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Contestation as continuity? Biofortification research and the CGIAR

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Introduction

Biofortification, the development of nutrient-dense staple crops, has been promoted both as a solution to 'hidden hunger' among poor populations in the developing world (Nestel et al, 2006) and as an exemplar of the kind of global public goods research for which the CGIAR system is renowned (Dalrymple, 2008). As an interdisciplinary field of research and development linking crop science with human nutrition and public health (CIAT and IFPRI, 2002), biofortification presents both challenges and opportunities for an international agricultural research system oriented towards genetics-led crop improvement (Anderson et al, 1991, p65). This chapter traces developments in biofortification research over a fifteen year period during which it emerged from the margins of the CGIAR to become a priority for research investment (von Braun et al, 2008).

Biofortification is a relatively new term which simultaneously refers to (i) a range of *technologies* designed to alter the grain nutrient levels in selected crop varieties; (ii) a development *intervention* combining goals of improved public health and poverty reduction; and (iii) an *idea* linking agriculture, nutrition and health in new ways (Brooks, 2006, p1). It is a multi-dimensional 'project' contested on a number of levels, in terms of its technical feasibility and efficacy (in controlled conditions), effectiveness and impact (in the 'real world') and appropriateness and desirability (in comparison with alternative solutions). This chapter analyses developments in biofortification research as an extended case study in contested agronomy[1], in which a body of knowledge about complex interactions between genotypes, soils, human bodies and populations has evolved over time, in ways that have both reflected and reinforced particular sets of interdisciplinary and inter-institutional relations. In the process, certain types of knowledge have presided over others, with the result that some dimensions of this complex, multi-dimensional project have been contested, while others have not.

The chapter traces successive stages of biofortification research within the CGIAR and among its partners, highlighting how these dimensions of potential contestation have played out at each stage, in ways that reflected the priorities of the time, location and particular characteristics of crops, nutrients and technologies. Despite these specificities, certain continuities can be identified. In particular, contestation has tended to focus on feasibility and efficacy questions that can be resolved within the confines of institutional science, at the expense of broader questions about effectiveness and appropriateness in the context of the needs, priorities and programmes of particular countries and populations. A notable exception is the contestation surrounding the controversial ‘Golden Rice’ project, which has been elevated to exemplary ‘case study’ status in the GM crop debate (Jasanoff, 2005; Taverne, 2007). In the process, a multiplicity of uncertainties about the less emotive, technical aspects of the project have been shielded from professional as well as public scrutiny (Brooks, 2010).

One dimension which has gone remarkably uncontested, at least by the international nutrition community, is the question of the appropriateness of biofortification as a nutritional intervention (although there are notable exceptions, for example see Johns and Sthapit 2004). This may be because biofortification does not, for this community, represent a fundamental change of paradigm. Since the mid 1990s the field has been by dominated by a ‘goal oriented nutrition' paradigm that is particularly amenable to scalable micronutrient delivery mechanisms such as industrial food fortification and pharmaceutical supplements (Gillespie et al, 2004; Latham, 2010). From this position, biofortification, despite its novelty, does not represent a significant point of departure. Instead, debates about impact are dominated by *ex ante* analyses extrapolating health and economic outcomes associated with a 'switch' from non-biofortified to biofortified varieties (Stein et al, 2005). By and large these analyses are based on frameworks from neo-classical economics, which do not take into account the diversity of ways in which rice is cultivated, processed and consumed within different cultural and agro-ecological contexts (Brooks, 2010).

A glance back at the CGIAR's first biofortification project (long before the term appeared) suggests this lack of debate about effectiveness and appropriateness, particularly with regard to addressing the nutritional needs of the poorest, was indeed problematic. Research began at the Mexico-based wheat and maize improvement centre (CIMMYT) on *opaque2* maize in the 1960s (Mertz et al, 1964), providing the foundation for the Quality Protein Maize (QPM) programme that has continued from the 1970s to this day. Accounts of the trajectory of QPM research reveal repeated cycles of optimism inspired by each new 'breakthrough', only to be tempered by field results that were insufficiently conclusive to justify either full endorsement or closure (Mertz 1997; see also Prasanna et al, 2001).[2] Today, QPM is grown extensively in East Africa, although the extent to which this is due to its nutritional qualities is uncertain (De Groote et al, 2010). In India, the national maize breeding programme prioritises QPM research (Prasanna et al, 2001), though its work is increasingly oriented towards the livestock feed market rather than the nutritional deficiencies of the poor (Hellin and Erenstein, 2009).

Will more recent biofortification initiatives focused on the micronutrients iron, zinc and vitamin A avoid these ambiguities and succeed in reaching the poorest? A more recent example and oft-cited biofortification 'success story' has been the promotion of orange fleshed sweet potato (OFSP) in sub-Saharan Africa. Naturally high in beta-carotene (the precursor of vitamin A), its substitution for white fleshed sweet potato has been a favoured food-based strategy of nutritionists for many years (Low et al, 2007; Hagenimama et al, 2001; Gichuki et al, 1997; Low et al, 2001). The untapped potential of OFSP to combat vitamin A deficiency led to the absorption of ongoing research activity into the HarvestPlus Biofortification Challenge Program as the basis for much of its early 'end user' work.[3] In contrast to other crops targeted by the CGIAR for biofortification, the OFSP project utilises well-developed products whose efficacy and desirability do not therefore attract contestation. Nevertheless, questions remain about the effectiveness of a nutrition intervention, based on food items that still require intensive promotion, even after twenty years of research and development efforts.[4]

Perhaps because of the conspicuous yellow colour associated with the trait, research on biofortification of crops with beta-catotene has tended to have a higher profile than research focusing on other nutrients. Varieties enriched with beta-carotene exhibit a yellow-orange colour which makes it possible to segregate biofortified from non-biofortified products; while cultivars bred for increased iron or zinc density are visually indistinguishable from other varieties. This has implications for labelling and pricing, as well as the potential for targeting particular populations 'at risk' from malnutrition related illness; raising a different set of challenges with regards to impact assessment. The focus of this chapter is on efforts, centred in the International Rice Research Institute (IRRI), to biofortify rice with the trace minerals iron and zinc. Contestation around this research has been relatively restrained mainly because the research has relied largely (but not exclusively) on 'conventional' plant breeding rather than more controversial transgenic technologies. A key claim made for iron- and zinc-dense varieties is that they offer a 'win win' solution combining nutritional benefits with improved agronomic performance (realising higher yields particularly in nutrient-deficient soils) (Bouis, 1996), making this a particularly interesting case for the study of contested agronomy.

This chapter traces the history of research aimed at producing iron- and zinc-dense rice varieties. It highlights, at each stage, which dimensions were contested and which were not, and how this contestation (or lack of it) was linked to particular configurations of actors, disciplines and broader institutional factors. It explores how the problem to be addressed by the research was defined or 'framed' (Schön and Rein, 1994); in ways that both reflected and reinforced particulars sets of interdisciplinary relations. These dynamics are viewed through the lens of interdisciplinary dynamics and contests that emerged in each stage of the research. This analysis highlights how scale assumptions embedded in certain disciplines (or in particular approaches within disciplines) could be marshalled to tilt the interdisciplinary playing field, with implications for research directions and science practice. Furthermore, these dynamics 'at the interface' (Long, 2001) between epistemic traditions unfolded within a broader institutional context that was itself in a state of perpetual transformation. A key contribution of the chapter is that it offers a cross-scale analysis of contested agronomy linking the micro-politics of interdisciplinary 'boundary work' (Gieryn, 1999) with the broader power-knowledge relations that characterise these increasingly globalised research networks.

The pre-breeding study – establishing feasibility (1994-1999)

This section outlines the series of events through which plant breeding for micronutrient density found its way onto the CGIAR research agenda. This was due, in large part, to a small network of like-minded people who championed the approach at a time when it was perceived by many within the CGIAR as unrealistic and somewhat eccentric. It focuses on particular moments when the biofortification research agenda was subtly reframed to bring in different constituencies, particularly the CGIAR plant breeders on which the approach (as conceived by its promoters) depended.

In 1993, IFPRI received funding from the USAID Office of Nutrition to identify ways in which CGIAR 'might undertake to join other international and national organisations in the fight against micronutrient malnutrition' (Bouis, 1995, p11). While this idea initially received a lukewarm response from CGIAR scientists (mindful of the early QPM experience) a breakthrough came with the discovery of a network of scientists advocating a 'food systems approach' to the problem of micronutrient malnutrition (Combs et al, 1996). This was envisaged as a holistic and 'inherently interdisciplinary' approach in which plant breeding research was integrated with research into micronutrient bioavailability[5] and food technology. The institutional home for this approach was the Cornell-based Federal Plant, Soil and Nutrition Laboratory (PSNL)[6] which 'had, since the 1930s, been investigating linkages between minerals in soils and the nutrition of plants, animals and humans in the United States' (Bouis, 1995, p12).

At this time Ross Welch of the PSNL introduced Howarth Bouis, based at IFPRI and the CGIAR's main advocate of biofortification research, to Robin Graham of the Waite Agricultural Research Institute at the University of Adelaide.[7] Graham was conducting research on crops bred for more efficient uptake of trace minerals such as iron and zinc from deficient soils (Bouis, 1995, p12-13). Graham's aim was to use this trait to improve wheat yields in zinc-deficient soils in Australia. Meanwhile a research programme was underway to adapt Australian zinc-efficient varieties for the zinc-deficient soils in Turkey, with the aim of improving plant and human nutrition simultaneously (Cakmak, 1996). It was estimated that 'Turkish wheat farmers would save $100 million annually in reduced seeding rates alone' (Cakmak, 1996, p13, emphasis in original).[8] Graham, Welch and Bouis envisioned a 'win-win situation' (Graham and Welch, 1996, p15-16) in which crop yields would be enhanced 'without additional farmer inputs' alongside improved nutritional quality (Welch and Graham, 2004, p356) through a strategy of 'tailoring the plant to fit the soil'. The implied synergies between plant and human nutrition benefits were still unproven at this stage, however (Bouis, 1995a, p18).

In 1994 IFPRI hosted a workshop entitled 'Agricultural Strategies for Micronutrients' which led to the establishment of the CGIAR micronutrients project (1994-1999) (Bouis et al, 1999). The merits of various breeding strategies were explored and mechanisms regulating plant and human nutrition were discussed. In the published output a strategic simplification was made, which proved critical to convincing CGIAR plant breeders to participate. It was articulated as follows: 'The genetics of these traits is generally simple, making the task for breeders comparatively easy…the primary selection criterion is a simple and efficient one – the micronutrient content of the seed' (Graham and Welch, 1996, p55). This problem redefinition spoke directly to the prevailing, genetics-led approach to crop research within the CGIAR by framing grain micronutrient content as an 'isolable problem' (Anderson et al, 1991), which could be approached in the same way as other stress-tolerant traits. And so the 'food systems' framing was replaced by a familiar CGIAR narrative – the solution was 'in the seed' (Brooks, 2010).

Meanwhile, a group of IRRI plant breeders led by Dharmawansa Senadhira were developing rice varieties for 'problem soils' characterised by salinity and mineral toxicity and deficiency. This group produced a cross called 'IR68144', an aromatic variety suited to 'cold elevated areas'. At this time, Senadhira became aware of the CGIAR micronutrients project, which prompted a shift to nutritional breeding objectives.[9] At the same time, the attention of his Filipino colleagues was drawn to a national campaign to combat iron deficiency anaemia following the 'Ending Hidden Hunger' conference in Montreal in 1991 (Gregorio et al, 2000, p382; see also Graham et al, 1999). As a result, while IR68144 contained elevated levels of both iron and zinc, it was its identity as a *high iron* cultivar that was emphasised. In 1999, an IRRI convened conference which brought together crop scientists and nutritionists to discuss strategies for 'improving human nutrition through agriculture' , provided Sehandhira's team with an opportunity to showcase their recently discovered 'high iron rice':

> A high-iron trait can be combined with high-yielding traits. This has already been demonstrated by the serendipitous discovery … of an aromatic variety – a cross between a high yielding variety (IR72) and a tall, traditional variety (Zawa Bonday) from India – from which IRRI identified an improved line (IR68144-3B-2-2-3[10]) with a high concentration of grain iron (about 21ppm[11] in brown rice)…. yields are about 10%, below those of IR72, but in partial compensation, maturity is earlier. This variety has good tolerance to soils deficient in minerals such as phosphorus, zinc and iron. (Gregorio et al, 2000, p383).

While the 'serendipitous discovery' of IR68144 appeared to confirm the feasibility of rice biofortification; questions remained about its performance in different agro-ecological conditions. The question of genotype-environment interactions, however, would be dealt with through the usual process of varietal evaluation following multi-location trials, so these were put on hold. For the time being, the focus shifted to the nutrition parameters of bioavailability and bioefficacy (the extent to which adsorption of these nutrients effects a measurable change in human nutrition status) as representing 'the final unknown' (Brooks, 2010). Bouis and Senadhira's team now looked to Angelita del Mundo, a nutritionist at the neighbouring Institute for Human Nutrition and Food at the University of Philippines, Los Banos, who had for many years advocated the incorporation of nutritional parameters into rice breeding programmes.[12] Del Mundo proposed a 'feeding trial' be conducted to test the bioefficacy of iron in IR68144; and proposed Catholic convents as an 'ideal' setting for such a study (Haas et al, 2000, p442). Collaborators would include Jere Haas of the Division of Nutritional Sciences at Cornell and John Beard from the Department of Nutrition at Pennsylvania State University. Following this presentation, new funding was secured from the Asian Development Bank (ADB) for continued research on iron-biofortified rice – on the condition that the feeding trial formed an integral part of the programme.[13]

The feeding trial – focus on nutrition (2000-2003)

This section focuses on the systematic nutrition study which, it was hoped, would convince the international nutrition and donor communities to support biofortification. The study that Del Mundo and her colleagues designed was an ambitious nine-month 'feeding trial' which involved, as research subjects, more than 300 religious sisters in ten Catholic convents across Metro Manila. As such it was both a landmark study and a major logistical challenge which was extremely demanding of the small, close-knit interdisciplinary team of nutritionists and plant breeders. This team or 'research family' as they called themselves displayed particular characteristics which shaped the study in ways that have tended to be overlooked during subsequent contestation.

With the prioritisation of the bioefficacy study, the emphasis of the project shifted to nutrition, using the 'high-iron rice' IR68144 as the material 'developed at the IRRI for experimental use' (Haas et al, 2005, p2825). The feeding trial was a 'prospective, randomised, controlled, double blind, longitudinal (9 month) intervention trial involving 317 women. 'The study had two arms: low-iron rice and high-iron rice, which were the exclusive sources of rice consumed [by the research subjects] for 9 months' (Haas et al, 2005, p2824). In preparation for the feeding trial, crop scientists at IRRI conducted a series of experiments to measure the effects of production, milling and cooking of IR68144 in comparison with the proposed control. Thus far, the screening of varieties for iron content had been conducted on dehulled but un-milled 'brown' rice. However in the Philippines (and elsewhere in the region) rice is usually consumed in its milled 'white' form. This was the first time that the research team had evaluated the effects of post harvest processing (milling, rinsing, cooking) on grain iron content. They found that milling and rinsing had a far greater impact on the iron content of cooked white rice than previously assumed, to the extent that the differential between the 'high iron' and 'low iron' rice was reduced to a level that threatened the viability of the study:

> In effect, the differential between IR68144 and PSBRc28 [the original control] is largely based on milling and not genotype…. The differential may be achieved if a commercially produced rice...will be used opposite to IR68144 … treatments such as milling of IR68144 and washing of rice prior to cooking should be taken into consideration to maximize the differential (Gregorio et al, 2003, Conclusions and Recommendations).

Adjustments had to be made in order to engineer the iron differential required for the study to go ahead; including the selection of a new control and the development of a milling strategy which involved under-milling IR68144 and over-milling the control. Since under-milled rice does not store well, supplies of the 'high iron' rice had to be delivered to the participating convents on a fortnightly basis. These adjustments placed demands on the researchers, which they absorbed willingly. The location of the research in Catholic convents held particular significance for the Filipino 'research family' who were all of the Catholic faith. Del Mundo, in particular, 'had always dreamed of working with religious sisters' in her research work (Del Mundo, 2003, p82). This convergence of 'science and religion'[14] was also reflected in the convent leaders' decision to accommodate the research once convinced that participation constituted a form of 'humanitarian service'.[15]

Questions remained, however, about how the 'high iron' status of IR68144 might be sustained beyond the carefully controlled feeding trial. The elaborate logistics required to maintain the identity of the 'high iron' material was just a taste of the challenges to come in maintaining its integrity as a commercial variety with distinct (yet invisible) characteristics. Consideration of the implications for traceability, pricing and attributable nutritional impact in 'real world' conditions was shelved. The seeds of future contestation were sown with the claim that such a partial and contingent success represented 'proof of concept' (an ambiguous claim in itself); particularly since the IR68144 materials had, by then, been submitted for varietal testing, with the expectation that the conclusion of the feeding trial would coincide with the launch of the Philippines' first high iron rice variety.

During routine varietal testing, the agronomic performance of IR68144 did not match expectations so it was released with the more cautious certification of a 'special variety' and named MS13 (Padolina et al, 2003, p11; Corpuz-Arocena et al, 2004). Meanwhile, MS 13 seeds were transferred to the Philippine Rice Research Institute (PhilRice) for seed multiplication and varietal promotion. It was at this point that agronomists began investigating the variability of 'high iron' character of MS13/IR68144 more closely, discovering significant variation in grain iron content across contrasting agro-ecological conditions and between seasons.[16] It was in the context of these questions about the relative contribution of the 'G' and 'E' factors that some agronomists began to question the wisdom of privileging a genetic-led approach to biofortification. Surely these findings suggested that environmental testing might play a useful role in informing breeding strategies (cf. Simmonds, 1991)? As one scientist explained: '…they identify genotypes first, without understanding the cultural practices that will optimise the expression of iron… If they did an agronomic study first, *then the true breeding parents would have been used'*.[17]

Globalising biofortification: negotiating programme-wide breeding targets (2004-2006)

In 2003 funding was secured for a joint proposal from CIAT and IFPRI for a Biofortification 'Challenge Program' called HarvestPlus (CIAT and IFPRI, 2002). This included funds from a new donor, the Bill and Melinda Gates Foundation (BMGF). This section charts the transformation of the ADB-funded regional rice biofortification initiative into the rice crop component of this new global programme. In the process, new actors congregated around a vision of a series of 'gold standard'[18] biofortified lines developed according to a system-wide framework of breeding targets. Meanwhile, the outputs of earlier research –

including the mixed performance of IR68144 – presented dilemmas for a new team of research managers poised to 'scale up' rice biofortification research.

The results of the feeding trial were published in 2005, with the conclusion that 'consumption of biofortified rice, without any other changes in diet, is efficacious in improving iron stores of women with iron-poor diets in the developing world' (Haas et al, 2005, p2823). This was an important milestone, which coincided with a change in personnel involved in rice biofortification research at IRRI.[19] A 'research family' rooted in the Philippine context gave way to an internationally-focused network of researchers now tasked with conducting iron-biofortified rice research under HarvestPlus.[20] Distancing themselves from 'IR68144/MS13 they asserted that while as a variety it was far from 'gold standard', the feeding trial had provided the necessary 'proof of concept' to justify investment in further research.

But what had been proven? As discussed in the previous section, problems had emerged in the run-up to the feeding trial and later in varietal testing that had cast doubts on the wisdom of a genetics-led approach to biofortification. While the former had highlighted the importance of post harvest practices in determining grain iron content (Gregorio et al, 2003); the latter suggested that environmental, rather than genetic factors might be more significant. By this time, however, the HarvestPlus Program, which institutionalised a genetics-led strategy, had been endorsed by newly established CGIAR Science Council. The Science Council was committed to a return to model of 'high impact' public goods research (Science Council, 2006) which within the CGIAR was equated with genetics-led research (Brooks, 2011a). Furthermore, this equation linking 'impact at scale' with a genetics-led approach had been key to securing the support of the BMGF for biofortification at a time when the CGIAR's traditional donors were still cautious.[21] The next step would therefore be to resume the search for rice germplasm with higher grain iron content, in accordance with centralised, programme-wide targets.[22] Having streamlined the problem definition thus, it was not long before IRRI scientists were debating whether transgenic methods might be a more efficient way to achieve these targets than 'conventional' plant breeding.[23, 24]

Those now tasked with steering rice biofortification research under HarvestPlus drew selectively from the previous research phase, claiming 'proof of concept' for the efficacy of iron-rice biofortification (as well as, even more questionably, a 'bioavailability number' for iron in rice-based diets[25]). At the same time the question of technical feasibility with respect to biofortification through conventional plant breeding was being re-opened – the key question now was whether HarvestPlus nutrient targets necessitated a transgenic approach. As a result, research at IRRI on iron biofortified-rice began to follow two parallel paths – based on the use of first, conventional plant breeding and second, transgenic techniques. This development suggested that the choice facing decision makers was between the objective merits of two technologies; obscuring the fact that the critical decision had already been made. In both cases research would follow a genetic-led strategy based on centralised targets based on calculations of 'impact' in relation to yet to generic 'populations at risk'. This shared understanding of the choices ahead enabled plant geneticists to define the parameters of engagement with other disciplines, including human nutrition.[26]

Nowhere was this more apparent than in an encounter between plant breeders and nutritionists over the setting of programme-wide breeding targets. With HarvestPlus framed as a strategy in which 'agriculture would be an instrument for human health' (Graham, 2002), these targets were to be set at a level that would achieve a significant health impact. However, it soon became clear such targets would be difficult to achieve within the first phase of the programme. Plant breeders proposed they work towards 'intermediate targets', as is consistent with the practice within the discipline of 'breeding up', and releasing a series of improved products over time, 'like Honda cars'.[27] But to the nutritionists this made no sense; since 'you either have the level for biological impact or you don't.'[28] The plant breeders won the argument and intermediate targets were adopted. For the nutritionists this was a turning point which demonstrated that HarvestPlus remained, first and foremost, a crop improvement programme. As one nutritionist remarked; 'whenever nutrition throws up a challenge, [plant breeders] move the goalposts!'[29]

With the changes accompanying the transition from the ADB-funded project to the globalised HarvestPlus programme, including the interdisciplinary contestation outlined above, a key lesson from the IR68144/MS13 experience failed to attract attention. When MS13 was released in 2003, members of the 'research family' anticipated a positive response from farmers and consumers, mindful of governmental initiatives to support fortification of staple foods with essential nutrients.[30] However the release coincided with the launch of a major subsidy programme for hybrid rice producers in the year leading up to the 'International Year of Rice' (PhilRice, 2006). Thus the high iron rice project was but a short chapter in a more complex story of science, policy and politics in the Philippines in which a narrative of rice self-sufficiency remains as emotive and powerful as it was at the height of the Green Revolution (Brooks, 2011b). When asked what was the most important lesson to be drawn from the experience of IR68144/MS13, one participant in the varietal assessment process put it succinctly: 'national priorities *matter*'.[31]

The shift to zinc: genetic or agronomic biofortification? (2007-2010)

By 2007 another series of shifts was underway. The HarvestPlus team had succeeded in securing funding for a second phase. The Challenge Program structure was being questioned during discussions then underway in the CGIAR around a series of 'mega programs'. Meanwhile, those steering iron rice biofortification research at IRRI recognised that the prospects of meeting HarvestPlus targets using conventional plant breeding alone were increasingly unlikely. Nevertheless, during the first phase of HarvestPlus, plant breeders at

IRRI had been screening known rice cultivars for both iron and zinc grain content. A key factor was the exact location of these nutrients within the grain. While a substantial amount of grain iron content is concentrated in the aleurone layer that is removed in the milling process (so that levels dropped below target levels in white rice – as had been discovered in preparations for the feeding trials) with grain *zinc* content milling had a relatively small effect (Johnson-Beebout et al, 2010). The decision was taken, therefore, to proceed with conventional plant breeding for zinc and transgenic research with respect to iron.

The shift to zinc created new spaces for the development of a different culture of interdisciplinary enquiry at IRRI. This collaboration was prompted by plant breeders' and soil scientists' shared sense of curiosity and puzzlement that neither had been able, from their own disciplinary perspective, to explain observed GxE interaction in grain zinc concentration. Encouraged by managerial changes supportive of interdisciplinary collaboration, a new cohort of young scientists has begun to explore new avenues of research. Importantly, this transformation has taken place, not according to an *a priori* plan, but through an evolutionary process that has followed the formation of lateral relationships between scientists, through serendipitous events, informal connections and friendship. As one scientist commented; 'it helped that we are all women about the same age, and we communicate more easily than the larger group which included mostly men, and mostly more senior scientists'.[32]

From late 2006 onwards this group continued to meet as a 'cross disciplinary group of zinc researchers within IRRI' to discuss their work, while continuing to design their own experiments in the normal way. Soil experiments were designed around a range of variables but utilised only one or two genotypes and were therefore 'only moderately interesting to breeders'. Similarly, breeders carried out multi-location trials from which they collected data via 'routine soil tests' which was of little use to soil scientists attempting to interpret the GxE results since this data did not relate to zinc availability. As one scientist explained; 'it took us a long time to realise how differently we understood GxE effects in different disciplines'[33] A turning point came when funding was secured to recruit a post-doctoral researcher for the project and, instead of an additional plant breeder or agronomist, a plant physiologist was appointed. This individual proved to be the vital link in the interdisciplinary web; able to explain to plant breeders and soil chemists *why* specific rice varieties perform differently in different environments. These interdisciplinary discussions, enabled as much by by personal relationships as any organisational plan, led to the design of a specific set of experiments to answer each others' questions. By early 2011 the group were planning 'plant breeding experiments in strategic locations' representing varying zinc availability thus enabling the simultaneous collection of plant physiology and soil-related data.

In parallel with these developments at IRRI, however, a new global project has been launched under the auspices of HarvestPlus, based on a different type of agronomy optimizing the use of zinc fertiliser technology. Tellingly, this project incorporates scalability assumptions comparable to those of genetics-led biofortification under the first phase of HarvestPlus. In this case a global mining industry in search of new ways to demonstrate corporate social responsibility and 'mineral stewardship' by promoting zinc as a product that is uniquely 'natural, essential, durable and recyclable' (Green et al, 2010) is emerging as a powerful new actor. Initiatives to date have included a high profile 'Zinc Saves Kids' supplementation campaign (in partnership with UNICEF[34]) and now the industry-sponsored 'HarvestPlus Global Zinc Fertilizer Project'[35]. The latter involves widespread application of zinc fertiliser as a 'short term' solution to serve as a stop gap until 'genetic biofortification' (still the 'optimum' strategy) produces its long awaited results:

> 'Obviously, application of Zn-containing fertilizers represents a quick and easy solution to the problem, and an important complementary approach to on-going breeding programs for developing new genotypes with high Zn density in grain' (Cakmak, 2008, p1).[36]

This view of zinc fertiliser as a 'silver bullet' is contested by agronomists working in the field. The initial success stories of zinc fertiliser-induced biofortification involved only wheat (Erenoglu et al, 2010; Cakmak et al, 2010). These studies demonstrated the effectiveness of both soil and foliar applications of zinc in increasing grain zinc content, in at least some Zn-deficient environments. However, rice is different from wheat in two important respects: first, since it is grown in flooded soils and 'flooding the soil changes everything' (Johnson-Beebout et al, 2010). In particular, soil-applied zinc fertiliser sometimes becomes rapidly unavailable to plants after the soil has been flooded (Johnson-Beebout et al, 2009). Second, zinc applied on the foliage is not as easily moved into the grain in rice as it is in wheat, due to fundamental physiological differences between the two species (Jiang et al, 2007; Stomph et al, 2009); though there is still debate about the level of genetic variation within rice varieties for this trait. Wissuwa et al (2008) have therefore cautioned against the use of zinc fertiliser as a generic solution; highlighting results showing 'native soil Zn status' as the dominant factor determining grain Zn concentrations 'followed by genotype and fertilizer'. They argue that it is 'not possible to simply compensate for low soil Zn availability by fertilizer applications' (Wissuwa et al, 2008, p37). Plant breeders, however, have contested this arguing that the genotypes used in the study did not include sufficient genetic variability to support such a conclusion.

Thus biofortification remains a site of contested agronomy. At IRRI contestation is confined to technical feasibility questions debated among crop scientists. Meanwhile nutrition studies are conducted elsewhere, with research partners in Bangladesh, with whom, under current organizational arrangements IRRI crop scientists have little interaction. Similarly, wider issues of effectiveness and appropriateness, such as whether poorer farmers will ultimately be able to afford zinc fertilizers, are 'dealt with' elsewhere within an increasingly dispersed global network.

Conclusions

This paper has taken biofortification research as a case study in contested agronomy, in which a body of knowledge about complex interactions between genotypes, soils, human bodies and populations has evolved over time, in ways that have both reflected and reinforced particular sets of interdisciplinary and inter-institutional relations. In the process, certain types of knowledge have presided over others, with the result that some dimensions of this complex, multi-dimensional project have been contested, while others have not. Research in each phase has been both groundbreaking and partial – something is always left out – with the consequences of blind spots inherent in one phase being carried over to the next. In this context, biofortification has been an arena of continual contestation, nourished by a succession of 'new paradigms', inflated claims and counterclaims, and never quite resolved.

These dynamics have been examined through the lens of interdisciplinary relations and contests that have characterised different stages of the research. Specifically, it has traced efforts centred at IRRI to develop rice cultivars enriched with the trace minerals iron and zinc. This analysis has shown that the 'software' of interdisciplinary collaboration – built on collegial relations that are difficult to cultivate at a distance – is as important as the hardware that can be drawn on an organisation chart. In particular, a crucial element of fruitful interdisciplinary exchange has been the formation of lateral connections between early career scientists (not yet as constrained by imperatives to simplify results and secure future funding) – who have been motivated to learn more about the function of each others' disciplines ,. Nevertheless, these have tended to be islands of beneficial interdisciplinary contestation and learning that have emerged at particular moments, through serendipitous connections, informal relations and friendship, which have not, thus far, been institutionalised. As a result, interdisciplinary collaboration throughout fifteen years of biofortifciation research at IRRI has been variable, inconsistent and partial; and opportunities for institutional learning elusive.

The globalisation of biofortification research is predicated on the principle of interdisciplinary collaborative research. In practice, however, the research is increasingly compartmentalised, with specialised components of research dispersed throughout global, heterogeneous networks of institutions and individuals. This effectively closes spaces for contestation, often when and where it is most needed. This paper has highlighted the inherent challenges in widening (rather than narrowing, as is the current trend) interdisciplinary exchange to incorporate broader issues – political as well as technical – that will ultimately have the greatest influence on the effectiveness of biofortification as a real world intervention. With zinc-biofortified rice now identified as a ‘product line’ within the Global Rice Science Partnership (GRiSP, formerly the Rice Crop ‘Mega program’) (IRRI AfricaRice and CIAT, 2010) this would be an appropriate time to review the lessons highlighted by this paper and consider their implications for research design and practice.

Notes

1 In this volume agronomy has been defined as 'the application of soil, plant and environmental sciences to crop production' (Sumberg et al, this volume). However this article uses the term agronomy as understood at IRRI where there is a clear organisational division between the constituent activities (and related disciplines) of crop improvement (genetics), crop management (agronomy) and grain quality (cereal chemistry and post-harvest/agricultural engineering) (Interviews, IHNF and IRRI, June 2006; http://www.harvestplus.org/ (26 February 2010)).

2 For example, a recent meta-analysis of community-based studies of the nutritional impact of QPM generated results that were encouraging but not conclusive (Gunaratna et al, 2009).

3 Interview, HarvestPlus, 31 January 2006.

4 Interview, former CGIAR director, 20 January 2006.

5 The term 'bioavailability' refers to the proportion of nutrient the body can extract from food items and make available for utilisation.

6 Federal plant nutrition and soil laboratory.

7 Interview, Cornell, 19 January 2006.

8 '"The potential economic returns on research aimed at helping Turkish farmers on zinc-deficient lands reduce their seeding rate are tremendous", says Braun [of CIMMYT's Wheat Programme]. "A reduction of 80kg/ha could save about 400,000 tons of seed a year, with an estimated value of US$80 million"' (CIMMYT, 1995).

9 Interview, IRRI scientist, 9 June 2006.

10 The full name of the variety, normally abbreviated to IR68144.

11 Parts per million (sometimes expressed as µg/g).

12 Interview, IHNF, UPLB, 26 May 2006.

13 www.adb.org/documents/prf/nutrition.asp (10 November 2005).

14 Interview, IRRI scientist, 16 December 2006.

15 Discussions with ‘family members’, en route to visit participating convents, 21 December 2006.

16 Interview, PhilRice, 7 June 2006.

17 Interview, PhilRice, 30 May 2006, original emphasis.

18 Interview, IFPRI, 17 January 2006.

19 Interviews, IHNF and IRRI, June 2006.

20 http://www.harvestplus.org/ (26 February 2010).

21 Interview, BMGF, 30 November 2005.

22 Interviews, HarvestPlus, January 2006.

23 Interviews, IRRI, November and December 2006.

24 This view solidified following publication of research showing that the bioavailability of iron in ferritin, the proposed source material, compared favourably with ferrous sulphate, a common fortificant (Davila-Hicks et al, 2004).

25 Interview, IRRI, 2 June 2006.

26 Interview, HarvestPlus, 31 January 2006.

27 Interview, IRRI scientist, 30 May 2006.

28 Interview, nutritionist, HarvestPlus, 16 February 2006.

29 Ibid.

30 Food Fortification Law (2000).

31 Interview, Rice Variety Improvement Group (RVIG) member, PhilRice. campus, Nueva Ecija, 17 January 2007.

32 Ibid.

33 Interview, IRRI scientist, 25 November 2010.

34 http://www.zincsaveskids.org/ (3 November 2010).

35 http://www.zinc-crops.org/publications/HarvestPlus_Zinc_Project.pdf (19 October 2010).

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