Institution: University of Warwick

Unit of Assessment: A5: Biological Sciences

Title of case study: Improvement of Seed Vigour and Performance in Crop Production

1. Summary of the impact

Reliable seed performance is the cornerstone of crop establishment, an important trait that determines the cost and resource efficiency of crop production. In practice, seed performance varies, and this creates a substantial global problem for seed producers and farmers. From 1980 until the present time, Finch-Savage and Rowse have provided knowledge, patented techniques and genetic backgrounds from their research programmes to enhance the performance of seeds in crop production. Seed production businesses worldwide use and continue to adopt these techniques. These include both national (e.g. Elsoms Seeds, UK; Seed Enhancements, New Zealand) and global (e.g. Syngenta and Bayer) companies. Therefore, the work of Finch-Savage and Rowse has had, and continues to have, a direct impact on food security, sustainable crop production and the profitability of farming and seed production businesses.

2. Underpinning research

Sub-optimal and variable crop establishment is universally recognized as a major limitation to crop yield. The cost (financial and environmental) of all remaining crop inputs (fertilizers, protective chemical sprays, harvesting, energy use etc.) remains the same, but yield is irreversibly diminished at this earliest stage of the production process by poor crop establishment. Seed performance (often called seed vigour) is the cornerstone of predictable crop establishment and is therefore essential if crop production is to be resource-efficient and cost-effective. Non-optimal seed quality and the resulting poor field performance negatively impacts food security and is a global problem for farmers and the seed companies that supply them. Seed quality limits all crops, but has particular importance for small-seeded field crops (e.g. oil seed rape) and many vegetable crops that have high nutritional and financial value.

Finch-Savage and Rowse conducted a sustained programme of work from 1980 to 2013 to understand the basis of variation in seed performance in the soil seedbed. For example, a key finding from the Finch-Savage group is that rapid germination, rather than stress tolerance, minimizes the negative impacts of seedbed conditions that result in poor establishment. It was further shown that this speed of germination trait could be manipulated prior to sowing both through genetic improvement and by physiological advancement treatments. Based on this type of research, a portfolio of processes (e.g. Drum Priming and Pre-germination) were developed that can be applied within a seed production company to enhance the subsequent field performance of crop seeds for farmers during crop production. Thus the on-farm problem of variable seedling establishment is addressed through added value to the seed, benefitting both farmer and seed company.

Research work by Rowse to understand how seeds responded to moisture in the soil resulted in the invention of a new physiological method ('Drum Priming') of enhancing seed performance and vigour[1]. This method works by a computer-controlled application of water to the seed in a rotating drum. Crucially the water applied is sufficient to initiate and progress germination processes, but insufficient to allow completion. Thus desiccation tolerance is maintained, allowing subsequent drying to facilitate normal commercial distribution of the seed to the farmer. By using drum priming, seedling establishment is faster, more uniform and more predictable across sowing occasions than from untreated seeds. The precise benefits differ between crop species, but consistently give the commercially recognisable benefits of enhanced yields and profits. This method was developed into a commercially robust patented (1992[a]) seed technology that has now been adopted in various forms by seed companies worldwide[f–l], and widely requested by farmers willing to pay a premium for the seed product. Rowse and Finch-Savage developed a variant of the technology that has recently been used to introduce drum priming to further companies (2008–2010; Seed Enhancements Ltd, New Zealand[f]). A further variant of the technology was also developed for high-value small seeds[3] and patented (1996)[b]. Optimisation of these techniques and identification of the full benefits has been the subject of research in the Finch-Savage group and many seed companies during the review period. The Finch-Savage group has also continued confidential, and therefore unpublished, work on treating and handling pre-germinated seeds in support of a

previously patented process (1990)[c].

Overlapping with this work, the Finch-Savage group carried out a quantitative genetic analysis using *Brassica oleracea* (cabbage family of crops) mapping populations[2]. This work demonstrated a genetic basis to speed of germination and identified quantitative trait loci (QTL) that influence this trait. Further work identified and characterised other aspects of seed performance, such as pre-emergence root growth and growth potential in degraded soils[4,5]. During the review period the most statistically significant speed of germination QTL was isolated within a chromosome substitution line and analysed. The QTL was further fine-mapped and a co-linear region was identified in *Arabidopsis* to facilitate molecular studies on the candidate genes present. Two genes were found to have seed performance phenotypes in knockout mutants (resulting in faster germination). Transformation of *Arabidopsis* with *B. oleracea* alleles of these genes delayed germination, confirming their involvement in seed performance. One of the genes identified is a regulator of alternative splicing and the other is of unknown function. Both genes are now the subjects of a patent filing (published 6 September 2013[d]) with Syngenta as the commercial partner, and a publication with potential high impact has been withheld while complete IP cover is being developed (e.g.[e]).

A significant output of the latter research work was to identify beneficial alleles of these genes in *B. oleracea.* To test commercial significance for plant breeding, Syngenta crossed these beneficial alleles into 7 commercial lines. Using industry vigour tests, it was shown that lines containing the beneficial alleles on average increased the percentage of seeds germinating under stress from 8 to 41% and eliminated the problem of induced secondary dormancy present in 80% of seed in lines without the beneficial alleles[d]. This conclusively shows that seed performance can be enhanced within a conventional breeding programme without necessarily resorting to GM technologies. It also shows the benefits have substantial commercial potential for both seed company and the recipient farmer. Continued work in *B. oleracea* and *Arabidopsis* now suggests these two genes modulate the seed response to abscisic acid (ABA), an inhibitor of germination. As a result of this further genetic work, a third related gene (a homologue of CYP707A2 in Arabidopsis) has been identified that modifies ABA content in the seed to alter seed performance[e].

University of Warwick staff

Professor William Finch-Savage, School of Life Sciences, 1981 – present.

Dr Hugh Rowse, School of Life Science, Research Leader (1975–2002) and Associate Fellow (2002–2010)

3. References to the research

Peer-reviewed publications

1. Rowse, H.R. (1996) Drum priming – a non-osmotic method of priming seeds. *Seed Science and Technology* 24, 281–294.
2. Bettey *et al.* (2000) Quantitative genetic analysis of seed vigour and pre-emergence seedling growth traits in *Brassica oleracea* L. *New Phytologist* 148, 277–286. *DOI: 10.1046/j.1469-8137.2000.00760.x*
3. Rowse, H.R. *et al.* (2001) Membrane priming – a method for small samples of high value seeds. *Seed Science and Technology* 29, 587–597.
4. Finch-Savage, W.E. *et al.* (2005) Sensitivity of *Brassica oleracea* seed germination to hypoxia: a QTL analysis. *Plant Science* 169, 753–759. *DOI: 10.1016/j.plantsci.2005.05.026*
5. Finch-Savage W.E. *et al.* (2010) Towards a genetic understanding of seed vigour in small-seeded vegetable crops using natural variation in *Brassica oleracea. Plant Science* 179, 582–589. *DOI: 10.1016/j.plantsci.2010.06.005*

Peer-reviewed, Ministry and Industrial Grants (Finch-Savage as PI)

'Identify and determine the importance of factors in the pre-emergence phase influencing seedling establishment', £525k, MAFF (1994–1997)

'To identify physiological and biochemical bases of seed vigour in vegetable crops' (HH1213sFV), £189k, MAFF (1997–2000)

'Seed vigour' £75k (3 × 12 months from 1998 to 2000) Germaines UK Ltd

'Seed vigour in vegetable crops'; Grant reference HH1218SFV; Amount awarded £208,066 (2000–2003) Defra (http://tinyurl.com/pcv7xk5)

'Molecular approaches to improved seedling establishment'; Grant reference HH3711SFV; Amount awarded £596,732 (2003–2007) Defra (http://tinyurl.com/oey4qt2)

'Drum Priming' £19k (2008) Lions Seeds, New Zealand

'Drum Priming' £19k (2009) Confidential commercial funding
'A trait-led approach which exploits natural variation in seed vigour to enhance crop establishment' (2007–2011) BBSRC Industrial Partnership Award. Amount awarded by BBSRC £412,558k; Grant reference BB/E006418/1. Funding from Syngenta Seeds (Industrial partner) £53,400. (http://tinyurl.com/ndth2yf).
'Towards improving parsnip seed quality – the role of genetics and environmental influences'; KTN SPARK Award (Technology Strategy Board) 2012 with Elsoms Seeds Ltd, Amount awarded £5,000.

4. Details of the impact

Research in the Finch-Savage group, and by Rowse, has provided knowledge, patented techniques[a-e] and processes and, most recently, identified influential genes and beneficial alleles of those genes to enhance seed performance. Cumulatively, the impact of this research is several-fold. Firstly, the end product of seeds with greater vigour improves crop establishment for farmers to enhance their crop productivity and resource use efficiency, and therefore more widely food security. Secondly, the enhanced seed is requested by farmers and so has increased value to the seed companies, increasing their profitability while protecting and enhancing their market share. Providing precise data from competing seed companies and a multitude of farmers is not feasible and therefore testimony from representative seed companies of contrasting sizes (national (Elsoms[g], Seed Enhancements Ltd[h]) and global (Syngenta[h], Bayer[i])) from different origins are used as indicators of these impacts. Elsoms, the UK's leading vegetable plant breeder and seed supplier, confirmed that 'the knowledge and expertise related to all aspects of seed germination/technologies from the Finch-Savage group continues to help the industry going forward in today's more challenging and unpredictable production environment'. Furthermore, 'The input we have had from the Finch-Savage group has led to the injection of new technologies into our organization so that we can offer better solutions for UK farmers and growers. Without such help larger multinational organisations can be ahead of our technologies, and we need to 'keep up' with them so that we can support our industry in the UK'[g]. For example, Elsoms started to use drum priming on a small-scale approximately 15 years ago with support from Rowse, but during the review period they have greatly increased the quantity of seeds and species treated following feedback from farmers on the commercial benefits they see in the performance of their seeds.

Throughout the world, seed companies supply farmers with seeds, a product that is judged on its field performance. The seed producers are also plant biotechnology companies, and seeds are their means of delivering genetic innovations across space and time. In global and European agriculture, the seed market is thought to exceed US$40 billion and £5 billion, respectively, identifying this as a major industry. Syngenta is one of the three largest global seed companies and has adopted technologies developed by Finch-Savage. For example, the innovative Syngenta seed products PreNova and PreMagic (sold principally in the USA) emerged from Finch-Savage's work and were considered to infringe his 1990 patent[c], and so Syngenta were challenged by the British Technology Group, which was charged with licensing the patent. After several years of dispute, Syngenta purchased the patent in 2005. More recently, Syngenta have been using alleles in *B. oleracea* identified by Finch-Savage[d,e]. The company confirmed 'technology advancements in crop production have led to an increased demand from growers and young plant raisers for high quality seeds. Simultaneously seed producers face challenges such as increased climatic uncertainties. These developments increase the importance of genetic backgrounds such as those identified by Prof Finch-Savage, which have intrinsic high seed vigour and can be reliably produced under different conditions'. In addition: 'our collaboration with Prof Finch-Savage has allowed us to show that the alleles indeed provide a major seed quality benefit when used in relevant commercial seed production environments'. An example of this benefit is described in section 2. The company is now extending work into other crops, such as oil seed rape, and this genetic approach is thought to be the way forward for enhancing seed performance in agriculture[h].

Innovations that enhance seed performance are adopted slowly by the seed industry. For example, significant adoption of the drum priming technique invented by Rowse began 20 years ago, but with continued research and development its use has expanded rapidly throughout the period of assessment and continues to expand. Seed Enhancements Ltd, New Zealand state that 'The technology is widely used by seed companies and seed treatment companies throughout the world, and I believe that it is the single most widely used priming technology – a huge compliment to Hugh Rowse, Bill Finch-Savage and the team at Wellesbourne'[f]. Prototype equipment, built by

Rowse and Finch-Savage at Wellesbourne, was installed and demonstrated to this company in 2008–2009 and they now supply New Zealand and some of Australia with primed seeds. Seed Enhancements Ltd also confirmed, 'I would estimate that the increased value of crops that we prime, to the growers would be many hundreds of thousands of dollars'. This is just one of many seed companies using drum priming and so this scale of benefits is reproduced many fold. In the UK, Elsoms[g] reported that 'In a conservative industry where change can take a long time… the quantities of primed vegetable seeds that are used in the UK are significant and rising every year as growers of different crops now realise the many benefits that they have from using primed seeds. As demands on producers become greater and growers need seeds to germinate both quickly and uniformly, I see no other option for growers than to use more primed seeds in the future'. This view is echoed by other seed companies, including Nunhems seeds[i], the plant-breeding and seed-producing subsidiary of Bayer: 'Seed quality levels required by professional growers of vegetables are increasing continuously'; 'drum priming has many advantages over other methods of seed improvement', and 'as a result, drum priming is now used commercially for several crops in our company, and also by other companies involved in seed enhancement of vegetables, field crops and grasses. Each year new applications/crops are added to the list of uses of drum priming'.

The work by Finch-Savage and Rowse, both independently and collaboratively, has been funded by Government ministries and, subsequently, by the BBSRC. In keeping with the philosophy of both funders, there have been close links with the seed industry throughout via direct funding, partnership, patent licencing and consultancy. As discussed above, the research has led to the technologies being taken up and developed further by the industry partners and other companies. Research and development in support of a portfolio of earlier patented inventions by Finch-Savage (1989–1996)[c] and by Rowse (1992,1996)[a,b] has extended into this review period (2008 onwards). The work by the Finch-Savage group on the genetic basis of seed performance in *B. oleracea*, in partnership with Syngenta, has IP cover from a patent published on 6 September 2013[d] . A second patent application on this topic was filed on 23 August 2013 through Warwick Ventures Ltd[e].

The Finch-Savage group continues to interact with many other seed companies to pass on accumulated knowledge on the improvement of seed performance. Finch-Savage was invited into Syngenta and Germains Seed Technology for internal workshops in 2011–2012 to present the results of his research. The purpose of the workshops was to coordinate research and development within the companies and to introduce new innovations in seed science. In both cases these workshops brought together company personnel from around the world working on seed quality. He was invited speaker at a commercial growers conference (60 participants) in New Zealand (2011) organised by Pukekohe Growers Supplies Ltd. He has presented his research findings and discussed these in the context of commercial seed production at a "Seeds Master Class" for seed company employees, run by the University of Wageningen (2012). As President of the International Society for Seed Science he also regularly interacts with commercial seed organisations such as the International Seed Testing Association based in Switzerland.

5. Sources to corroborate the impact

Patent portfolio includes:

a. US5119589 A: Methods of priming seeds (1992) Rowse, H.R. (http://tinyurl.com/ooauxko)
b. WO 1996008132 A1: Seed priming (1996) Rowse, H.R. and McKee, J.M.T. (http://tinyurl.com/odnpf8o)
c. EP0202879: Seed treatment (1990) Finch-Savage, W.E. (http://tinyurl.com/osb354p)
d. WO2013127809: Modulation of seed vigour (publication date 6 September 2013) Finch-Savage, W.E. *et al.* (http://tinyurl.com/ocabk2l)
e. UK Patent Application Number 1315154.3; 23 August 2013.

Letters of support

f. Managing Director, Seed Enhancements Ltd, New Zealand. (Identifier 1).
g. Managing Director, Elsoms Seeds Ltd, UK. (Identifier 2).
h. Global Head of Seed Physiology, Syngenta, The Netherlands. (Identifier 3).
i. Scientist, Seed Physiology, Nunhems Netherlands BV, A Bayer company. (Identifier 4).