WGIN legacy document 2003 - 2014

Overall outcomes and outputs achieved by the entire 10 year WGIN project

1. **Regular interactions with all the UK based wheat breeding companies**
   A total of 32 management meetings were held over the 10 year period. On average 18 people attended each meeting with 50% from the wheat industry and 50 % from academia. As a result of these regular interactions, the two communities have been connected and this has definitely influenced how the overall WGIN project has evolved. At these meeting there is a considerable dissemination of unpublished data and resources as well as discussions on emerging problems in the wheat crop. The full details of the participation at each meeting are given in **Appendix 1**. As a direct result of these frequent meetings, the wheat breeders maintain, regularly review and discuss collectively a list of priority traits for wheat improvement. This has led to the inclusion of new trait topics in the WGIN2 project and to the development of additional wheat projects funded by other sponsors.

2. **Generation of new germplasm resources, distributed throughout UK academia and industry and the additional 'in field' use of the WGIN trials**
   Major new germplasm resources were generated in WGIN including mapping populations, near isogenic lines, mutagenised populations, novel collections of hexaploid and diploid wheat and molecular markers. A total of 80 requests were made by UK and overseas academics and industry for genetic stocks, grain samples, markers or access to a specific WGIN trial to take measurements and / or additional samples. All requests were fulfilled. In **Appendix 2,** these requests are summarised. Many of these requests have already led to either peer reviewed publications and / or new funded wheat projects on additional traits.

3. **New knowledge disseminated via peer reviewed publications**
   Eighteen peer reviewed publications arising directly from the funded project. Interestingly, the number arising from wheat studies involving other sponsors is higher at 23 articles. This latter success demonstrates the high level of additional impact that has been achieved by others through the immediate use of the newly generated WGIN resources. Collectively, these papers cover a wide range of topics and have been produced by academics based at seven UK universities, one overseas university, three UK institutes and one overseas institute. **Appendix 3** provides the full details for each paper.

4. **New unpublished knowledge disseminated to various types of academia and industry stakeholders**
   A stakeholder distribution list containing in excess of 300 individuals has been maintained throughout the project. In addition up to 8000 individuals are contacted annually via HGCA, NABIM and NFU distribution lists inviting them to the annual Stakeholder event, and to read the latest newsletters and new contents on the website. During the annual Stakeholder event any PI who had won funding for a new wheat projects is invited to attend and to give an oral presentation. The WGIN e-mail is used regularly for specific queries and enquiries.

5. Community led discussion on emerging topics of collective interest to the wheat breeding community

Since 2010, as part of the annual Stakeholder event, through joint breeder-academic consensus we have selected a topic for discussion by an invited panel of experts. The topics covered were 'UK wheat field yields lagging behind breeders projections (2010), Successful 2nd and 3rd wheat crops and issue of Take-all root disease (2011), Emerging disease Patterns (2012), and Yield and quality stability (2013). Each of these discussions has identified many gaps in our current understanding of the wheat crop performance, the stability of key traits, the underlying genetic and mechanistic basis of many traits and the potential inter-dependence of key traits.

6. Collective discussion and exploration of new traits for wheat improvement

The WGIN project has provided a 'launch pad' for several newly appointed PIs and existing PIs and research teams to start work on trait improvement in bread wheat and to join the UK wheat research community. Projects that have been successfully initiated using the newly generated WGIN resources include improved photosynthetic capacity, heat stress at crop anthesis, resistance to aphid infection and studies of grain development and composition including spatial patterns of protein distribution and increased grain protein content.

7. Training the next generation of wheat scientists

This is a major unanticipated outcome of the WGIN project. A total of 20 PhD students have directly benefitted from the ongoing field experiments, genetic resources and stored grain samples provided by WGIN. Nine PhD students have already graduated. These 20 students have been registered at six UK Universities and 2 overseas Universities (China and Hungary). Five of the main supervisors receive no direct funding from WGIN. In addition, there has been considerable opportunity to train undergraduates and MSc students (17 students) and overseas visitors (10 students) in wheat research by involving them in field experimentation. The full details showing the breadth of the WGIN associated training activities are given in **Appendix 4.**

8. Organising a series of 'open invitation' overseas workshops linking UK academics and industry to relevant international wheat communities.

Additional BBSRC funding was successfully won on six occasions to support joint wheat workshops with academic and industry based scientists in China, Brazil, India, France (x2), CIMMYT Mexico (x2), and Central and Eastern Europe (x2). Typically these workshops were attended by up to 15 UK wheat academics, 3 to 5 UK wheat breeding companies and a similar number from the participating country / countries. The main benefits have been the sharing of information, exchange of resources, exchange of personnel for specific training and the writing of joint grants and publications.

9. Generating considerable new income for wheat research in the UK

A total of 47 new wheat research projects using one or more of the new resources generated within WGIN have been funded. The new funds raised for wheat research are in excess of £40.3 million. This new research includes topics already under investigation within

WGIN but also 28 projects on new topics. Within these new funds, £11.0 million has been gained for 31 projects lead by PIs not sponsored within WGIN. A wide range of funding agencies have become involved, including BBSRC, HGCA, defra, EU, European Research Council , the wheat breeding industries and various charities. Most projects are either 3 or 4 years duration, whilst three are of 5 years duration. These data are summarised in **Appendix 5**.

10. **Representatives from non-EU countries and the EU commission coming to find out about how this government sponsored public –private project works**

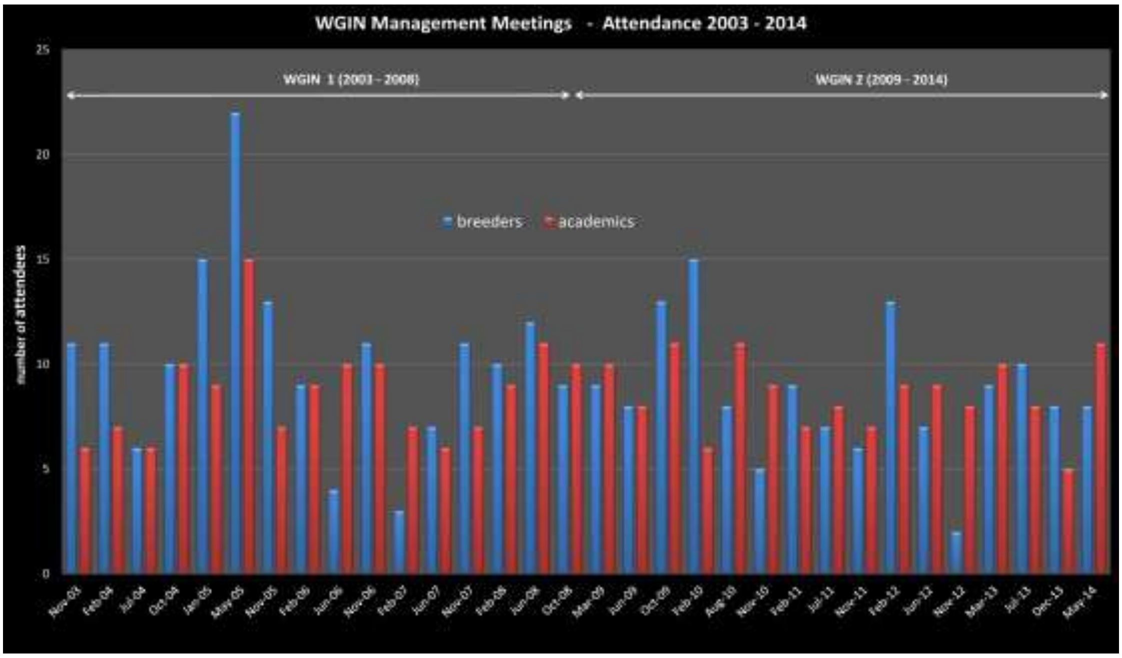
11. **Acquisition of a continuous10 years of field data on key traits using commercially relevant wheat cultivars including yield, nitrogen use efficiency and soil health.**

    Unpublished data is provided by request or via the password protected WGIN Wikispace site which is accessed by the nine UK based wheat breeding companies.

12. **A 10 years run of stored grain samples from the varietal diversity field trials linked to detailed weather data, that could be explored for the stability of multiple traits .**

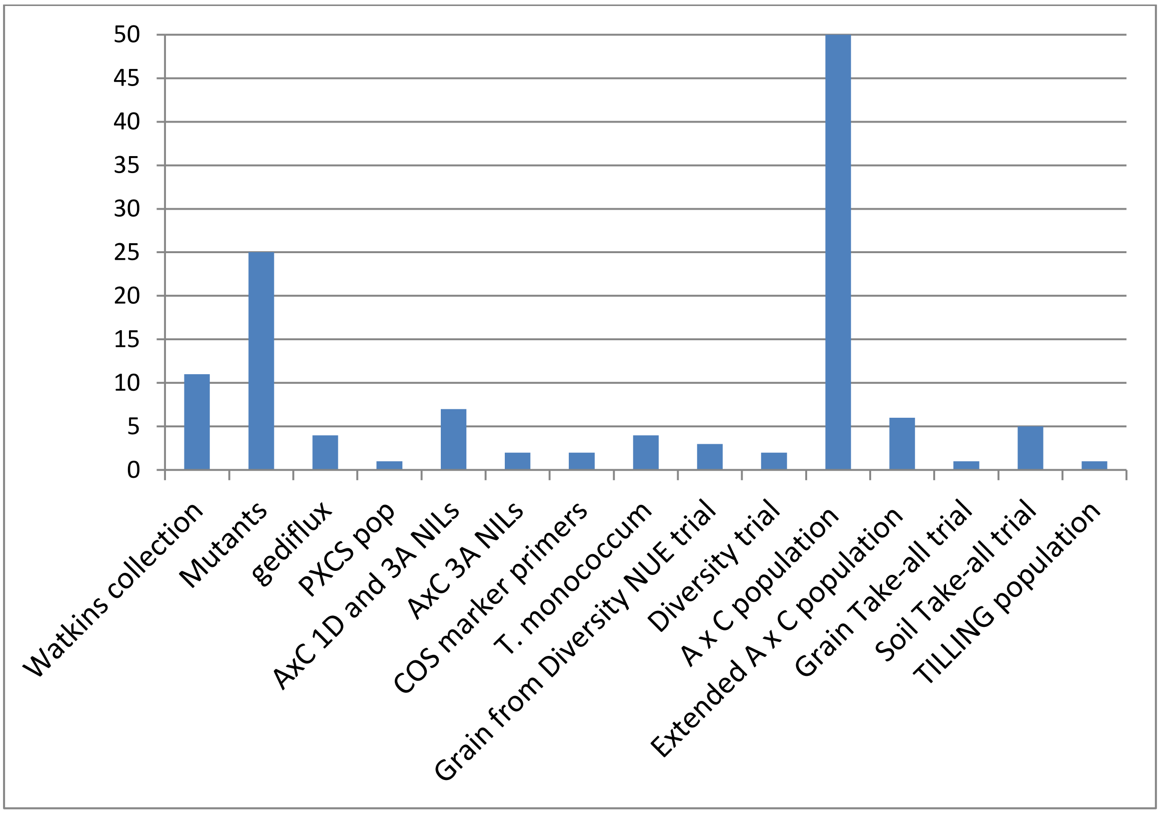
    This carefully archived grain resource obtained from the annual WGIN diversity NUE trial is now vast, in excess of 8000 samples, 500g in size, one from each plot, stored at minus 20^{o}C . So far very few groups have actively used this unique sample resource and the associated metadata. Potentially, many projects could directly benefit by including these samples in their analysis. The vast range of weather experienced over the cropping years would be extremely valuable when exploring the stability of any grain trait between cultivars and seasons.

Appendix 1: Attendance of WGIN management meetings

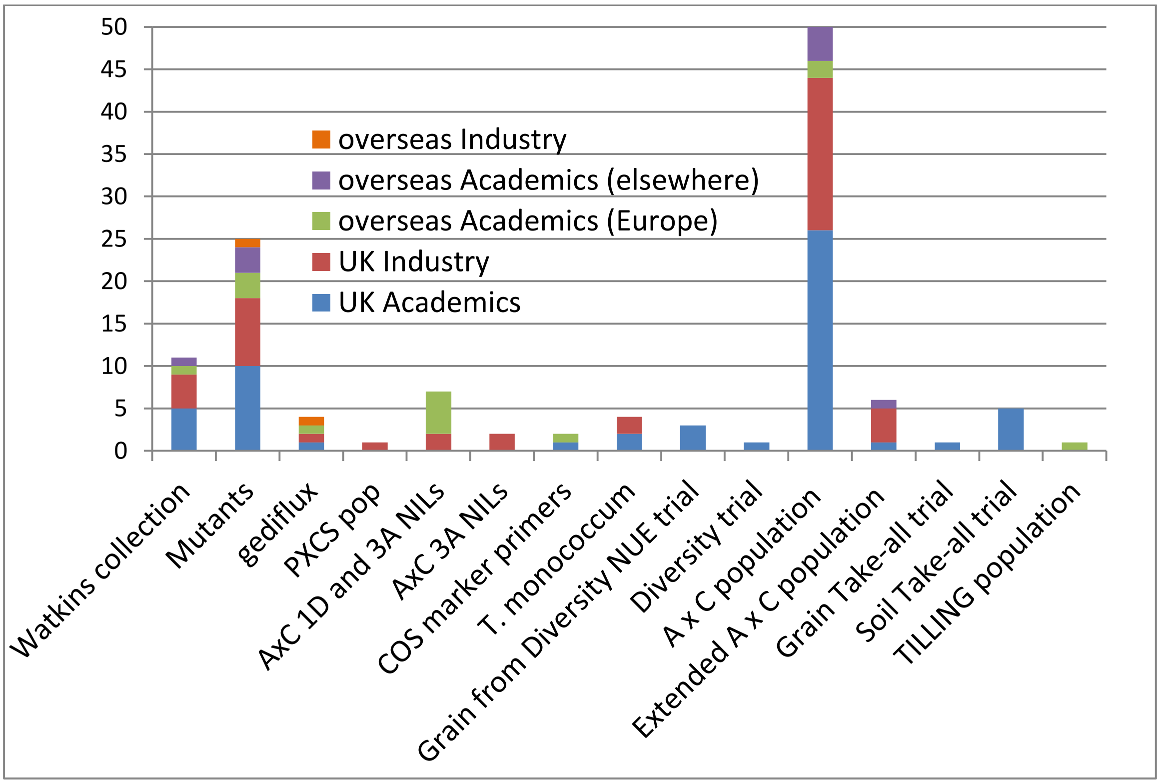


Appendix 2: requests for WGIN resources

a) Requests for each resource (sum total 124)



b) Requests by academic institutions and industry in the UK and overseas



Appendix 3: Peer-Reviewed Articles – Total 40

Non-WGIN funded research - 23 articles

Wang, S. et al (2014). Characterization of polyploid wheat genomic diversity using a high-density 90 000 single nucleotide polymorphism array. **Plant Biotechnology Journal** (2014), doi: 10.1111/ pbi.12183

Galushko, V. and Gray, R. (2014). Twenty five years of private wheat breeding in the UK: Lessons for other countries. **Science and Public Policy** (2014) pp. 1-15, doi:10.1093/scipol/scu004

Burt, C. , Griffe, L. L., Ridolfini, A. P., Orford, S., Griffiths, S. and Nicholson, P. (2014). Mining the Watkins collection of wheat landraces for novel sources of eyespot resistance. **Plant Pathology** doi: 10.1111/ppa.12221

Molnar, I., Kubalakova, M., Simkova, H., Farkas, A., Cseh, A., Megyeri, M., Vrana, J.,Â Molnar-Lang, M. and Dolezel, J. (2014). Flow cytometric chromosome sorting from diploid progenitors of bread wheat, *T. urartu*, *Ae. speltoides* and *Ae. tauschii*. **Theor Appl Genet** (2014) 127:1091-1104

Wan, Y., Sanchis Gritsch, C., Hawkesford, M. J. & Shewry, P. R.(2014). Effects of Nitrogen Nutrition on the Synthesis and Deposition of the Omega-Gliadins of Wheat. **Annals of Botany** 113, 607-615

Allen, A. M., Barker, G. L. A., Wilkinson, P., Burridge, A., Winfield, M.,Coghill, J., Uauy, C., Griffiths, S., Jack, P., Berry, S., Werner, P., Melichar, J. P. E., McDougall, J., Gwilliam, R., Robinson, P. and Edwards, K. J. (2013) Discovery and development of exome-based, co-dominant single nucleotide polymorphism markers in hexaploid wheat (*Triticum aestivum* L.). **Plant Biotechnology Journal** 11, 279-295

Shaw, L.M., et al. (2013). Mutant Alleles of Photoperiod-1 in Wheat (*Triticum aestivum* L.) That Confer a Late Flowering Phenotype in Long Days. **PloS ONE** 8(11): e79459. doi:10.1371/journal.pone.0079459

He, J., Penson, S., Powers, S.J., Hawes, C., Shewry, P.R. and Tosi, P. (2013). Spatial Patterns of Gluten Protein and Polymer Distribution in Wheat Grain. **J. Agric. Food Chem**. 61, 6207-6215

Wilhelm, E.P., et al. (2013). Genetic Characterization and Mapping of the Rht-1 Homoeologs and Flanking Sequences in Wheat. **Theoretical and Applied Genetics** 126(5), 1321-1336

Molnar, I., et al., (2013). Syntenic Relationships Between the U and M Genomes of Aegilops, Wheat and the Model Species Brachypodium and Rice as Revealed by COS Markers. **PloS ONE** 8(8): e70844. doi:10.1371/journal.pone.0070844

Campbell, G.M., et al. (2012). Modelling Wheat Breakage During Roller Milling Using the Double Normalised Kumaraswamy Breakage Function: Effects of Kernel Shape and Hardness. **Journal of Cereal Science** 55, 415-425

Chen, L., Huang, L.Z., Min, D.H., Phillips, A., Wang, S.Q., Madgwick, P.J., Parry, M.A.J., and Hu, Y.G. (2012). Development and Characterization of a New TILLING Population of Common Bread Wheat (Triticum aestivum L.). **Plos One** 7

Gasperini, D., Greenland, A., Hedden, P., Dreos, R., Harwood, W. & Griffiths, S. (2012). Genetic and Physiological Analysis of Rht8 in Bread Wheat: an Alternative Source of Semi-Dwarfism With a Reduced Modified Sensitivity to Brassinosteroids. **Journal of Experimental Botany** 63(12), 4419-4436

Lukac, M., Gooding, M. J., Griffiths, S. & Jones, H. E. (2012). Asynchronous Flowering and Within-Plant Flowering Diversity in Wheat and the Implications for Crop Resilience to Heat. **Annals of Botany** 109, 843-850

Macdonald, A. J. & Gutteridge, Richard J. (2012). Effects of Take-all (*Gaeumannomyces graminis* var. *tritici*) on Crop N Uptake and Residual Mineral N in Soil at Harvest of Winter Wheat**. Plant Soil** 350, 253-260

Allen, A.M, Barker G. L. A., Berry, S.T., Coghill, J.A., Gwilliam, R., Kirby, S., Robinson, P., Brenchley, R. C., D'Amore, R., McKenzie, N., Hall, A., Bevan, M., Hall, N. & Edwards, K.J. (2011). Transcript-Specific, Single-Nucleotide Polymorphism Discovery and Linkage Analysis in Hexaploid Bread Wheat (Triticum aestivum L.). **Plant Biotechnology Journal**, 9(9): 1086-1099

Burt, C. & Nicholson, P. (2011). Exploiting Co-Linearity Among Grass Species to Map the Aegilops ventricosa-Derived Pch1 Eyespot Resistance in Wheat and Establish its Relationship to Pch2. **Theoretical and Applied Genetics** 123, 1387-1400

Botticella, E., Sestili, F., Hernandez-Lopez, A., Phillips, A., and Lafiandra, D. (2011). High resolution melting analysis for the detection of EMS induced mutations in wheat SbeIIa genes. **BMC Plant Biol**. 11.

Howard, T., Rejab, N.A., Griffiths, S., Leigh, F., Leverington-Waite, M., Simmonds, J., Uauy, C. & Trafford, K. (2011). Identification of a Major QTL Controlling the Content of B-type Starch Granules in Aegilops. **Journal of Experimental Botany** 62(6), 2217-2228

Rakszegi, M., Kisgyorgy, B. N., Tearall, K., Shewry, P. R., Lang, L., Phillips, A. and Bedo, Z. (2010). Diversity of agronomic and morphological traits in a mutant population of bread wheat studied in the Healthgrain program. **Euphytica** (2010) 174, 409-421

Sestili, F., Botticella, E., Bedo, Z., Phillips, A. and Lafiandra, D.(2010). Production of novel allelic variation for genes involved in starch biosynthesis through mutagenesis. **Mol Breeding** 25, 145-154

Gegas, V., Nazari, A., Griffiths, S., Simmonds, J., Fish, L., Orford, S., Sayers, L., Doonan, J. & Snape, J. (2010). A Genetic Framework for Grain Size and Shape Variation in Wheat. **Plant Cell** 22 (4) 1046-1056

Waugh, R., Leader, D. J.,Â McCallum, N.Â and Caldwell, D. (2006). Harvesting the potential of induced biological diversity. **Trends in Plant Science** 11(2), 71-79

WGIN funded research – 17 articles

Hawkesford, M. J.(2014). Reducing the reliance on nitrogen fertilizer for wheat production. **Journal of Cereal Science** 59, 276-283

Chope, G.A., Wan, Y., Penson, S.P., Bhandari, D.G., Powers, S.J., Shewry, P.R. and Hawkesford, M.J. (2014). Effects of Genotype, Season, and Nitrogen Nutrition on Gene Expression and Protein Accumulation in Wheat Grain. **J. Agric. Food Chem.** dx.doi.org/10.1021/jf500625c

Barraclough, P. B., Lopez-Bellido, R., Hawkesford, M. J. (2014). Genotypic Variation in the Uptake, Partitioning and Remobilisation of Nitrogen During Grain-Filling in Wheat. **Field Crops Research** 156, 242-248

Bai, C., Liang, Y. & Hawkesford, M. J. (2013). Identification of QTLs Associated With Seedling Root Traits and Their Correlation With Plant Height in Wheat. **Journal of Experimental Botany** 64, 1745-1753

Parry, M. A. J. & Hawkesford, M. J. (2012). An Integrated Approach to Crop Genetic Improvement. **J Integr Plant Biol**. 54, 250-259

Griffiths, S., Simmonds, J. , Leverington, M., Wang, Y., Fish, L., Sayers, L., Alibert, L., Orford, S., Wingen, L. & Snape, J. (2012). Meta-QTL Analysis of the Genetic Control of Crop Height in Elite European Winter Wheat Germplasm. **Molecular Breeding** 29, 159-171, DOI 10.1007/s11032-010-9534-x (publ online 2010)

Derkx, A.P., et al. (2012). Identification of Differentially Senescing Mutants of Wheat and Impacts on Yield, Biomass and Nitrogen Partitioning. **Journal of Integrative Plant Biology** 54(8), 555-566

Barraclough P.B., Howarth, J. R., Jones, J., Lopez-Bellido, R., Parmar, S., Shepherd, C. E. & Hawkesford, M.J. (2010). Nitrogen Efficiency of Wheat: Genotypic and Environmental Variation and Prospects for Improvement. **Eur J Agron** 33, 1-11

Parry, M. A. J. & Hawkesford, M. J. (2010). Food Security: Increasing Yield and Improving Resource Use Efficiency**. Proc Nutr Soc** 69(4), 592-600

McMillan, V. E., Hammond-Kosack, K.E. & Gutteridge, R. J. (2010). Evidence that Wheat Varieties Differ in their Ability to Build-up Inoculum of the Take-all Fungus, *Gaeumannomyces graminis* var. *tritici*, Under a First Wheat Crop. **Plant Pathology** 60, 200-206

Griffiths, S., Simmonds, J., Leverington, M., Wang, Y., Fish, L., Sayers, L., Alibert, L., Orford,S., Wingen, L., Herry, L., Faure, S., Laurie, D., Bilham, L. & Snape, J. (2009). Meta-QTL Analysis of the Genetic Control of Ear Emergence in Elite European Winter Wheat Germplasm. **Theoretical and Applied Genetics** 119(3), 383-95

Jing, H. C., Bayon, C., Kanyuka, K., Berry, S., Wenzel, P., Huttner, E., Kilian, A. & Hamond-Kosack, K. E. (2009). DArT Markers: Diversity Analyses, Genomes Comparison, Mapping and Integration with SSR Markers in *Triticum monococcum*. **BMC Genomics** 10: 458. doi:10.1186/1471-2164-10-458

Jing, H. C., Lovell, D., Gutteridge, R., Jenk, D., Kornyukhin, D., Mitrofanova, O. P., Kema, G. & Hammond-Kosack, K. E. (2008). Phenotypic and Genetic Analysis of the *Triticum monococcum - Mycosphaerella graminicola* Interaction. **New Phytologist** 179, 1121-1132

Al-Kaff, N., Knight, E., Bertin, I., Foote, T., Hart, N., Griffiths, S. & Moore, G. (2008). Detailed Dissection of the Chromosomal Region Containing the Ph1 Locus in Wheat *Triticum aestivum*: With Deletion Mutants and Expression Profiling**. Annals of Botany** 101(6), 863-872

Jing, H. C., Kornyukhin, D., Kanyuka, K., Orford, S., Zlatska, A., Mitrofanova, O. P., Koebner, R. M. D. & Hammond-Kosack, K. E. (2007). Identification of Variation in Adaptively Important Traits and Genome-Wide Analysis of Trait-Marker Associations in *Triticum monococcum***.** **Journal of Experimental Botany** 58, 3749-3764

Hayden, M. J., Stephenson, P., Logojan, A.M., Khatkar, D., Rogers, C., Elsden, J., Koebner, R. M. D., Snape, J. W. & Sharp, P. J. (2006). Development and Genetic Mapping of Sequence Tagged Microsatellites (STMs) in Bread Wheat (*Triticum aestivum* L). **Theoretical and Applied Genetics** 113, 1271-1281

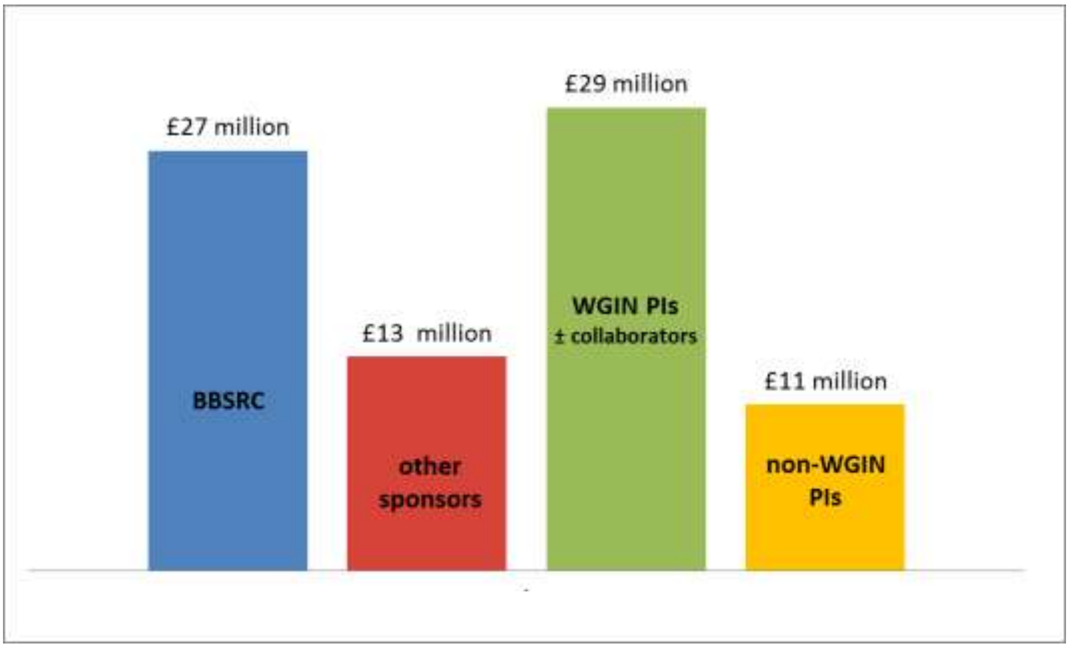
Kanyuka, K., Lovell, D., Mitrofanova, O. P., Hammond-Kosack, K. E. & Adams, M. J. (2004). A Controlled Environment Test for Resistance to Soil-Borne Cereal Mosaic Virus (SBCMV) and its Use to Determine the Mode of Inheritance of Resistance in Wheat cv. Cadenza and Screening *Triticum monococcum* Genotypes for Sources of SBCMV Resistance. **Plant Pathology** 53, pp 154-160

Appendix 4 : Training the next generation of wheat scientists

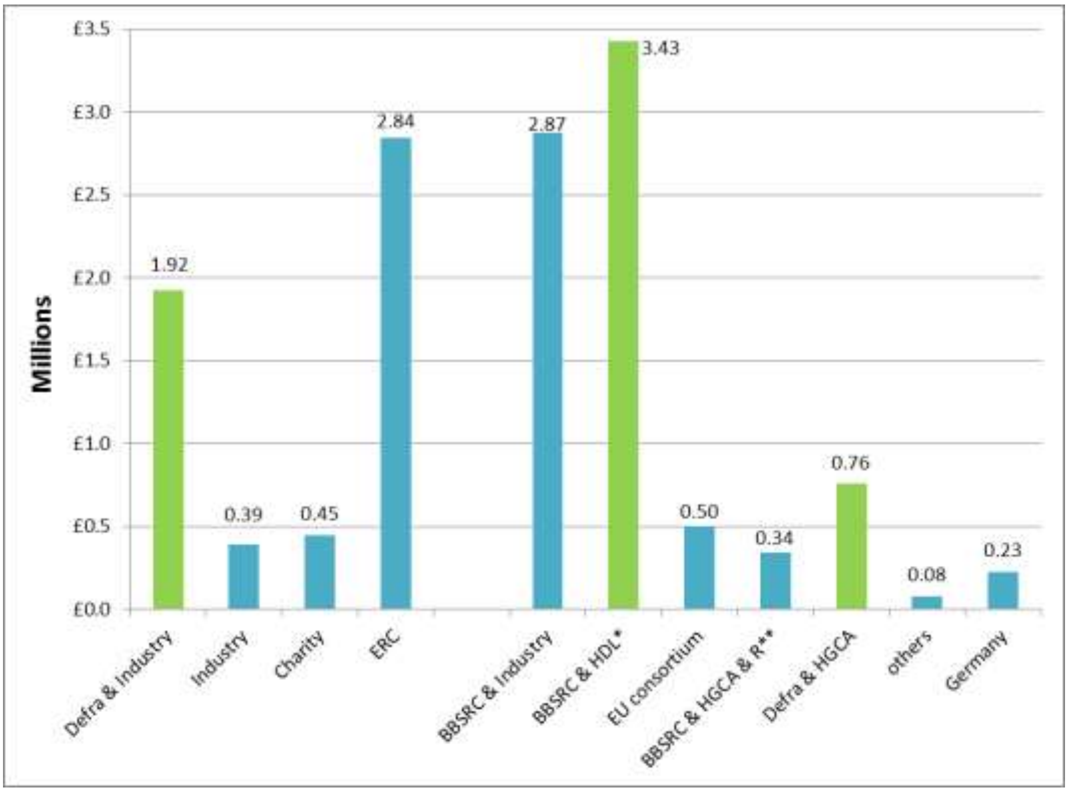
PhD students	
Total	**20**
Graduated	9
In progress	11
Awarding Body	
UK Universities	**18**
University of Exeter	2
University of Nottingham	6
University of East Anglia	7
University of Reading	1
University of Oxford	1
Oxford Brookes University	1
Overseas Universities	**2**
University of Pannonia, Hungary	1
Northwest A & F University, China	1
Sponsor	
BBSRC (total)	12
(of which) DTP	4
(of which) CIRC	1
Industry (fully funded)	2
Industry (partially funded)	2
HGCA (partially funded)	2
John Lawes Trust	1
Food security	1
Other students and fellows	
Post Doctoral fellow (short term visit)	1
MSc student	1
UK Undergraduate summer students	16
Overseas undergraduate /graduate students	10
Casual workers	4

Appendix 5: New funds won for wheat research using WGIN resources and knowledge

a) The main funding sources and PIs



b) Details of the other sponsors



Abbreviations: HDL* - HGCA, Defra and LINK and R** - Scottish Government (RESAS)