Exploiting resource use efficiency and resilience traits in ancient wheat species

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HGCA funding	£37,500	Total cost	£75,000

What was the challenge/demand for the work?

Globally, 590 million metric tonnes of wheat are produced each year, however by 2025, the estimated requirement is projected to be 840 million tonnes (Murchie *et al.*, 2009). Over the course of the 20th Century, wheat yields notably increased due to improved cultivars that derived from breeding initiatives. However, these plant types are often reliant upon the established environmental conditions in which they were bred (Calderini & Slafer, 1998; Frederick & Bauer, 1999).

Further genetic enhancements in modern wheat are thought to be somewhat limited, since it has been hypothesised that early domestication and focussed breeding schemes have caused a genetic bottleneck, consequently reducing the allelic variance within the modern wheat gene pool (Peleg *et al*., 2005). This limited gene pool makes it increasingly difficult to select for new plant types that have the capability to resist biotic and abiotic stresses (Sparkes, 2010), consequently reducing overall productivity through drought, salinity, temperature and nutrient imbalances (Trethowan & Mujeeb-Kazi, 2008). Even new plant types, bred to be high yielding, have negligible yields in harsh environments, illustrated by observed yields being inversely proportional to environmental stresses imposed (Araus *et al.*, 2002). This is further indicated by yield increments in the United Kingdom being ten times those witnessed in Australia (Araus *et al.*, 2002). Furthermore, it is also thought that the genetic uniformity of modern wheat will make wheat vulnerable to disease epidemics (Gororo *et al.*, 2002). It is, therefore, imperative that the modern bread wheat (MBW) gene pool is supplemented with more variance, and it is thought that this will most likely derive from external sources (Trethowan & Mujeeb-Kazi, 2008).

The 'founder effect' states that the allelic variation within modern wheat gene pools is diminutive compared to their wild progenitors. Ancient species purportedly have an abundance of allelic variation, yet yield potential and physiological characterisation for these species has been lacking in any great detail. Increased understanding of resource capture of radiation and water will improve the efficiency of production and potentially lead to reduced agricultural inputs in wheat production. Therefore there is a need to collect robust data relating to resource capture traits for these ancient wheat species. The underlying mechanisms of efficient resource capture traits are highly complex; it is necessary to dissect these mechanisms in ancient wheat to identify the advantages they confer as well as their genetic basis. Ultimately, this could provide an opportunity through which modern wheat gene pools may be improved to stabilise yields, particularly in sub-optimal environments, thus increasing production per unit resource, thereby enhancing the productivity and efficiency of crop systems.

How did the project address this?

The project was designed to test whether the preliminary data collected, namely concerning architectural characterisation, light interception and conversion (biomass production, radiation use efficiency, harvest index and grain yields) of an assortment of ancient wheat species, specifically including plants with a range of ploidy such as einkorn, emmer and spelt in addition to a number of elite modern wheat varieties, were consistent across growing season and conditions. Where previous work included one cultivar/landrace of each cytological group, the current project aimed to assess a greater number of representatives in order to observe whether the traits, such as enhanced radiation use efficiency (RUE), water use efficiency (WUE) and green area persistence, observed throughout preliminary analyses, were characteristic of the species or were simply cultivar-associated traits. Data collection from field and glasshouse experiments focussed on reporting a variety of physiological characteristics by assessing a broad but fundamental spectrum of resource use efficiency traits in ancient species, whilst comparing these with cultivars that were available in the UK.

Analyses encompassed three main elements of growth and development, focussing on physiological aspects of water and radiation use efficiency, namely 1) canopy interception, 2) leaf photosynthetic capabilities and 3) water use. During the first two years of experimentation, data derived from conventionally managed field trials. These provided a catalogue of traits linked to radiation capture, conversion efficiencies, partitioning and yield formation. Investigations of these traits were also carried forward into the three glasshouse experiments that followed, where assessments were scaled down to the leaf level in order to see whether the enhanced RUE, observed in preliminary results and within the previous field trials, derived from carbon assimilation at the leaf level using Infra-Red Gas Analysis (IRGA). Glasshouse experiments were also established to investigate the water use efficiency of this non-UK material using IRGA, carbon isotope discrimination and biomass to water uptake ratios. This final component aimed to elucidate the previously reported WUE of these species throughout the wheat life cycle in order to assess water utilisation throughout growth and development.

What outputs has the project delivered?

The project confirms that there is sufficient variation for physiological traits linked to water and radiation use within ancient wheat species. It therefore appears that the diverse allelic variation that has been previously reported (Trethowan & Mujeeb-Kazi, 2008) could provide a source with which the modern bread wheat (MBW) gene pool may be supplemented. The current work aimed to investigate a wide spectrum of contributing factors to resource use, focussing on as many characteristics as possible due to the highly complex nature of resource use. The work highlighted the potential importance of several key traits that appear to influence the efficiency and assimilation/utilisation of carbon and water, these include:

- Enhanced RUE. Preliminary data indicated a capability for high RUE particularly in spelt and einkorn. Results from field experiments in 2010 and 2011 indicate that spelt had enhanced RUE, although data was not entirely conclusive as a result of confounding variables within the field trials, most notably plant emergence.

- Variation in biomass partitioning. Much of the project was geared towards understanding where assimilated carbon was directed in ancient wheat species. Modern cultivars had an enhanced harvest index (expected due to intensive breeding initiatives), however ancient wheat species directed more biomass towards tiller production, indicating a low proficiency to produce economic yield.
- Comparable biological yield production. Preliminary data indicated a capability for high biological yield production particularly in emmer and spelt. Glasshouse and field trial data corroborated these results where spelt and emmer showed a proficiency to produce biological yields that were comparable to those of modern bread wheat (although this was not indicated by yield analyses).
- High photosynthetic capability/variation for leaf physiology. Using IRGA, emmer and einkorn were observed to have high maximum rates of photosynthesis under saturated light. This potentially indicates variation in the fundamental physiology of the leaf between genotypes (such as abundance of photosynthetic enzymes, pigments and other compounds, although these were not investigated) however, specific leaf area (SLA) results did indicate that leaf thickness differed, and was generally thinner among ancient species, which could be indicative of variation for the positioning of leaf photosynthetic machinery, potentially the origin of the enhanced RUE previously observed.
- Enhanced instantaneous transpiration efficiency (ITE) and variation for the mechanism by which it occurs. Glasshouse experiments supported the findings of preliminary results, suggesting that emmer and spelt were conservative in their use of water, having a high photosynthetic rate to water transpired ratio (ITE). Enhanced ITE appeared to derive from either increased photosynthetic rates (emmer) or comparably low transpiration rates (spelt species). The mechanisms for which differed among the three species, although einkorn, which also displayed enhanced ITE, displayed an intermediate mechanism of the two.
- WUE was assessed on three different levels, ITE through IRGA, carbon isotope discrimination of grain and biomass to water uptake ratios, each of which highlighted the efficiency of spelt and general conservative use of water by ancient wheat species in general.
- Canopy longevity. Across field and glasshouse experiments, spelt species characteristically maintained flag leaf green area beyond other investigated genotypes, essentially increasing the duration over which carbon may be assimilated and therefore biological yield to accumulate, indicating these genotypes were capable of utilising the high incident radiation within the UK winter wheat growing season. Furthermore, the continued accumulation of biomass indicated that this green area was functional. Additionally, green area longevity was increasingly apparent under drought conditions, indicating that the trait may be an adaptation expressed in resource-limited environments, and although ‘stay green’ was seemingly conserved throughout the species, some plasticity was observed, indicated by the lack of ‘stay green’ where plants were watered without limitation.

The current work therefore suggests that survival and duration may be prioritised over productivity in ancient wheat, with some genotypes indicating increased RUE, WUE and leaf longevity. The origin of the variance for RUE, however, was not clear, although further research did highlight the potential factors that may have contributed to these findings, namely green area longevity, intrinsic photosynthetic capability of the leaf and enhanced WUE; all of which contributed to a proficiency to produce biological yields that were comparable to those of MBW. Furthermore, leaf level IRGA also highlighted variation for the mechanism whereby species maintained ITE, which could be harnessed to produce novel wheat varieties with adaptations to specific environmental conditions. This collection of traits therefore, does highlight potential successful adaptations conferring resource use efficiency, which could be highly valuable to supplement the MBW gene pool for increased yield stability and productivity in increasingly limited environments and has widely associated with increased crop productivity.

Who will benefit from this project and why?

The current project generated a large amount of data. The PhD project primarily concentrated on the physiological characterisation of a larger group of representative of these three ancient wheat species than had been previously investigated, providing a basis for future work in this area as well as supplementary information for another PhD project at The University of Nottingham that aims to assess the same genotypes for variation in root traits. This research indicates that there is sufficient variation for traits which could be used to improve radiation and water use efficiency and, therefore, warrants further investigation. In particular, the enhanced WUE and green area longevity traits could provide promising adaptations to plants within resource-limited environments. Therefore they highlight avenues through which the biological yield per unit resource may be boosted in the production of modern wheat cultivars increasing yield stability, particularly in sub-optimal environmental conditions, thereby enhancing the productivity and efficiency of modern wheat cropping systems.

The current work has provided a greater (although by no means comprehensive) understanding of biological yield formation through resource capture and some potential traits on which an extension of this research should focus. With further investigation, resource capture and utilisation efficiency, and the morphological traits that confer these advantages, could provide the necessary genetic gains to improve MBW. Follow up work should focus on the production of genetic markers to identify the genes from which they derive, facilitating their introgression into novel wheat cultivars through back-crosses. A preliminary evaluation of the offspring of a spelt x wheat cross was established to expedite this shortly after the current project was undertaken. This information would provide a basis through which the genetic variation within modern bread wheat may be utilised to enhance the selection of resource use efficiency within the MBW gene pool. Such supplementation of allelic variance for resource use in MBW could prove invaluable, ultimately improving the long-term productivity for the grower under increasingly prevalent resource limitations

If the challenge has not been specifically met, state why and how this could be overcome

This research provides a broad basis of the fundamental aspects of resource use and physiology of ancient wheat species. The current experiment has provided useful data concerning growth, development and yield-forming processes of these ancient wheat species, which has been previously lacking. However, results were not always conclusive. Of the large data set, there were confounding variables, one such being difficulty in establishing field trials where plant density was homogenous across all genotypes, in addition to extremes of weather which affected emergence and increased the incidence of lodging. Further investigation would require increased provision for those factors thought to be associated with some of the variation observed, for instance increasing plant density and subsequently reducing the populations until they were all consistent or using seed treatments; adapting experiments in such a way, would allow more robust interpretation of the data collected.

How have you benefited from this studentship?
I have benefitted immensely from this studentship. Throughout my PhD, I have developed a diverse skill set that enables me to effectively design, implement and report field, glasshouse and laboratory studies. Through the process of bringing a long-standing project to completion, I have also developed a high degree of specialist knowledge whilst improving my research independence, analytical techniques, diligence and organisation. Furthermore, through involvement of knowledge transfer activities, including two Association of Applied Biologists (AAB) resource use efficiency conferences, Cereals events, as well as postgraduate symposia held by The University of Nottingham and HGCA, I have developed the ability to communicate my research effectively to a variety of audiences. My future plans are to work within the agricultural sector, specialising in research where the focus is directed towards increasing the efficiency and productivity of cropping systems using effective and sustainable solutions through crop protection and improvement.

Lead partner	The University of Nottingham
Scientific partners	None
Industry partners	None
Government sponsor	None