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Evidence Project Final Report

Department for Environment Food & Rural Affairs

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Project identification

1. Defra Project code: CH0106

2. Project title:
   Wheat Genetic Improvement Network (WGIN) - Improving the resilience of UK wheat crop through crop genetics and targeted traits analysis

3. Contractor organisation(s):
   Prof. Kim E. Hammond-Kosack
   Department of Biointeractions and Crop Protection
   Rothamsted Research
   Harpenden
   Hertfordshire, AL5 2JQ

   Dr Simon Griffiths,
   Crop Genetics Department
   John Innes Centre,
   Norwich

4. Total Defra project costs (agreed fixed price): £941,892.94

5. Project: start date ..... 20th Feb 2015

   end date ..... 31st July 2018

6. It is Defra's intention to publish this form.

Please confirm your agreement to do so..... **YES** ☐

(a) When preparing Evidence Project Final Reports contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the Evidence Project Final Report can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.

In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Work Package 1: Maintain and expand a network of UK researchers and stakeholders. WP1.1: Maintaining and improving the WGIN platform through regular meetings – *During WGIN 3 we have held 11 management meetings with the breeding companies and other significant parties working on wheat improvement as well as three large WGIN stakeholder meetings (n = 70-110 participants) held each November. The Nov 2017 stakeholder meeting was done jointly with the new BBSRC funded ISP Designing Future Wheat and involved a lot of new academics and industry participants. In addition, a joint GINs event was held at the JIC in Feb 2016 to showcase the overall achievements of the four GINs (n=150 participants + the press)* ***WGIN has been able to expand the UK researcher and stakeholder network by ~40% over the past 3 years****;* WP1.2: Maintain and update a website and add in new data types – *Updated throughout the project, immediately after each management meeting with all meeting minutes, presentations, new data sets and information on new publications*; WP1.3: Utilise the technologies available through collaborations (in UK and abroad) to maximise opportunities for UK wheat improvement. *The application of new techologies was particularly evident through the use at the University of Bristol Genomes Facility of the 35K wheat breeders array for many types of genotyping biparental populations; the T. monococcum collection and developing the new Avalon x Cadenza TILING path resource; via the use of the MYBaits technology (Arbor Biosciences, Michigan, USA) for the large wheat promotome capture experiment; and the extensive use of drone technology (DJI, Shenzhen, China, supplied by Buzzflyer, Sudbury UK, sensors from Sony, Japan and Optris, Germany) to assess the JIC spring drought trials; the take-all trials; and the WGIN diversity trials.* ***By interacting with sub-contractor companies and other specialist academic/non-academic teams, a wealth of new technologies were used to achieve the WGIN objectives. These technologies and the newly generated tools and resources can now be used in other UK and international wheat improvement projects***; WP1.4: Regularly disseminate of WGIN results, new technologies and resources information to the wheat research community and the wheat industry, and improve the potential for industry exploitation (including via WGIN Newsletters) – *This was achieved through oral and poster presentations given at national and international meetings/workshops/conferences by all team members, tours of the WGIN trials to institute visitors, plot demonstrations and posters at the annual Cereals event held each July (Cambridgeshire and Lincolnshire), the publication of peer reviewed papers with press releases and specific interviews with journalists leading to articles in the arable farming magazines / regional newspapers. Four WGIN Newsletters were produced*; *Established and actively used the WGIN twitter account since Jan 2018. The WGIN twitter handle is @WheatGIN.* ***The breadth and extent of the WGIN dissemination activities done throughout the past 3 years has ensured that regular progress on trait improvements, technology advances and newly developed resources took place well in advance of the final peer***

reviewed publications (see page 6), thereby accelerating early uptake by the nine UK based wheat breeding companies. These dissemination activities also catalysed the development of new wheat improvement projects which have been funded by other UK and non-UK sponsors. The total new funds brought into wheat research as a result of WGIN activities since 2015 is £29,940,463 (see page 12). Eleven new wheat PhD projects (each of 4 years duration) have also commenced, which is helping to train the next generation of wheat scientists. WP1.5: Establish industry-led forum to promote the uptake of newly characterised resources into associated projects. – *Although initial attempts were made in year 1 to establish a forum with the nine UK based wheat breeding companies, this proved too time consuming for them to continue.*

Work Package 2: Maintain archive and produce new and freely-available information resources for genetic improvement of wheat. WP2.1 Ensure availability and distribution of all archive WGIN data as well as newly produced genetic and genomic data – *This was done throughout the project.* ***Most of the WGIN seed distribution is now done via the JIC Germplasm Resource Unit (GRU) to ensure Nagoya compliance and to ensure the correct MTA and receiver information is centrally recorded;*** WP2.2 Production of new disease trait data making them publicly available via the WGIN information site, including yellow rust, brown rust, Septoria tritici blotch, powdery mildew (when present in the field) and two species of aphids; *These are described in detail in specific powerpoint presentations given at the regular management meetings and in the WGIN Newsletter. Both of which are available from the WGIN website.* ***The new disease resistance traits immediately available to the commercial wheat breeders include, (a) three novel sources of resistance in the Watkins hexaploid wheat collection that confer resistance to both the old and new races of yellow rust and each has a simple mode of genetic inheritance. (b) Resistance to both UK species of aphid in the diploid species T. monococcum. Four commercial companies have requested the rust resistant lines for prebreeding which started in 2017 and one company has also helped the WGIN team to rule out the possibility that these lines contain previously genetically and molecularly well characterised major resistance genes. The identified aphid resistance in T. monococcum was taken forward in WGIN3 via introgression breeding (see section WP3.3 below). All the breeding companies are now exceptionally interested in developing wheat lines resistance to both aphid species and to the viruses that each vectors. This is because with the increasing ban on insecticides, (EU Directive 2009/128/CE) the wheat breeders have intensified their search for resistance traits.*** *Three Triticum monococcum mapping populations were developed and phenotyped for resistance to two cereal aphid species (Rhopalosiphum padi and Sitobion avenae) up to the F_4 population, results have been made available via the WGIN website and raw data is available on request.* WP2.3 Exploring in detail the genetic components of key traits including exploring the Paragon NILs, drought tolerance, yield and quality resilience (NUE, grain N and C content, grain minerals, canopy longevity), improve the marker coverage on key mapping populations and key Watkins lines using of Breeder (BR) array. ***The continuation of the nitrogen-diversity trial extended the run of experimentation and resultant data, first collected in 2004 to 18 seasons. This now provides researchers and the wheat breeders with a globally unique dataset on more than 68 mainly UK wheat varieties with a core set of 15, at 4 N-input levels. During this long study period a wide range of annual growing conditions were experienced from near normal, to prolonged periods (typically many months) of exceptionally non-seasonal wet, dry, cold or hot conditions.*** *Variation in resilience for yield and nitrogen use efficiency parameters has been obtained along with an evolving understanding of the year to year variation, due to soil and climate factors. This dataset has been further expanded with analysis of multiple years for grain mineral content (an important nutritional quality parameter). Clear interactions with N-supply going beyond simple yield effects are evident. Pre- and post-anthesis nitrogen and mineral acquisition were monitored for the first time.* ***The nitrogen-diversity trial has proved an ideal test bed for aerial drone -based monitoring with methods for growth (height) and canopy coverage and N-status (spectral analysis) as well as developing drone thermal imaging techniques to explore the effects of drought stress on the wheat crop.*** *This last technology has been successfully applied to the water use efficiency studies in section WP4.3. The highlights for the drought trial done over 2 years at JIC (3rd years still in progress) were that selected PxG lines performed better than Garcia under drought conditions.* ***The most drought resistant wheat lines from the Paragon x Garcia mapping population carried one or both QTL loci for increased yield under severe UK drought were successfully nominated for the DFW Breeders Toolkit (BTK) in 2018 within the BBSRC funded Designing Future Wheat project. Via this route these wheat lines with improved yield performance under UK drought conditions will now be simultaneously field evaluated at all nine commercial wheat breeding sites and four UK academic locations.*** Improve the marker coverage for the A^mA^m genotype in the core *T. monococcum* (*Tm*) collection using the (BR) array – *This approach added ~900 markers for use in specific biparental crosses and permitted the 1st QTLs for take-all resistance to be mapped using two seasons of data.* ***The entire WGIN collection of 263 Tm accessions was genotyped using the 35K Axiom BR array and its structure determined. This now provides the first structured global resource for this under utilised Triticum species that can be explored for any wheat improvement trait***;

WP2.4 New QTLs development for each of the traits identified in WP2.3 with a LOD > 3.0. Several QTLs

with a LOD > 3.0 have been identified for specific traits. *A few of these major QTLs were found to be consistent between years whereas other QTLs have only been detected so far in a single year or in two years with overall similar growing seasons. A feature of the past 5 years of WGIN field research has been that growing seasons are highly dissimilar, with regard to patterns of rainfall, temperature and sunlight.* ***The high season-to-season variability has helped to stretch the phenotyping of the germplasm and has lead to the identity of varieties that either do particularly well in a few related environmental scenario's or varieties that have good resilence and perform well in multiple difficult environmental scenarios. The most resilient varieties have been nominated for detailed subtrait analyses and the breeders have used these varieties extensively in their crossing programmes, to try to future proof the UK wheat crop.***

Work Package 3: Maintenance of existing wheat lines and accessions and creation of new ones, exploring new traits. WP3.1 Establishment/maintenance of Avalon-Cadenza population and other new populations and trials; complete the two mapping populations (to F6) for *T.monococcum* for take-all resistance and genotype, complete the F2 mapping populations for *T.monococcum* for aphid resistance, genotype the Pargon x Garcia population – *all successfully completed*

WP3.2: Development of new near isogenic lines in wheat; create the next generation Avalon x Cadenza (A xC) population. Use the available A x C NILS to create a minimal TILING path of individual C segment introgression into a Avalon background and individual A segment introgression into a Cadenza background. *This has been carried out and 5300 F2-3 populations from 57 NILs will be available to allow selection of target segments. Data will be presented on the WGIN website in 2018.* ***The development of the WGIN TILING resource is exceptionally significant. This is because the A x C populations, originally generated between 2003 and 2008 in WGIN, is now the most phenotyped wheat population globally for 100s of different traits. The availability of these new minimal TILING A x C NILs permits the rapid fine mapping and confirmation of each of these major and minor QTLs. Subsequently, the isolation of the underlying causal sequences can be rapidly achieved from early 2019 onwards because both the Avalon and Cadenza genomes have been fully sequenced and will become publically available. The individual wheat breeding will then develop gene-centric markers for each of these new traits to use within their preferred high throughput genotyping platforms. This will considerable accelerate the QTL introgression and evaluation process in modern elite germplasm improvement.***

WP3.3: Develop new *T. monococcum* introgression for take all resistance, septoria resistance and aphid resistance using key accessions. *This has been achieved for both disease resistance traits using tetraploid T. durum (either Kronos or Hoh501) as the initial female crossing parent and then by backcrossing the F1 again as the female to hexaploid wheat (Paragon), because the F1 is male infertile. The Tm x Td F1 hybrid complex plants exhibit many traits from both parents and large grain were produced from the backcross to T. aestivum Paragon. A rise in plant fertility was noted in the BC crossing compared to the F1 crossing. The BC1 plant generation have been grown in the glasshouse over summer 2018 and successfully re-backcrossed to T aestivum Paragon.* ***T. monococcum is an under ultilised species in modern wheat improvement even though this species is known to possess many desirable traits not found in other progenitor species. The successful implementation of this introgression strategy within WGIN means that many traits of high interest could potentially be captured via a similar pre-breeding strategy and subsequently passed on to the commercial breeders in a hexaploid background that is immediately suitable for field phenotyping as well as crossing.***

WP3.4: Quantifying variation in below ground traits and the function of the root system, including specific Paragon A x C NILs, Paragon x Garcia population and WGIN diversity (all 1st wheat crops) – *This was done by including soil moisture probes in the field trials, and using proxy measurements such as UAV observations and physiological traits.* ***A wide range of novel tool evaluation and methodology development has occurred within the various WGIN field trials. The wheat breeders have been able to view and explore a range of new possibilities for high throughput fine phenotyping and through taking proxy measurements. Although the data sets generated are often exceptionally large, which at the moment are time consuming to analyse and to interpret, over time many of these new approaches and analysis pipelines, following appropriate investment, could become fully embeded within commercial wheat breeding programmes.***

Work Package 4: Broadening the genetic base for wheat improvement. WP4.1: Continue to identify novel sources of genetic variation within wheat germplasm with potential for improving the sustainability of the UK wheat crop; reevaluate 10 accessions from the Watkins collection for resistance to multiple foliar fungal pathogens – *5 accessions were shown to still provide an excellent level of foliar resisatnce to the new yellow rust races*,; reevaluate *T. monococcum* collection for resistance to the Warrior race of yellow rust – *the 1st year of field trialling of the collection of 294 Tm accessions revealed that all were fully resistant and therefore it was concluded that Tm is a non-host for the wheat attaching races of yelllow rust. Post this negative result no further experimentation was done*, identify other suitable wheat collections that

may provide new sources of variation for the traits of interest – *one slug resistant Watkins line was identified using a novel petri dish based assay, the evaluation of this line under field conditions will take place in WGIN 4.* WP4.2A: Classify germplasm variants for a catalogue of crop-relevant genes, using high-throughput screens, add relevant information into CerealsDB data archive – *this was done using the Phenospex platform at the JIC and nearly all the data has been added into CerealsDB* ; WP4.2B carry out exome capture on a priority list of genes to be developed in conjunction with the breeders and UK academics, for up to 96 wheat genotypes- *following discussions with the academic and industry comunities in early 2016 this became a promoter capture experiment (a promotome analyses) for 1,395 genes. The experiment was deliberately delayed until the full genome of Chinese Spring became available in early 2017 to permit a set of promoter specific selective baits to be made. The final large data set was received in November 2017 and after QA checking for accuracy was released to the academic project consortium members and the nine wheat breeding companies via a secure portal in March 2018.* ***The WGIN promotome capture experiment, which used a technology developed for high throughput human genetic analyses, was 100% successful and now provides a globally unique homoeologue specific data set covering 95 wheat genotypes and 1,395 genes selected by the UK wheat improvement community. This AA, BB, DD homoeologue dataset can now be used for multiple research and commercial purposes for ten different clusters of wheat traits, namely yield resilience, grain composition, grain development, biotic stress (fungi and insects), abiotic stress (drought and high temperature), nutrient use efficiency, canopy development/whole plant architecture, flower biology, root architecture and recombination. In particular the wheat breeders can use the new promotome data to explore the haplotypes currently available in commercial elite varieties and to identify new haplotypes that could be exploited to further 'stretch' the trait phenotype of interest. The 15 Watkins lines and the Sears Synthetic line are particularly good choices for the breeders to identify and use novel promoter sequences. The entire data set can also be used immediately by the breeders to further explore the pedigrees of the current elite wheats and to pinpoint lines that were previously not known to harbour potentially useful variant promoter sequences of unknown origins (i.e. via rogue pollen / rare recombination events / natural mutations). One company has already designed new KASP markers to exploite these new data for these purposes.***

WP4.3: Establishment/maintenance of field trials for traits such as: NUE, drought tolerance, vigour or others identified by stakeholders; see WP2 for the traits to be evaluated via these field trials – *all trials planned were successfully completed.*

WP4.4: Development of gene-specific marker data for the new traits by combining the data generated in WP 4.2 with the existing and newly generated field phenotyping data from WP 4.3. *This activity is still underway and has become particularly complex because of the diversity of growing seasons that have been experienced over the past 8 years. Therefore when exploring QTL data across trial years each season's weather conditions need to be explored in detail to try to identify the matching and mis-matching seasons.*

WP4.5: Analysis of the genetic basis of trait variation, assess the effects of variant genes. Make available the A x C NIL genotypes (developed in WP 3.2) for subsequent physiological studies on any trait. *Over 5000 CSSL lines will become available in late 2018. The lines will carry precise substituted chromosome segments and because of the high density genotyping carried out at Bristol, both academic users and the commercial heat breeders will be able to precisely select the lines they need from the genotyping data which will be available on the WGIN website.* ***The implications for the CSSL lines are fully explained in WP3.2 above and will permit many more traits to be fully resolved once the fine phenotyping of these lines is completed.***

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Exchange).

See separate file for this detailed information.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Publications and other outputs

2018

Saintenac, C., Lee, W-S., Cambon, F., Rudd, J.J., King, R., Marande, W., Hélène Bergès, Phillips, A.L., Uauy, C., Hammond-Kosack, K.E., Langin, T., and Kanyuka, K. (2018) An evolutionary conserved pattern-recognition receptor like protein controls gene-for-gene resistance to a fungal pathogen in wheat. Nature Genetics 50, 368–374, doi:10.1038/s41588-018-0051-x (with Rothamsted and BBSRC press release)

McMillan, V.E., Canning, G., Moughan, J. R.P. White, J.R.P., Gutteridge, R.J. and Hammond-Kosack, K.E**.** (2018) Exploring the resilience of wheat crops grown in short rotations through minimising the build-up of an important soil-borne fungal pathogen. Nature Scientific Reports 8**,** 9550. (with Rothamsted press release)

Osborne, S.-J., McMillan, V., White R. and Hammond-Kosack, K. E. (2018) Elite UK winter wheat cultivars differ in their ability to support the colonisation of beneficial root-infecting fungi Phialophora. Journal of Experimental Botany 69**,** 3103-3115 (with Rothamsted and RC UK press release)

Paula Prieto, Helga Ochagavía, Roxana Savin, Simon Griffiths, Gustavo A Slafer: *Dynamics of Floret Initiation/Death Determining Spike Fertility in Wheat as Affected by Ppd Genes under Field Conditions*. Journal of Experimental Botany 03/2018;, DOI:10.1093/jxb/ery105

Helga Ochagavía, Paula Prieto, Roxana Savin, Simon Griffiths, Gustavo A Slafer: *Dynamics of Leaf and Spikelet Primordia Initiation in Wheat as Affected by Ppd-1a Alleles under Field Conditions*. Journal of Experimental Botany 03/2018;, DOI:10.1093/jxb/ery104

Laura E. Dixon, Alba Farré, E. Jean Finnegan, Simon Orford, Simon Griffiths, Scott A. Boden: *Developmental responses of bread wheat to changes in ambient temperature following deletion of a locus that includes FLOWERING LOCUS T1 .: Thermal responses of FT-B1 in bread wheat*. Plant Cell and Environment 01/2018;, DOI:10.1111/pce.13130

2017

Acevedo-Garcia, J., Spencer, D., Thieron, H., Reinstädler, A., Hammond-Kosack, K.E**.,** Phillips A.L. and Panstruga, R. (2017) *mlo*-based powdery mildew resistance in hexaploid bread wheat generated by a non-transgenic TILLING approach. Plant Biotechnology Journal 15, 367-378. (with press release in Germany)

Aradottir, G.I., Martin, J.L., Clark, S.J., Pickett, J.A. & Smart L.E. (2016). Searching for wheat resistance to aphids and wheat bulb fly in the historical Watkins and Gediflux wheat collections. Annals of Applied Biology doi:10.1111/aab.12326

Hawkesford MJ (2017) Genetic variation in traits for nitrogen use efficiency in wheat. Journal of Experimental Botany 68, 2627-2632

Heyneke, E.;Watanabe, M.;Erban, A;Duan, G;Buchner, P. H.;Walther, D.;Kopka, J;Hawkesford, M. J.;Hoefgen, R.(2017) Characterization of the wheat leaf metabolome during grain filling and under varied N-supply. Frontiers in Plant Science 8, 1-18.

Simon, A. L., Wellham, P. A. D., Aradottir, G. I., Gange, A. C. (2017) Unravelling mycorrhiza-induced plant susceptibility to the English grain aphid Nature Scientific Reports doi:10.1038/srep46497

Helga Ochagavía, Paula Prieto, Roxana Savin, Simon Griffiths, Gustavo A. Slafer: *Duration of developmental phases, and dynamics of leaf appearance and tillering, as affected by source and doses of photoperiod insensitivity alleles in wheat under field conditions*. Field Crops Research 12/2017; 214:45-

55., DOI:10.1016/j.fcr.2017.08.015

Yerlan Turuspekov, Aida Baibulatova, Kanat Yermekbayev, Laura Tokhetova, Vladimir Chudinov, Grigoriy Sereda, Martin Ganal, Simon Griffiths, Saule Abugalieva: *GWAS for plant growth stages and yield components in spring wheat (Triticum aestivum L.) harvested in three regions of Kazakhstan*. BMC Plant Biology 11/2017; 17(S1):51-61., DOI:10.1186/s12870-017-1131-2

2016

Farré A., Sayers L., Leverington-Waite M., Goram R., Orford S., Wingen L., Mumford C., Griffiths S. (2016) Application of a library of near isogenic lines to understand context dependent expression of QTL for grain yield and adaptive traits in bread wheat. BMC Plant Biology 16 161 http://dx.doi.org/10.1186/s12870-016-0849-6

Fenner H. Holman, Andrew B. Riche, Adam Michalski, March Castle, Martin J. Wooster and Malcolm J. Hawkesford (2016) . High Throughput Field Phenotyping of Wheat Plant Height and Growth Rate in Field Plot Trials Using UAV Based Remote Sensing, Remote Sensing 8(12), 1031, doi: 10.3390/rs8121031

Foulkes, M. J., DeSilva, J., Gaju, O*., et al.* 2016. Relationships between delta C-13, delta O-18 and grain yield in bread wheat genotypes under favourable irrigated and rain-fed conditions. Field Crops Research **196**, 237-250. http://dx.doi.org/10.1016/j.fcr.2016.07.006 (from the WGIN 2 sub-contractor project)

Harper, A., Martin, Trick, M., He, Z., H., Clissold, L., Fellgett, A., Griffiths, S., Bancroft, I. (2016) Genome distribution of differential homoeologue contributions to leaf gene expression in bread wheat Plant Biotechnology Journal 14(5):1207-14. doi: 10.1111/pbi.12486

Gardiner, L-J, Bansept-Basler, P., Olohan, L., Joynson, R., Brenchley, R., Hall, N.,
O'Sullivan, D.M. and Hall, A. (2016) Mapping-by-sequencing in complex polyploid genomes using genic sequence capture: a case study to map yellow rust resistance in hexaploid wheat. The Plant Journal 87, 403-419. No author funded by WGIN. This study used the A x C mapping population resource.

Greenslade A.F.C., Ward J.L., Martin J., Corol D.I., Clark S.J., Smart L.E., Aradottir G.I. (2016). *Triticum monococcum* lines with distinct metabolic phenotypes and phloem based resistance to the bird cherry oat aphid *Rhopalosiphum padi*. Annals of Applied Biology DOI: 10.1111/aab.12274

Mehrabi, Z., McMillan, V.E., Clark, I.M., Canning, G., Hammond-Kosack, K. E., Preston, G., Hirsch, P.R. and Mauchline, T.H. (2016) Pseudomonas spp. diversity is negatively associated with suppression of the wheat take-all pathogen. Nature Scientific Reports 6, e29905. (With Rothamsted press release).

Jones H., Lukac M., Brak B., Martinez-Eixarch M., Alhomedi A., Gooding M., Wingen L., Griffiths S. (2016) Photoperiod sensitivity affects flowering duration in wheat The Journal of Agricultural Science FirstView 1-12.
Kowalski A., Gooding M., Ferrante A., Slafer G., Orford S., Gasperini D., Griffiths S. (2016) Agronomic assessment of the wheat semi-dwarfing gene *Rht8* in contrasting nitrogen treatments and water regimes Field Crops Research 191, 150-160

2015
Ma J., Wingen L. U., Orford S., Fenwick P., Wang J., Griffiths S (2015)
Using the UK reference population Avalon×Cadenza as a platform to compare breeding strategies in elite Western European bread wheat. Molecular Breeding 35:70 http://dx.doi.org/10.1007/s11032-015-0268-7

PhD thesis
Sarah-Jane Osborne (submitted Sept 2016, successful viva Jan 2017) Exploring the genetic and mechanistic basis of resistance to take-all disease in wheat. SJO field phenotyped one *T. monococcum* mapping populations developed in WGIN. PhD Thesis University of Nottingham – Rothamsted Research DTP. Supervisors (main) and Vanessa McMillan (trainee) (RRes) and John Foulkes (UoN) Internal Examiner Professor Matt Dickinson and External Examiner Dr Matthew Cromey (formerly a senior Plant Pathologist in New Zealand specialising in cereal root diseases)

Oral presentations and scientific outreach that was done in addition to the three WGIN stakeholder events, the joint GINS event in 2016 and the four WGIN Newsletters.

2018

Oral presentations
Simon Griffiths, Discovering new and useful variation in the AE Watkins Collection. Vavilov Seminar. IPK Gatersleben 14th Feb 2018

Gia Aradottir, Kim Hammond-Kosack et al. 7-9 March 2018 Organised and Hosted 23rd International Plant Resistance to Insects Symposium at Rothamsted which attracted ~70 delegates from all over the world.

Malcolm Hawkesford 23–26th Mar 2018: Presented the Keynote Lecture "An automated high throughput platform for monitoring crop performance in the field" and chaired a session at the 2nd Asia-Pacific Plant Phenotyping Conference 2018, Nanjing, China

Gia Aradottir - April 2018 Invited speaker Biovision Alexandria, Egypt, Invited speaker. 'Enhancement of Crop Pest Resistance'.

30-31st May 2018 Joint UK-Central Asia BBSRC funded workshop Almaty, Kazakhstan included four presentations on WGIN research activities and four discussion sessions involving WGIN traits and resources. The presentations were

Kim Hammond-Kosack Controlling soil-borne fungal pathogens
Malcolm Hawkesford - Improving NUE including the use of high throughput phenotyping
Gia Aradottir - Wheat resistance to cereal aphids
Simon Griffiths - Global journeys of adaptive wheat genes

Malcolm Hawkesford 5th July 2018: Presented "Scanalyzer and drone: high throughput field phenotyping of wheat" at Warwick University

Michael Hammond-Kosack 3rd -5th July 2018 12th Meeting of the Brazilian Wheat and Triticale Research Commission (RCBPTT). Talk title 'WGIN Wheat Promotome Capture' Passo Fundo, Brazil ~ 300 in the audience from EMBRAPA institutes / universities, Brazilian breeding companies, agronomists, crop protection companies. This seminar was also live streamed to several Universities in Brazil and Kansas State University in the USA.

Scientific Outreach
Established and actively used the WGIN twitter account since Jan 2018. The WGIN twitter handle is @WheatGIN

Article on WGIN for the Northern Farmer magazine (published May 2018) Kim Hammond-Kosack and Simon Griffiths interacted with journalist Wendy Short to produce the article which reported on the impact of the WGIN1, 2 and 3 research to the farming community.

Andrew Riche 26-27th May 2018: Presentations on the drones at the Herts Show, Redbourn, Hertforshire, UK

'Designing Future Wheat – is it all in the genes?' Arable Farming magazine article June 2018, p26-27. Report on the full progress of WGIN1, 2 and 3 by reporter Heather Briggs following email discussions with the entire WGIN team.

Rothamsted Research Festival of Ideas Open Science weekend 22-24th June 2018. Over the Open Science weekend between 8,500-9,000 visitors were hosted by Rothamsted https://www.rothamsted.ac.uk/175. The 'Wheat Genome in Action' interactive game based on the WGIN promotome capture experiment was devised by Michael Hammond-Kosack. The 21 wheat chromosomes (projected onto a Velcro covered screen as the A, B or D homoeologue sets) were reproduced to the scale of 1m=330Mbp, upon which the centromeres and 70 genes covering the 10 trait categories were placed. Each player threw a total of nine (3x3) Velcro covered balls to hit a 'trait gene' on each of the 3 sub-genomes. The function of each 'hit gene' was then explained in both scientific and layperson terms.

Each participant that hit a gene then received a small prize by randomly sampling a mixed box of winter and spring wheat grain obtained from the 2017 WGIN diversity trial, and with a few instructions was encouraged to grow wheat in their garden or allotment. Participants that hit the same gene on all three homoeologues received a dried wheat tiller as a prize as well. In total, approximately 450 people (mostly, but not exclusively, children) successfully played the game/ received a prize and about the same number of visitors watched on. A second display, again inspired by WGIN, explained the origin of modern wheat and the species that are present in the primary, secondary and tertiary wheat improvement pools. Visitors were also shown either a video or a live demonstration of how wheat crossing is done.

2017

Oral presentations

5th April 2017: Malcolm Hawkesford presented "Integration of root and soil expertise into the yield studies" at Crop Efficiency Research Day, Bayer, Monheim am Rhein

26th April 2017 Vanessa McMillan Take-all-wheat presentation. Royal Agricultural University students,

27 April 2017 Gia Aradottir - Invited DTP Summer School presentation at Nottingham on presenting controversial science in the media

3rd May 2017: Malcolm Hawkesford presented "Automated and high throughput imaged-based field phenotyping technology at Rothamsted" at Cranfield University

8th May 2017: Malcolm Hawkesford presented "Opportunities for enhanced nutrient use efficiency" at Waitrose Agronomy Conference

17th May 2017: Malcolm Hawkesford organised and hosted a Prospective Nitrogen Initiative meeting, organised by the EWG in Nitrogen Use Efficiency on behalf of the Wheat Initiative

11th June2017: Malcolm Hawkesford participated "Science on the Farm" at the Open Farm Sunday, Waitrose Leckford Farms

15th-16th June 2017: The Phenotyping Group presented their work at "Cereals 2017", Boothby Graffoe,
20th June 2017: Malcolm Hawkesford presented "Nutrient Use Efficiency in Wheat and Prospects for Improvement" at Ghent University

July 2017: Gia Aradottir Symposium on Insect-Plant Interactions, Tours, France. Presentation entitled "Cereal aphid feeding behaviour – commonalities and differences depending on aphid species and wheat susceptibility"

11-13th September 2017: Vanessa McMillan British Society for Plant Pathology Presidential Meeting, , University of Nottingham, UK. Talk title: 'Identifying genetic resistance to the take-all fungus in diverse germplasm collections'.

29th September 2017 : Vanessa McMillan Take-all-wheat presentation Nottingham/Rothamsted DTP Project Showcase,

10-16th October 2017: Malcolm Hawkesford presented "Technical Challenges and solutions for designing future wheat" and Yongfang Wan presented "Challenges and solutions for designing future wheat" (to researchers) and "Rothamsted, the world's oldest agricultural experiments, and the future of wheat" (to undergraduates) during a visit to Sichuan Agricultural University, China.

22-28th October 2017: Malcolm Hawkesford presentation "Nutrient use efficiency in wheat: prospects for improvement' at the Nature Conference: Agricultural Genomics 2017, Wuhan, China

30th November-5th December 2017: Malcolm Hawkesford presentation "Developments in automated field phenotyping of wheat at Rothamsted" at the Plant Phenomics Conference, CAS, Beijing

9-11 November 2017: Gia Aradottir - Sense about Science Standing up for Science Europe panellist in Warsaw

30 November 2017: Gia Aradottir - Tow lectures on alternative crop protection strategies and breeding for resistance to final year students at Royal Holloway

Conference poster

Vanessa Mcmillan 2nd Plant Microbiome Symposium, 19th-21st February 2018, Amsterdam, Netherlands. Poster title: 'Exploring the influence of wheat cultivar on soil microbiome structure and take-all inoculum build-up'.

Scientific Outreach

Vanessa McMillan Presentation on take-all root research and discussion with RRes Farm staff, 9th January 2018

Clare Lister JIC Breeders day June 2017 'WGIN3: Dissecting UK Drought Tolerance in Paragon x Garcia: This Year we have a Drought!"
Clare Lister and Simon Griffiths: Article on Drought Trial in Eastern Daily Press
http://www.edp24.co.uk/business/farming/john-innes-centre-trial-aims-to-find-wheat-which-can-resist-spring-droughts-1-5024746
Simon Griffiths and Clare Lister: YouTube video for Mustard TV about Drought Trial
https://www.youtube.com/watch?v=Zdu4BSwGQVE&t=30s&index=6&list=PL9VIpvFxEivBIm1ATlz5Ay8SP2bC1K2xv

Gia Aradottir - 13-14 December 2017 BBC Royal Institution Christmas lectures filming, showed on BBC4 at Christmas (26-28th Dec) and available on Royal Institution website.

2016

Oral presentations

Simon Griffiths Plant and Animal Genomes, San Diego, USA Jan 2016 QTL Cloning Workshop
'Identification of Genes Controlling Earliness per se and Short Day Photoperiod Response in Bread Wheat'

Kim Hammond-Kosack- talked to NFU young farmers visit to RRes in February 2016. described the WGIN project and the 20:20 wheat project.

Kim Hammond-Kosack, WGIN: Wheat Genetic Improvement Network. A Public - Private Partnership Project started in 2003. Defra's Genetic Improvement Networks, Stakeholder event 'Uncorking the genetic 'GINie' for British crops, The John Innes Conference Centre, Norwich Research Park, Norwich, 22nd Feb 2016

Sarah-Jane Osborne, Vanessa McMillan, Richard Whalley, John Foulkes and Kim Hammond-Kosack (10th March 2016). Exploring the genetic and mechanistic basis of resistance to take-all disease in wheat. Rothamsted Research PhD Symposium

Andrew Riche Measuring Crop Traits by Remote Sensing, presentation to group of West Herts Farmers, March 2016

Gia Aradottir, Biovision Alexandria, Egypt, Invited speaker. Title of presentation: The future of crop protection April 2016

Sarah-Jane Osborne, Vanessa McMillan, Richard Whalley, John Foulkes and Kim Hammond-Kosack (26th April 2016). Exploring the genetic and mechanistic basis of resistance to take-all disease in wheat. BBSRC DTP Spring School, University of Nottingham.

Gia Aradottir, Turkey-UK Workshop "Wheat Improvement: Opportunities for collaboration", delivered a presentation "Searching for insect resistance in wheat" May 2016

Vanessa McMillan – gave a talk to undergraduate students from the University of Hertfordshire, 3rd June 2016

Vanessa McMillan – gave a talk to farmers from the Kelloggs Origins programme, 2nd November 2016

Sarah-Jane Osborne, Vanessa McMillan, Richard Whalley, John Foulkes and Kim Hammond-Kosack (17th-18th November 2016). Exploring the genetic and mechanistic basis of resistance to take-all disease in wheat. AHDB Crops PhD Symposium, Stratford Manor Hotel, Stratford-upon-Avon.

Kim Hammond-Kosack ' Picky Plant Pathogens: Focus – Fusarium and take-all fungi, Nanjing Agricultural University, 21st November 2016

Gia Aradottir, presented current priorities for insect pests in wheat at the Wheat Initiative Expert Working Group on Durable Pest and Disease Resistance in Wheat Workshop in Minneapolis, USA November 2016

Vanessa McMillan – gave a talk on the WGIN project at the Procam Advanced Agronomy Seminar, 13th December 2016

Poster presentations

Sarah-Jane Osborne, Vanessa McMillan, Richard Whalley, John Foulkes and Kim Hammond-Kosack. Exploring the genetic and mechanistic basis of resistance to take-all disease in wheat. Defra's Genetic

Improvement Networks, Uncorking the genetic 'GINie' for British crops, The John Innes Conference Centre. 22nd February 2016.

Vanessa McMillan, Gail Canning, Richard Gutteridge and Kim E. Hammond-Kosack. Identifying root resistance to the take-all fungus. Monogram Conference, NIAB, 12-14th April 2016.

Scientific Outreach

Kim Hammond-Kosack – 'Is it all in the genes' Arable Farming write up of the Defra's Genetic Improvement Networks, Stakeholder event in Feb 2016

Vanessa McMillan, Joe Moughan, Sarah-Jane Osborne and Kim Hammond-Kosack Cereals 2016 event: plot and poster display on our take-all research by (June 2016)

Andrew Riche Farming in the future using UAVs to assist with crop research, presentation at BA Festival of Science, Swansea, Sept 2016.

Clare Lister JIC Breeders day June 2016 'WGIN3: Dissecting UK drought tolerance in Paragon x Garcia'

2015

Oral Presentations

Kim Hammond-Kosack oral presentation on the WGIN project to ~50 MSc Plant Sciences Students University of Nottingham (Feb 215) at Rothamsted

McMillan VE – Monogram conference @ RRes, April 2015 on genetic control of take-all disease

Gia Aradottir presented "Searching for insect resistance in wheat", MonoGram 2015 29 April- 1 May 2015

McMillan VE – Rothamsted Research Day, May 2015 –on genetic control of take-all disease

Malcom Hawkesford plenary talk 22nd Sept International Wheat Meeting, Sydney Australia; including WGIN trials. The WGIN diversity trials continues to be a major testing ground for UAV technology for crop/trial monitoring.

McMillan VE – Rhizosphere microbiome workshop @ RRes, August 2015 – ppt on LowTAB trait

>McMillan VE - INIA-Rothamsted workshop Uruguay, September 2015 – ppt on LowTAB trait

Kim Hammond-Kosack, Jason Baverstock and Vanessa McMillan Hutchinsons conference in Peterborough on the 19th November 2015 on the tech stand for Rothamsted Research showcasing the WGIN project and Take-all research

Vanessa McMillan and Kim Hammond-Kosack - The Wheat Genetic Improvement Network – a public-private partnership project (2003-2017) NABIM – Dec 2015, London

Poster Presentations

Gia Aradottir, on 'Searching for aphid resistance in wheat', English-French aphid Special Interest Group in Paris November 2015

Scientific Outreach

6th May Nabim; Malcolm Hawkesford oral presentation on trials and stability work

9th June CF Industries (USA) visit; Malcolm Hawkesford presentation of NUE and nutrient work

10-11th June Cereals 2015 – displays and presentation, on Take-all LowTAB and root resistance traits (V McMillan and Kim Hammond-Kosack) and Aphid Resistance (Lesley Smart)

18/19 June 2015 Wheat Initiative expert working group on NUE met at Rothamsted and visited WGIN field trials

New funding won (2015 to the present)

PhD projects, DTP rotation projects, overseas visitors

DTP2 PhD Studentship - Elizabeth Chapman (2016-2020) – "Balancing the genetics of source and sink to increase the productivity of bread wheat" Main Supervisor Simon Griffiths, JIC.

Nottingham DTP PhD: Amma Simon (2016-2020) Unravelling interactions between cereal aphids and ancestral wheat lines to elucidate mechanisms of aphid resistance. The student is based full time at

Rothamsted research. Main supervisor Gia Aradottir, and additional supervisors Lin Field, Kim Hammond-Kosack and John Foulkes

DTP2 PhD studentship: (2015-2019) Deploying Effector And Genomics Approaches To Genetically Dissect Disease Interactions Between The Necrotrophic Fungal Pathogen *Parastagonospora nodorum* And Wheat (*Triticum aestivum*). Main supervisor James Cockram (NIAB), Co- supervisor Prof Richard Oliver (Curtin University, Perth , Western Australia.

DTP2 PhD studentship: (2016-2020) The genetic dissection of cereal root traits. Main supervisor Eric Obers (NIAB), co-supervisor James Cockram (NIAB)

University of Nottingham DTP PhD studentship: (2016-2020) Elucidating the role of DELLAs in controlling GAMYB activity during wheat grain development. Main Supervisor Stephen Thomas (Rothamsted), co-supervisors Alison Huttly (Rothamsted), Zoe Wilson (University of Nottingham)

University of Nottingham DTP PhD studentship: (2016-2020) Understanding the role of phytohormones in controlling heat-stress tolerance during pollen development in wheat. Main Supervisor Stephen Thomas (Rothamsted), co-supervisor Zoe Wilson (University of Nottingham)

University of Nottingham DTP PhD studentship: (2017-2021) Evaluating the potential of Phialophora spp. for the control of take-all disease in wheat (University of Nottingham). Main supervisor Vanessa McMillan (Rothamsted Research), co-supervisor Kim Hammond-Kosack and Kostya Kanyuka (Rothamsted Research) and Matthew Dickinson (UoN)

Kanat Yermekbayev: PhD student studying adaptation in Kazakhstan funded by Bolashak, Kazakstan, started Oct 17.

Axel Lucmorte-Sainte-Cricq: student on Erasmus+ programme, phenotyping of Paragon x Garcia drought trial, 12 weeks summer 2017

Yulia Popovych: Student on International Undergraduate Summer School at JIC, identifying lines carrying 4A DTEM QTL, 10 weeks summer 2016

New research programmes and projects

Graham Moore@JIC (PI) with 37 coPIs accross eight UK research institutes / universities, CoIs from WGIN include Shewry, P, Hawkesford, M., Kanyuka, K, Aradottir , G and Hammond-Kosack, K at RRes and Simon Griffths at JIC. BBSRC Cross Institute Strategic Programme(ISP) Designing Future Wheat (BBS/E/C/000I0250). Total value **£19 million** April 2017 – March 2022.
https://www.jic.ac.uk/research/designing-future-wheat/

Gia Aradottir (Rothamsted Research) Project Title: Aphid resistant wheat for the smallholder farmer in Africa

Funded by Technology Strategy Board: Agri-Tech Catalyst - Early Stage Feasibility - Round 4 Eligible costs estimated at £237,723; Rothamsted Research grant **£71,923**. April 2016- March 2017 – 1 year

Jason Rudd, Kim Hammond-Kosack and Kostya Kanyuka (Rothamsted Research) Project title : Effector-directed approaches for improved disease resistance breeding in wheat. Funded by Syngenta **£588,887**. Sept 2016 to Dec 2018.

Stephen Thomas and Peter Hedden (Rothamsted Research) Title: Mitigating the effects of heat stress-induced yield loss in wheat

Innovate UK/BBSRC - KTP 010298 **(£220,000**) Oct 2016 - Oct 2019 – 3 years

Rowan Mitchell (Rothamsted Research) Title: Novel wheats for distilling. Innovate UK (BB/N019164/1) **(£76,517**) March 2016 – March 2019 - 3 years, 1 month

Keith Edwards (University of Bristol) with multiple Co-Is. Title: Releasing natural variation in bread wheat by modulating meiotic crossovers. BBSRC Strategic LoLa **(£2,800,000**) 2016-2021 – 5 years

Keith Edwards (University of Bristol) Title: Indo-UK Centre for the improvement of nitrogen use efficiency in wheat. BBSRC – Newton Fund BB/N013360/1 **(£188,000**) 2016 -2019 – 3 years

Anthony Hall (Earlham Institute, Norwich) Title: IWYP: Using Next Generation Genetic Approaches to Exploit Phenotypic Variation in Photosynthetic Efficiency to Increase Wheat Yield. BBSRC **(£1,508,962)** 2016-2019 - 3 years

Anthony Hall (Earlham Institute, Norwich) and Keith Edwards (UoBristol) Title: IWYP: International Wheat Yield Partnership: A genetic diversity toolkit to maximize harvest index by controlling the duration of developmental phases. **(£160,000)** 2016-2019 - 3 years

Anthony Hall (Earlham Institute, Norwich) and several Co-Is (Keith Edwards, Martin Parry (U of Lancaster) , Elizabete Carmo Silva (U of Lancaster), Malcolm Hawkesford, Peter Shewry). Title: IWYP: International Wheat Yield Partnership: Wider and faster: High-throughput phenotyping exploration of novel genetic variation for breeding high biomass and yield in wheat **(£155,000)** 2016-2019 - 3 years

Anthony Hall (Earlham Institute, Norwich) Title: INTRIEPI: INvestigating TRiticeae EPIgenomes for Domestication. European Research Area (ERA-CAPS) **(£2,100,000)** 2016-2019 - 3 years

Anthony Hall (Earlham Institute, Norwich) and co-Is Martin Parry and Elizabete Carmo Silva (U of Lancaster Title: Combining field phenotyping and next generation genetics to uncover markers, genes and biology underlying drought tolerance in wheat. BBSRC - UK-DBT **(£954,000**) 2016-2019 - 3 years

Ji Zhou (Earlham Institute, Norwich) - GP069JZ1Q CropQuant – The Next Generation Crop Monitoring Workstation for Precision Agriculture **(£122,958.00**) 2016 – 1 year

Ji Zhou (Earlham Institute, Norwich) - GP080JZ1M Eastern Agri-Tech Growth Initiative Grant Proposal **(£49,075.00**) 2016 1 year

Ji Zhou (Earlham Institute, Norwich) GP105JZ1B CropQuant - Next-generation cost-effective crop monitoring system for breeding, crop research and digital agriculture **(£16,340.00**) 2016 – 1 year

Peter Shewry, Malcolm Hawkesford and Till Pellny (Rothamsted Research) BBSRC Link Project "Developing novel types of low protein wheat for breadmaking" BB/N000854/1. January 2016-December 2019. This LINK project is supported by 7 x breeders; 6 x industry; 1 x non breeder **(£319,000**).

Agritech Innovation Centre – Crop Health and Protection – phase 2 of the bid. £2.6 million for Rothamsted for specialist equipment **£1.6 million** and 3 FTEs over 3 years. Total project £23 million over 3 years. Lead Fera York, other academic partners CABI, University of Newcastle and University of Cranfield. Eight core industry partners, including Bayer, Unilever, Tescos, Frontier and Wellcome Trust farms. From March 2016. Leads at RRes are Lin Field, Kim Hammond-Kosack, Paul Neve and Andrew Spencer.

Andy Phillips (Rothamsted) and Cristobal Uauy (John Innes Centre). Selling the entire Cadenza TILLING population to a European company **(£240,000**) Dec 2016

Patent applications

Kostya Kanyuka, Cyrille Saintenac, Florence Cambon, Wing-Sham Lee, Thierry Langin and Kim E. Hammond-Kosack Plant Fungal Resistance Gene (Wheat Stb disease resistance) – UK Patent Application No. 1522146.8. Submitted to the European Patent Office on 15.12.2015. Updated with new data Dec 2016 International Patent Application No PCT/GB2016/053929, February 2017. This project started in 2004 by using the WGIN original and extended Avalon x Cadenza DH mapping population to fine map the Stb6 gene. It has also screened and used mutants from WGIN Cadenza TILLING populations to confirm that Stb6 conferred resistance against specific Septoria isolates.

Training the next generation of wheat scientists

MSc project at Rothamsted: Student: Lucas Bruguier (2016) Developing molecular markers for BYDV in *Rhopalosiphum padi* and *Sitobion avenae* and testing how BYDV transmission differs for aphids feeding on susceptible and resistant wheat varieties. Supervisors: Gia Aradottir and Martin Williams

MSc student – (2016) Collaboration with Professor Charles Godfray and Dr Ailsa Mclean at Oxford University. The effect of aphid symbionts on aphid ability to feed on resistant and susceptible wheat varieties.

Nuffield student, (2016) supervised by Amma Simon (Rothamsted)

The 30 variety Diversity trial has been utilised by a PhD student in the Hawkesford group, assessing grain protein distribution in a subset of lines.

The diversity trial was also utilised by a 2nd PhD student, visiting the Hawkesford group at Rothamsted, in

2015/16, investigating the impact of foliar applied N on yield and quality characteristics.

PhD student Sarah-Jane Osborne (2012-2016) based full time at Rothamsted used many of the techniques developed for take-all research in WGIN 1 and 2 to complete a PhD on the Wheat root–take-all-Phialophora complex. This project was funded through the BBSRC – DTP University of Nottingham with additional funding from Agrii and HGCA.

PhD student Joseph Moughan (2013-2017) based full time at Rothamsted used many of the techniques developed for take-all research in WGIN 1 and 2 to complete a PhD entitled **'**Uniting genetics and chemistry to reduce the severity of take-all root disease in commercial second wheat crops. Main supervisor RRes Kim Hammond-Kosack, co-supervisors RRes Vanessa McMillan . Academic Supervisor (University of Exeter) Chris Thornton. Funding source: Syngenta UK

A third PhD student, working with Dr Y Wan at Rothamsted has also utilised the Diversity trial, assessing low protein wheat quality.

A DTP- PhD student based full time at NIAB (2015-2019) is being training to explore fungal effector-wheat genotype interactions and is using the Paragon EMS, Chinese Spring x Paragon RILs (Main supervisor-Dr James Cockram) .

PhD student funded by the Oman Government Fellowship (Main supervisor Tim Mauchline (Rothamsted Research), co-supervisors Rob Jackson and Liz Shaw (both at Univ. of Reading) is using the WGIN Pseudomonas bacteria colection isolated from a 3rd wheat WGIN take-all field trial in 2012, and the current WGIN 1st and 3rd wheat take-all triials, in a project entitled 'Characterising the influence of different wheat cultivar rhizospheres on variations in microbiome diversity and functionality (Oct 2015- Sept 2019)

A DTP- PhD student based full time at NIAB (2016-2020) is being training to undertaking a genetic dissection of cereal root traits and is using Avalon x Cadenza NILs. (Main supervisor-Dr Eric Obers)

PhD student George Lund based full time at Rothamsted Research is using the WGIN Pseudomonas bacteria colection isolated from a 3rd wheat WGIN take-all field trial in 2012, in a project entitled 'The impact of microbial communities on the incidence of foliar fungal disease symptoms in wheat' . This project is funded through the BBSRC – DTP University of Nottingham. Main supervisor Jason Rudd (Rothamsted Research) and co-supervisors Tim Mauchline (Rothamsted Research) and Paul Dickisnion (Univ of Nottingham) (Oct 2016 – Sept 2020)

PhD student on a Walsh Fellowship (Main supervisor Tim Mauchline (Rothamsted Research), co-supervisors Wilfred Otten (Cranfield), Fiona Brennan (Teagasc, Ireland) and Penny Hirsch Rothamsted Research), is exploring the wheat microbiome in a project entitled 'Soil AgRIA – Exploiting mycorrhizal selection of beneficial rhizosphere bacteria from the soil microbiome'. This project is using the 1st and 3rd wheat WGIN take-all trials (Oct 2017 – Sept 2021).

PhD student Petros Sigalas (supervisor Malcolm Hawkesford) fully funded by the French Chemical company Roullier, will be using the WGIN diversity trials from 2018 to 2022 to explore wheat tiller numbers.

A total of 12 undergraduate summer students were employed each summer for 10 weeks to help with the wheat pathology trials at Rothamsted Research. These were trained and supervised by Dr Vanessa McMillan. These were funded either by WGIN (n=10) or the British Society for Plant Pathology(n=2).