Institution:
Bangor University, 10007857

Unit of Assessment:
UoA 7 - Earth Systems and Environmental Sciences

Title of case study:
Increased efficiency in global rice breeding

Period when the underpinning research was undertaken:
2000 - 2016

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor John Witcombe	Professorial Research Fellow	April 1990 – present
Dr Krishna Joshi	Research Co-Ordinator	September 2004 – December 2012
Dr Daljit Virk	Senior Research Fellow	December 1994 – August 2018, Honorary Senior Research Fellow November 2018 – present

Period when the claimed impact occurred:
1 August 2013 – 31 July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Bangor research (funded by the Department for International Development) demonstrated that adoption of a better-cross strategy, where rice-breeders more carefully select parental lines before crossing, improves efficiency in rice breeding. It resulted in the improved rice variety (Sunaulo-Sugandha), which provides food security and household incomes to Nepalese smallholder farmers of over GBP1,000,000 per year. Bangor's research-success also led to a paradigm shift in the International Rice Research Institute, which adopted Bangor's better-cross strategy in 2014 in a key project 'Transforming Rice Breeding'. This increased efficiency of IRRI's innovation-transfer to rice farmers globally, with a minimum estimated return of GBP36,770,000 per year in 2020.

2. Underpinning research

Context

Rice is a staple food for nearly half of the world's households. The International Rice Research Institute (IRRI) transfers innovation to rice-dependant communities, delivering global economic, environmental and food-security benefits. Prior to 2014, IRRI rice breeding programmes all advocated a high-volume cross strategy, based on the assumption that all crosses had equal probabilities of success, hence the probability of finding a beneficial cross increases as more crosses are made. This assumption was rejected by Bangor researchers, because it is based on the extraordinary premise that the rice-breeder has no ability to choose crosses that are more likely to succeed.

How Bangor research challenged convention

A key component of Bangor research, led by Professor John Witcombe (funded by the Department for International Development (DFID) **[3.a, 3.b, 3.c]**) is client-oriented breeding (COB), which dramatically reduces the number of crosses in the breeding programme to greatly increase the breeding efficiency **[3.1, 3.2, 3.3, 3.4]**. Witcombe's modelling determined the optimum cross number, where the earliest stringently-selected crosses ('better crosses') had more chance of success than later ones. The optimum cross number was consistently many-fold fewer than in

conventional breeding practices, when determined for varied rates of decline in the probability of a cross succeeding as the number of crosses made increases **[3.3]**.

The **better-cross strategy** was substantiated by evidence from the work of Witcombe, Dr Krishna Joshi and Dr Daljit Virk (2000–2012) in three, Bangor-led rice breeding programmes in India, Nepal and Bangladesh, where it was compared with the conventional high-volume-crossing used by IRRI and the national programmes of these three countries. The success rates of crosses made by the two strategies were measured by the proportion that produced officially recommended or farmer-adopted rice varieties. For the four conventional programmes success was about 1 in 200 (0.5%) whereas 66% of the better crosses succeeded. The likelihood of such high success rates occurring by chance is 1 in 100 million, so the difference must result from better choice of parents **[3.3]**. Supported by research-results from COB between 2000 and 2014 **[3.4]**, this evidence was widely disseminated by the Bangor team at international plant breeding conferences.

Switching to the **better-cross strategy** of rice-breeding was shown to greatly increase efficiency, by reducing the considerable resources used for crossing (tens per year compared with several hundred), halving the land required for growing the progeny of crosses by reducing the wastage on failed crosses, and improving the quality of the crosses **[3.3, 3.4]**.

Bangor research showed that the better-cross strategy had more power to succeed in breeding a difficult-to-breed varietal type with aromatic grain, for which previous conventional breeding had limited success globally and none in Nepal **[3.5]**.

3. References to the research

Research Outputs

3.1 **Witcombe, J. R., Joshi, K. D.**, Gyawali, S., Musa, A. M., Johansen, C., **Virk, D. S.** and Sthapit, B. R. (2005) Participatory plant breeding is better described as highly client-oriented plant breeding. I. Four indicators of client-orientation in plant breeding. *Experimental Agriculture*, **41**(3), 299–319. DOI (Peer-reviewed journal article, Submitted to RAE08)

3.2 **Witcombe, J. R.**, Gyawali, S., Sunwar, S., Sthapit, B. R. and **Joshi, K. D.** (2006) Participatory plant breeding is better described as highly client-oriented plant breeding. II. Optional farmer collaboration in the segregating generations. *Experimental Agriculture,* **42**(1), 79–90. DOI (Peer-reviewed journal article)

3.3 **Witcombe, J. R.**, Gyawali S., Subedi M., **Virk, D. S.** and **Joshi K. D.** (2013) Plant breeding can be made more efficient by having fewer, better crosses. *BMC Plant Biology,* **13**, 22. DOI (Peer-reviewed journal article, Submitted to REF2014)

3.4 **Witcombe, J. R.**, **Virk, D. S.** and **Joshi, K. D.** (2019) 'Rice PPB in India and Nepal: Client-oriented breeding using few, carefully chosen crosses', in Westegen, O. and Winge, T. (Eds) *Farmers and Plant Breeding - Approaches and Perspectives*. Routledge. (Chapter 4). Copy available on request

3.5 **Witcombe, J. R.**, Devkota, K. P., Tripathi, M. P., Gyawali, S., Subedi, M., Shrestha, P. K., Chudhary, B. N., Yadav, R. B., Yadav, M., Chaudhary, D., Yadav, R. B., Chaudary, D., Gautam, A. P., Akhtar, T., Khatiwada, S. P., Adhikariu, N. P., Chapagain, K., and **Joshi, K. D.** (2008) A proposal for the release of an aromatic rice variety Suanulo Sugandha. Application to be made for approval and release of crop varieties to Government of Nepal. Ministry of Agriculture and Cooperatives: National Seed Board. (Research report). Copy available on request

Grants

3.a **Witcombe, J. R., Virk D. S.** (2000-2003) *Participatory crop improvement in high potential production systems - piloting sustainable adoption of new technologies.* UK Department for International Development (DFID) [now the Foreign, Commonwealth & Development Office (FCDO)] GBP254,841 (Bangor University: R7542)

3.b **Virk, D. S., Witcombe, J. R.** (2002-2006) *Participatory plant breeding in rice and maize in eastern India.* UK Department for International Development (DFID) [now the Foreign, Commonwealth & Development Office (FCDO)] GBP282,682 (Bangor University: R8099)

3.c **Joshi, K. D.** (2002-2006) *Improvement of rainfed cropping systems in the High Barind Tract of Bangladesh.* UK Department for International Development (DFID) [now the Foreign, Commonwealth & Development Office (FCDO)] GBP250,712 (Bangor University R8269)

4. Details of the impact

Economic impact of novel high-quality rice

A new aromatic-grained variety, Sunaulo Sugandha (translation 'Golden Fragrant'), was a product of Bangor's **better-cross strategy [3.5, 5.1]**. It has aroma, slender grain and higher yield traits that conventional breeding efforts in Nepal had failed to combine in a successful variety. Sunaulo Sugandha became the only modern aromatic variety to be grown in Nepal in 2014 when it was grown on over 3,000ha in 6 districts in the Western Development Region, accounting for 2.5% of the rice area **[5.1]**, corroborated for Makwanpur district by a survey in 2015 **[5.2]**. This new variety has benefited the livelihoods of the poor in Nepal, from 2014 onwards. Its high market price (40% more than non-aromatic quality rice) has benefited Nepalese farmers by over GDP1,000,000 per year (based on the average yields of this variety on farmers' fields). Sunaulo Sugandha has continued to be grown and to benefit farmers every year to 2020 as evidenced by certified seed production and sales by seed companies such as Anamolbiu Pvt Ltd (APL) **[5.3.]**.

International impact: change to rice breeding programme of IRRI

Globally, the Bangor-led research has had a significant impact on the activity of the International Rice Research Institute (IRRI)'s public-good rice breeding programme. This is documented by rice breeders at IRRI **[5.4, 5.5]** where the fundamental change of adopting Bangor's **better-cross strategy** has led to a recent major paradigm shift . By 2019 IRRI had adopted the **better-cross strategy** as its mainstream approach and, as a result, had abandoned their previous high-cross number strategy. This paradigm shift was informed by the IRRI collaborative project, Transforming Rice Breeding (TRB), a Bill and Melinda Gates Foundation project (2014 to 2018), where the better-cross approach was introduced. In 2019, IRRI authors **[5.4]** cite only Bangor-led research to justify adopting the better-cross approach: "*Several hundred crosses would be routinely performed each season prior to TRB however we reduced this number to about 100 crosses/year. Thus, our paradigm regarding the number of crosses shifted from quantity to quality…* **[3.3]**." IRRI has acknowledged the significant impact of Bangor's research in influencing their current breeding programme (2020) **[5.5]**, which sets the agenda for breeding methods in the public sector in at least 30 developing countries. Seeds of advanced lines or released varieties with greater resilience to biotic and abiotic stresses, better nutrition and higher yields are directly distributed to national breeding programmes globally.

Using the better-cross strategy to substantially reduce number of crosses is a huge change by IRRI that "*freed up time and resources*" **[5.4]**. Fewer, better crosses reduce land areas by 50% because simpler trial designs are needed to produce the same number of advanced breeding lines as a many-cross programme **[3.3]**. The better-cross strategy induces several-fold savings in labour for making crosses. These benefits should produce at least a 10% increase in breeding efficiency. The exact economic benefit of new breeding lines realised by IRRI through adopting the better-cross strategy is not available without extensive research. However, a 2016 review of the impact of IRRI's rice improvement programme **[5.6]** estimated that average economic benefits (per year), would range from GBP194,600,00 to GBP735,000,000 for 3 key rice-growing countries combined. As 2 countries (Indonesia and the Philippines), account for 13% of the world's rice production (with economic benefits of approximately GBP478,000,000 per year), the **total economic gain from IRRI's rice improvement programme** can be extrapolated to **approximately GBP3,677,000,000 per year globally, with an estimated 1-10% of this due to the adoption of Bangor's better-cross strategy** (GBP36,770,000 to GBP367,700,000 per year **in 2020**). A more recent meta-analysis (2018) on improving the efficiency of IRRI breeding by another method (rapid generation advance) concluded "*for large breeding programmes benefits from improved efficiency can add up to several billion US dollars*" **[5.7]**.

The global impact of a paradigm-shift in rice breeding is an aggregate of the adoption of hundreds of economically beneficial, high-quality rice varieties across South and South-East Asia (and in

other key rice-growing countries) by approximately 144,000,000 rice farmers, the majority of whom are smallholders.

5. Sources to corroborate the impact

5.1 **Crop Development Directorate Department Nepal (2015)** Rice varietal mapping in Nepal - Implication for development and adoption of aromatic rice variety Sunaulo Sugandha (product of Bangor's better-cross strategy).
http://www.doacrop.gov.np/downloadfile/Rice_Varietal_Mapping_1470895701_1512106555.pdf
5.2 **Open-access rice-variety publication by Nepalese authors (2015)** verifies that Sunaulo Sugandha was grown in the Makwanpur district of the Western Development Region of Nepal: (Khanal, S. and Mahesh Badal, M. (2015) Characterization of Available Rice Varieties through Diversity Block In Makwanpur and Sarlahi Districts, Nepal. *Ecronicon Agriculture*, 2.2, 307–316.)
https://www.ecronicon.com/ecag/pdf/ECAG-02-000033.pdf
5.3 **Testimonial-letter from the CEO of rice-breeding company (Anamolbiu Pvt Ltd (APL))** (participant in the impact process) provides evidence for the continued certified seed production of Sunaulo Sugandha since 2014.
5.4 **IRRI publication (2019)** cites Bangor research **[3.3]** as justification for a paradigm shift in number of crosses: from quantity to quality of crosses: (Collard, B.C. et al (2019) Transforming Rice Breeding: Re-Designing the Irrigated Breeding Pipeline at the International Rice Research Institute (IRRI). *Crop Breeding Genetics and Genomics* 2019,1, e190008.)
https://doi.org/10.20900/cbgg20190008
5.5 **Testimonial from Global Lead, Rice Breeding Platform at IRRI** (participant in the impact process) corroborating Bangor-led research as having a significant influence on their current breeding programme.
5.6 **Review of IRRI's rice improvement programme impact (2016)** demonstrates the impact of IRRI's contribution to the development of modern rice varieties and their estimated benefits: (Yamano, T. *et al*. (2016) Adoption and impacts of international rice research technologies. *Global Food Security*, *8*, 1–8.)
https://doi.org/10.1016/j.gfs.2016.01.002
5.7 **Meta-analysis on improving the efficiency of IRRI breeding (2018)** illustrates the expected efficiency-benefits from IRRI's improved breeding methods (in this case rapid generation advance): (Lenaerts, B. *et al*. (2018) Global impact of accelerated plant breeding: evidence from a meta-analysis on rice breeding. *PloS One*, *13*(6), p.e0199016.)
https://doi.org/10.1371/journal.pone.0199016