International Development from 1990 to 2005 towards the development and application of marker-assisted breeding tools for pearl millet. Future applications of these tools (as well as benefits from avoidance of grain and stover yield losses in the second year of an epidemic) will profit society as a whole representing a well-spent research investment.

21. Based on the evidence in the studies listed above, for each country detail how the poor have benefited from the application and/or adoption of the output(s) ***(max. 500 words):***

- *What positive impacts on livelihoods have been recorded and over what time period have these impacts been observed? These impacts should be recorded against the capital assets (human, social, natural, physical and, financial) of the livelihoods framework;*
- *For whom i.e. which type of person (gender, poverty group (see glossary for definitions) has there been a positive impact;*
- *Indicate the number of people who have realised a positive impact on their livelihood;*
- *Using whatever appropriate indicator was used detail what was the average*
- *percentage increase recorded*

While applications have begun, adoption of outputs is still at too early a stage for evidence of direct benefits to the poor to have been documented. This needs to be done over the next 2 to 4 years in India. As applications for in other countries are just being initiated, it would be premature to expect that direct benefits to the poor could be documented in sub-Saharan Africa in less than 5 years time.

Environmental Impact

H. Environmental impact

24. What are the direct and indirect environmental benefits related to the output(s) and their outcome(s)? ***(max 300 words)***

This could include direct benefits from the application of the technology or policy action with local governments or multinational agencies to create environmentally sound policies or programmes. Any supporting and appropriate evidence can be provided in the form of an annex.

Adoption of the HHB 67 Improved will lead to a direct increase in productivity per unit area without the use of additional external inputs (fertiliser, pesticides, irrigation). This can be achieved without changes in management practices and is environmentally beneficial. The land area required to increase productivity will not increase, thereby reducing the pressure to increase the area of land under cultivation.

HHB 67 Improved is more resistant to downy mildew disease and so is less likely to lead to an increase in the use of fungicides, thereby reducing the risks to human health and giving a better balance to the natural pest-predator cycle.

25. Are there any adverse environmental impacts related to the output(s) and their outcome(s)? ***(max 100 words)***

26. Do the outputs increase the capacity of poor people to cope with the effects of climate change, reduce the risks of natural disasters and increase their resilience? ***(max 200 words)***