European Innovation Partnership (EIP) Wales

Organic Ancient Cereal Supply-chain

"Investigating the potential for cultivating heritage and ancient wheat in Southwest Wales"

Final report

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Executive Summary

Modern agriculture relies on very few crop species, leading to low agrobiodiversity and low food diversity, but there is a renewed interest in ancient and heritage cereals as an alternative to mainstream modern varieties. Ancient cereals, or more specifically ancient wheats, are those wheat species that are hulled and are ancestors of modern bread wheat, for example Einkorn, Emmer and Spelt. There is some overlap of the terms and no agreed definition of Heritage grains but these are generally considered to be crops grown or bred before the introduction of modern high input agricultural practices often termed the "green revolution" and the use of the "high-yielding variety". These ancient and heritage grains are suitable for organic and low input production whilst also being adapted to more marginal environments. Reintroduction of such alternative wheats could improve the sustainability of arable crop production and allow for their widespread cultivation in areas such as southwest Wales. In addition, there is a growing awareness of the nutritional value of such grains as well as a reconnection to traditional foods and farming heritage, which the reintroduction of landraces and ancient species can support. There is also a desire to produce more local, homegrown food, and a need to shorten and localise supply chains, highlighted by recent global events challenging the current globalised large scale supply chain paradigm.

The EIP Ancient Cereals project ran from April 2019 to October 2021 and set out to investigate the agronomy of ancient and heritage wheat grown in Pembrokeshire, taking an approach that embedded the research within commercial farming operations to gain a "real world" perspective, exploring factors relevant to the farmers and helping to understand the key issues for farmers seeking to carry out crop system diversification.

Trials were set up in Spring 2019 across four farms in Pembrokeshire investigating the agronomy of an ancient and a heritage wheat compared to a modern variety. Certain management factors of interest were included, varying seed rates and undersowing, decided through the farmer led research approach. After this preliminary study, trials were set up in Autumn 2020 across three farms looking at ancient and heritage winter wheats and again in Spring 2021 across three farms, looking at ancient, heritage and modern wheat as well as intercropping of the wheats with field beans.

The study revealed heritage wheats can yield equivalent to modern varieties under organic conditions, as evidenced by the spring heritage wheat April Bearded compared to the modern variety Mulika over two growing seasons. In 2019, the modern variety Mulika yielded more than the ancient wheat Einkorn but was not significantly different to the April Bearded yield. In 2021 there was no significant difference in the yields of the modern variety compared to the heritage wheats April bearded and Atle or the ancient wheat Emmer. Yields of the winter crops were generally poor due to low seed quality and suboptimal drilling, however, results showed that the Welsh landrace Hen Gymro, the old variety Maris widgeon, the heritage wheat Rivet and the ancient wheat Emmer can offer promising alternatives to the current modern landrace being grown in the area, Torth y Tir. Protein content was found to be higher for the heritage and ancient wheats compared to the modern variety and this cannot be completely explained in terms of a yield protein trade-off since the modern wheat did not always yield significantly higher than the heritage wheats. The spring heritage wheat April Bearded appears to show grain protein deviation (GPD).

Investigation of the management factors of undersowing and seed rates in 2019 showed that lower seed rates of the heritage and ancient crops can maintain yield by compensation through yield components but increased the risk of weed cover from lower plant populations. Meanwhile, there was no detrimental effects on yield or quality from undersowing crops with clover, instead a significant reduction in weed cover from the practice was found. The heritage wheat April bearded was more

weed suppressive than the modern wheat Mulika in 2019. Intercropping with the heritage bean variety Maris bead had no effect on yield or quality but was sown at a low seed rate. The intercropping practice tended to reduce weed cover compared to the monoculture.

The taller heritage and ancient wheats were found to be at a higher risk of lodging, a risk increased by cultivation under non-organic conditions. The risk of lodging can be reduced by lower plant populations. Foliar disease assessment revealed that the modern variety Mulika had the best resistance to foliar disease owing to the breeding efforts in this area, with the heritage wheats often showing high levels of yellow rust, particularly April bearded and to a lesser extent Emmer, whilst ancient wheat Einkorn showed good disease resistance generally. The differences in disease resistance highlights the importance of local adaption and the requirement for testing different genotypes to find the best adapted crops for a particular environment.

Grain from the 2020/21 trials was used in baking trials to help assess the end use value of the crops tested. Mulika, the modern crop was ranked highest in terms of baking and taste tests. Rivet, a heritage wheat related to Durum wheat, ranked second with a blend of all wheats ranking third. Contamination and reduced aging time were issues for flour quality to be addressed for future baking trials.

Ancient and heritage wheats can play a role in crop and food system diversification, helping enhance agrobiodiversity. They have great potential for small local supply chains, connecting consumers to food traditions and healthy, nutritious cereal products whilst contributing to a greater level of home-grown cereals in Wales. Ancient and heritage wheats offer a good alternative to modern varieties, especially under organic and low-input husbandry to diversify cropping systems and can be cultivated in Pembrokeshire successfully but require adjustments to management taking account of their differences to modern varieties. With several genotypes of ancient and heritage wheats in existence, it is important to test them to determine suitability for a given environment. As well as evaluation in the field, it is important to test grain for its end use suitability and quality to ensure small local supply chain success, linking farmers, processors, and consumers. This process can help identify additional qualities often overlooked by large scale supply chains like flavour or food heritage and traditions.

Some barriers have been identified during the project; the need for local infrastructure to support diversification practices and in the case of ancient wheats, the need for a small-scale de-huller. When diversifying away from commodity crops, seed supply is a key issue as these are not commercially available genotypes. Seed is hard to find and may be of low quality if being swapped by farmers. Many crop genotypes are available and accessible in gene banks although initial seed supply is low, requiring multiplication over several years.

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1.Introduction

1.1 Diversification of Wheat for Organic and Low Input Farming

Following the industrialisation and globalisation of agriculture in the mid-20th century, there has been a general decline in agrobiodiversity with the world relying on only a few species of crops grown as monocultures (Thrupp,2000). There is a need and, for some, a desire to increase agrobiodiversity which can be achieved through the use of underutilised species as well as simplifying and localising supply chains for enhanced food sovereignty (Quaye et al. 2013; Corvo & Matacene, 2019) and increased food system resilience (Dunning et al, 2015; Hendrickson, 2015). In the context of this project, we will define as "ancient" all hulled wheats and any common wheat (*Triticum aestivum*) grown or bred before the industrialisation of agriculture in the 1960s as "heritage wheat".

There is a growing interest in Wales to produce more homegrown food, including the increased cultivation of arable crops within Wales to supply consumer demand for Welsh cereal products. Growing wheat in Wales, whilst also diversifying the species and genetics, and moving from monocultures to polyculture, represents an opportunity to increase agrobiodiversity, increase the proportion of homegrown cereals, and reduce inputs used for cereal production, therefore, enhancing the overall production, sustainability, and resilience of arable cropping in Wales.

The genus *Triticum* represents a wide group of wheat species that have been historically cultivated across the British Isles. *Triticum aestivum* known as common or bread wheat is the most commonly grown and widespread wheat species today. There are however several other species including *Triticum spelta* (Spelt), *Triticum dicoccum* (Emmer) and *Triticum monococcum* (Einkorn), that are known as "ancient wheats" as ancestors of modern wheat and owing to their hulled nature, and heritage wheats including *Triticum durum subsp. turgidum* (Rivet) that were widely cultivated in the past. These species are expected to perform well under organic and low input farming systems, given their adaption to historic farming systems that didn't use herbicides, fungicides, and synthetic fertilisers. In addition, heritage wheats including landraces and populations of common wheat, with their genetic diversity, also represent an opportunity to diversify the genetics of wheat crops grown in the UK. There is a general lack of agronomic information on these crops, particularly in more marginal regions such as Pembrokeshire, with most research conducted on high yielding modern varieties bred for intensive high input agriculture and carried out in more typical and optimum cereal growing environments. This leaves farmers and those end users wishing to utilise such historic and underutilised crops without relevant information for their circumstances and growing environments.

1.2 Aims and Objectives of the work

The project aims to investigate the agronomy of ancient and heritage wheats through farmer led trials and evaluate crop performance in baking trials to assess the potential for cultivation in Southwest Wales. The project also aims to increase awareness of the use of alternative wheats in the supply chain for local grain economies and the diversification of local food systems.

Specific objectives include:

- Conduct on-farm field trials over two growing seasons using ancient and heritage wheat and benchmark varieties to provide comparisons of field performance.
- Collect specific crop trait data including height, cover, foliar disease, lodging, grain yield and grain quality for all crops grown.
- Develop the participating farmers experience and understanding of growing alternative wheat crops and investigate additional management factors as selected by the farmers.
- Measure performance in baking trials to classify end use potential of the grain.

- Develop generalised recommendations for farmers wishing to grow novel cereal crops in Wales, highlight issues and barriers to successful diversification.

1.3 The Operational Group

The original operational group consisted of Caerhys Organic Farm, Torth y Tir, Caerfai Farm and the Welsh Grain Forum. It was established out of a desire to improve the understanding of ancient and heritage wheat agronomy and marketing. Membership of the delivery group consists of the lead farmer a peasant farmer/baker, a project coordinator, researchers, and additional participating farmers with the Welsh Grain forum acting as a steering group for the project. Names of participants and their roles within the project are detailed in Table 1.0.

Table 1.0 Project team

Name and Organisation	Role
Gerald Miles, Caerhys Organic Farm	Operational Group - Lead Farmer, Triallist
Rupert Dunn, Torth y Tir Community Bakery	Operational Group - Farmer, Baker, Triallist
Wyn Evans, Caerfai Farm	Operational Group - Farmer, Baker, Triallist (Withdrew 2020)
Steven Jacobs, Anne Parry, Andy Forbes, Welsh Grain Forum	Operational Group – 'Non-Farming Actors'
Dominic Amos, Henrietta Lowth, Organic Research Centre	Research contractor -Research, data collection, data analysis, trial co-ordinator, report writer
Andrew Neagle, Anuna Craft Bakery	Baking trials contractor
Tony Little, RSK ADAS	Innovation Broker - project development, project co-ordinator, project management

2.Materials and Methods

2.1 Methodological approach

The Farm trials were set up as farmer-led experiments and were laid out as "field scale" strips in commercial fields that were divided according to accessions and experimental factors including seed rate, undersowing and intercropping. The trials were replicated across sites within each season and had the added advantage of being embedded in commercial organic and regenerative farming systems. The project was set up as an empirical study to assess the cultivation of novel wheat crops to develop a better understanding as experienced through on-farm implementation. This approach was taken to ensure that farmer experience, scientific insight and technical expertise underpin the understanding of the problem and the current state of play to increase overall relevance of the outcomes.

2.2 Weather data

The 2019/20 growing season was characterised by an especially warm winter particularly through February, record-breaking high temperatures in July and an especially hot summer followed by significant rain in Autumn (MET Office). Figure 1.1 shows monthly average maximum and minimum temperatures and cumulative rainfall for the period.

The 2020/21 growing season was characterised by extremely wet and stormy weather in Autumn followed by an equally wet winter. Spring 2021 was characterised by especially cold, dry weather in April and cold, wet weather in May and a wet late summer and early Autumn, leading to a late harvest in September (MET Office). Figure 1.2 shows monthly average minimum and maximum temperatures and cumulative rainfall for the period.

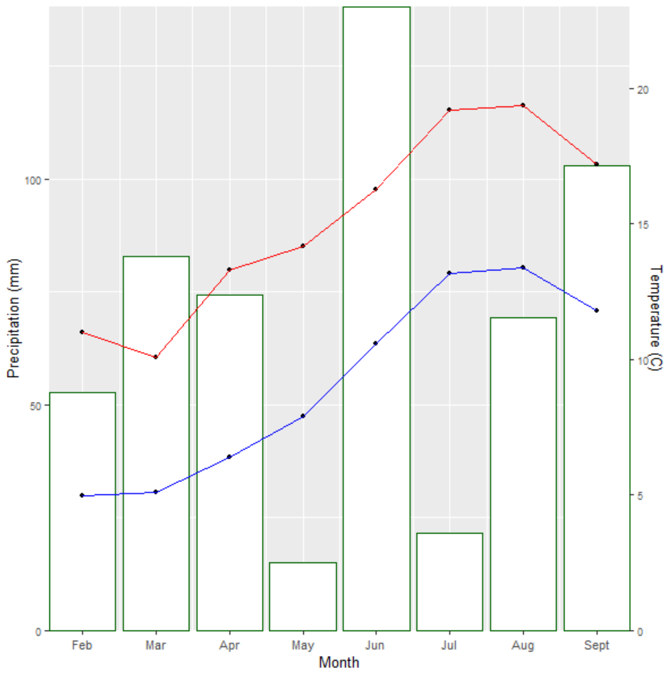

Figure 1.1 . 2019 trial growing season (spring crops drilled May, harvested September) average monthly min (blue line) and max (red line) temperature and total monthly precipitation (green bars). Source MET Office, Aberforth station (Lat 52.139 Lon -4.570, 133 metres amsl).

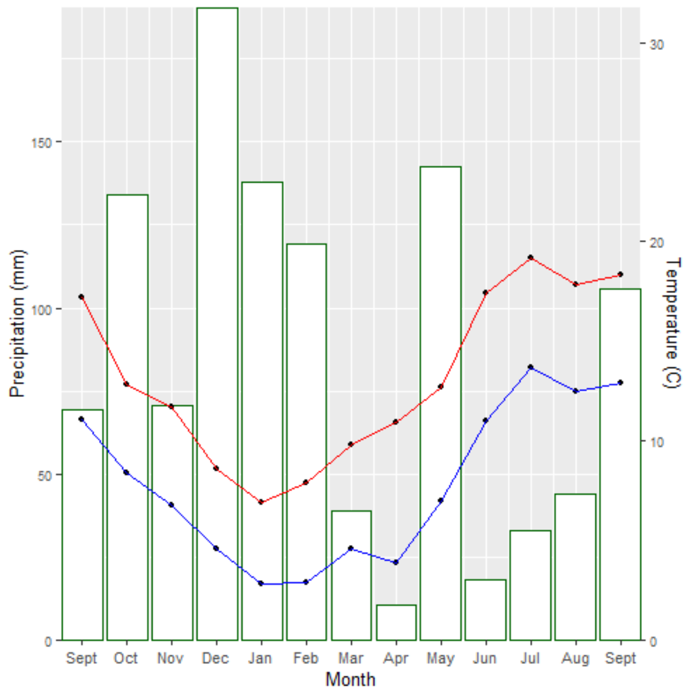

Figure 1.2 . 2020/21 trial growing season (winter crops drilled October, spring crops drilled April, all crops harvested September) average monthly min (blue line) and max (red line) temperature and total monthly precipitation (green bars). Source MET Office, Aberforth station (Lat 52.139 Lon -4.570, 133 metres amsl).

2.3 Trial Sites

Trial sites were all located on commercial farms in Pembrokeshire, surrounding St Davids, and were selected by the lead farmer, and provided by other local interested famers with fields chosen according to current crop rotations. Fields were generally selected that were certified organic or managed organically at least in the years of the trial.

Table 2.0 Trial site details

Farm	Field	Season	Soil Type, pH, P, K, Mg, OM	Previous Cropping
Brynbank	1	Spring 2019	Clay. pH 5.6, P 13.2mg/l (Index 1), K 58mg/l (Index 0), Mg 70.8mg/l (Index 2), OM 5.7%	Oats
Caerfai	2	Spring 2019	Clay Loam. pH 6.7, P 10.2mg/l (Index 1), K 57.6mg/l (Index 0), Mg 141 mg/l (Index 3), OM 5%	Grass Ley with clover
Rhodiad	3	Spring 2019	Clay. pH 5.7, P 34.8mg/l (Index 3), K 43.5 mg/l (Index 0), Mg 91.5 mg/l (Index 2), OM 3.8%	Stubble turnips
Bug Farm	4	Spring 2019	Clay. pH 5.7, P 32.6mg/l (Index 3), K 112mg/l (Index 1), Mg 94.9mg/l (Index 2), OM 3.6%	Grass Ley
	5	Autumn 2020	Medium Clay Loam. pH 5.9, P 52.8mg/l (Index 4), K 93.1mg/l (Index 1), Mg 59.4mg/l (Index 2), OM 6.4%	Grass Ley
	4	Spring 2021	Heavy Clay. pH 5.9, P 25.8mg/l (Index 3), K 61.3mg/l (Index 1), Mg 67.7mg/l (Index 2), OM 5.4%	Wheat
Caerhys	6	Autumn 2020	Heavy Silty Clay. pH 6.4, P 32.2mg/l (Index 3), K 34.6mg/l (Index 3), Mg 67.5mg/l (Index 2), OM 6.5%	Barley
	7	Spring 2021	Medium Clay Loam. pH 6.2, P 33.4mg/l (Index 3), K 53.6 mg/l (Index 0), Mg 79.4 mg/l (Index 2), OM 5.4%	Barley
Brawdy	8	Autumn 2020	Medium sandy silt loam. pH 6.4, P 35.4mg/l (Index 3), K 62mg/l (Index 1), Mg 59.5mg/l (Index 2), OM 6.3%	Grass Ley
Whitesands	9	Spring 2021	Medium Clay Loam. pH 5.6, P 9mg/l (Index 0), K 65.8mg/l (Index 1), Mg 77.4mg/l (Index 2), OM 4.7%	Grass Ley

2.4 Treatments and Design

Following the farmer led approach and a farmer interest in investigating different factors, accessions, and sowing seasons, the trials were not replicated across seasons, giving three separate but consistent and overlapping trials within the project. Trials were not replicated within farms but were replicated across farms treating the farm as a block. Generalised trial designs for each season can be found in the three figures below, Figure 2.1, 2.2 and 2.3. Tables 2.1, 2.2 and 2.3 provide key details for the trials. The list and details of each crop accession included for each season of trials is contained within Table 2.4.

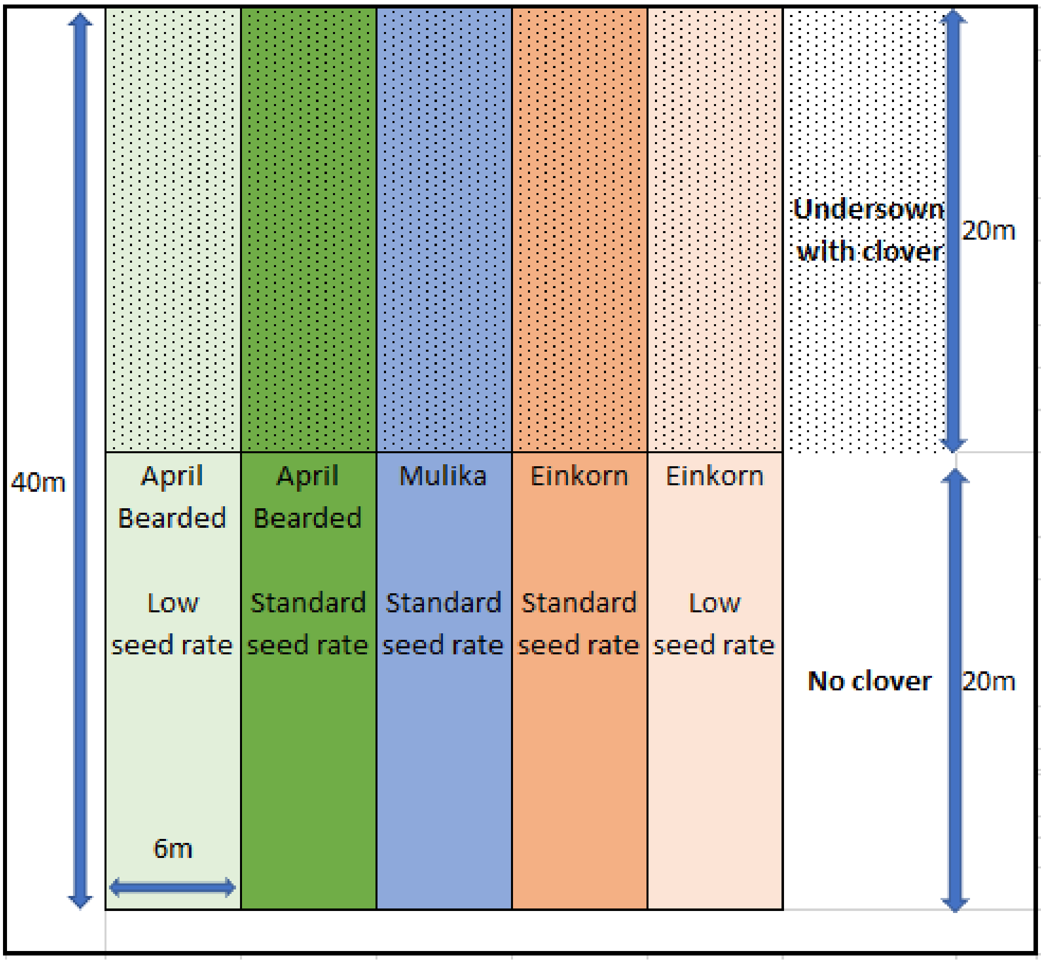

Figure 2.1 Trial design in Spring 2019, replicated across four sites

Table 2.1 Spring 2019 trial details

Treatment	Seed rate	Drilling Date	Harvest Date	notes
April Bearded low seed rate	350 seeds/m2 (150kg/ha)	09/05/19	19/09/19	
April Bearded standard seed rate	400 seeds/m2 (170kg/ha)			Heritage wheats generally sown at lower seed rates than modern semi-dwarf varieties
Mulika	450 seeds/m2 (213kg/ha)			Modern variety sown at high seed rate due to lower lodging risk and because crop is less competitive
Einkorn standard seed rate	275 kg/ha			Limit to highest seed rate on drill meant standard plot was two passes of the lower seed rate.
Einkorn low seed rate	137.5 kg/ha			Difficulty of counting hulled grains and calculating TGW means seed rates usually done in kg/ha
Clover under sown	10kg/ha	10/05/19	n/a	

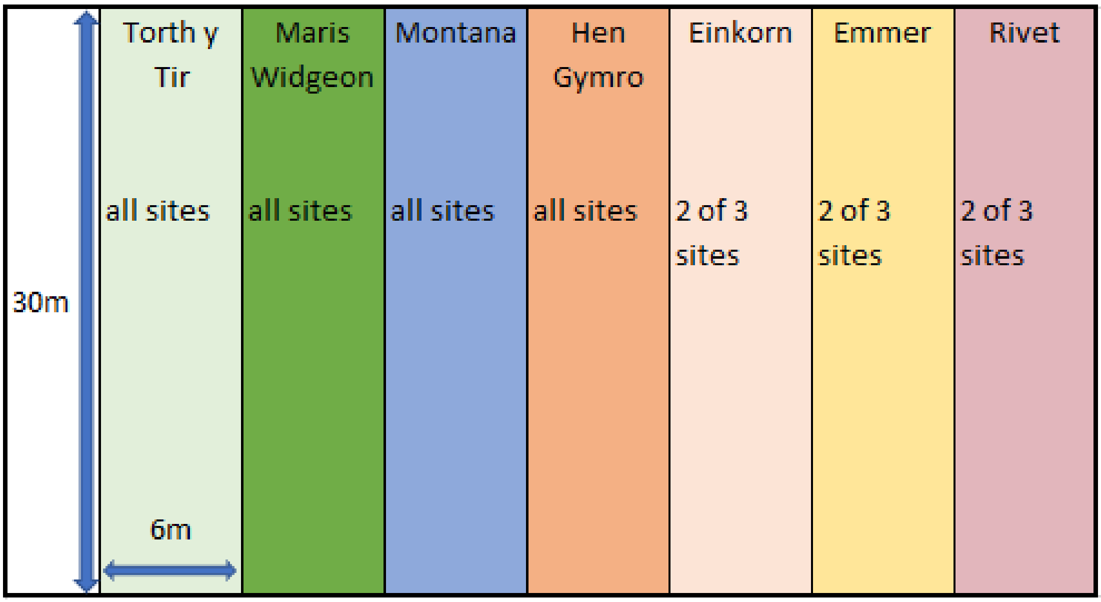

Figure 2.2 Trial design in Autumn 2020, replicated across three sites. NB. Due to limited seed supply Einkorn, Emmer and Rivet were each included at only two of three sites as a mini balanced incomplete block e.g., Einkorn, Emmer at site 1, Emmer, Rivet at site 2, Rivet, Einkorn at site 3.

Table 2.2 Winter 2020 trial details

Treatment	Seed rate	Drilling Date	Harvest Date	Notes
Hen Gymro	450 seeds/m2	22/10/20	07/09/21	Heritage wheats generally sown at lower seed rates than modern semi-dwarf varieties
Maris Widgeon	450 seeds/m2			
Montana	500 seeds/m2			Modern variety sown at high seed rate due to lower lodging risk and because crop is less competitive
Torth y Tir	450seeds/m2			
Einkorn	150kg/ha (~400seeds/m2)			Difficulty of counting hulled grains and calculating TGW means seed rates usually done in kg/ha
Emmer	180kg/ha (~400seeds/m2)			
Rivet	450 seeds/m2			

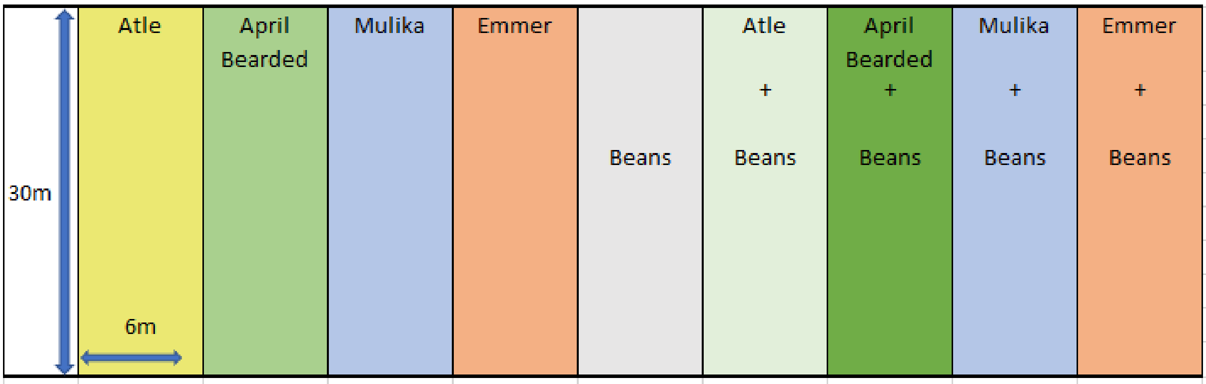

Figure 2.3 Trial design in Spring 2021, replicated across three sites.

Table 2.3 Spring 2021 trial details

Treatment	Seed rate	Drilling Date	Harvest Date	Notes
April Bearded	450 seeds/m2	20/04/21	07/09/21	Heritage wheats generally sown at lower seed rates than modern semi-dwarf varieties
Atle	450 seeds/m2			
Mulika	500 seeds/m2			Modern variety sown at high seed rate due to lower lodging risk and because crop is less competitive
Emmer	400 seeds/m2			Larger seed size meant that a lower seed rate should lead to a similar number of plants.
Beans Monocrop	50 seeds/m2			
Beans Intercrop	12.5 seeds/m2			25% standard seed rate of 50 seeds/m2

2.5 Crop selection

The farmers were responsible for selecting the majority of the crops tested with current farm crops included as well as crops identified as being of interest. Additional crops were added as modern benchmarks for the purposes of the experiment as well as some crops identified through previous research as being suitable for organic farming. A full list of the crops included in the project can be found in table 2.5

Table 2.5 Crop Accession details

Accession	Species	Description	Source	Season
cv April bearded	*Triticum aestivum*	A British heritage spring wheat suited to later sowing it was widely cultivated from the mid-19th to the mid-20th C.	Seed not commercially available, sourced from a farmer	Spring 2019 Spring 2021
var Atle	*Triticum aestivum*	A Swedish heritage variety released in 1936.	Seed not commercially available, sourced from a farmer	Spring 2021
cv Hen Gymro (Mixture of lines S70, S72 and VIR Hen Gimro)	*Triticum aestivum*	"Old Welshman", historic landrace wheat of West Wales, well suited to the local conditions and in regular cultivation until the early 20th Century.	Originally from gene banks, multiplied by Brockwell Bake and given to the Welsh grain forum	Autumn 2020
var Maris Widgeon	*Triticum aestivum*	Heritage wheat variety developed in 1964 by the Plant Breeding Institute in Cambridgeshire, still commercially available and remains in cultivation amongst organic farmers.	Trial seed not available in 2020, sourced from a farmer	Autumn 2020
var Montana	*Triticum aestivum*	German e-quality winter wheat. Used as a modern control variety in the winter wheat trials.	KWS trial seed overwintered from 2019	Autumn 2020
var Mulika	*Triticum aestivum*	A modern pure line, included in the trials as a control variety. It is a commonly grown late winter and spring milling wheat.	Trial seed from Senova	Spring 2019 Spring 2021

cv Torth Y Tir	*Triticum aestivum*	Heritage population, mega mixture of hundreds of genotypes created by a farmer in Brittany, cultivated in Southwest Wales in recent years and now used as primary wheat crop for Torth y Tir community bakery in Pembrokeshire.	Torth y Tir Bakery farm crop	Autumn 2020
Einkorn – cv unknown (Spring 2019)	*Triticum monococcum*	Ancient hulled wheat species. The first of the wheats to be domesticated around 10,000 years ago. Generally autumn sown but can be sown in the spring (facultative). Many genotypes exist and some modern varities have been bred.	Seed from a Polish farmer shared with Caerhys Farm	Spring 2019
cv "CCP" (Autumn 2020)			Seed from ORC trials soured from Hungarian academy of Sciences	Autumn 2020
Emmer – cv "Zweikorn" (Autumn 2020)	*Triticum diccocum*	Ancient, hulled wheat species. Ancestor of durum wheat, cross between Einkorn grain and a wild grass. One of the first domesticated wheat species 9000 years ago. Many genotypes exist and some modern varities have been bred	Seed from ORC trials soured from Hungarian Academy of Sciences	Autumn 2020
cv unknown (Spring 2021)			Rejected grain from Felin Ganol Watermill	Spring 2021
Rivet – cv Blue cone	*Triticum turgidum*	Heritage wheat species, first grown in England during the Norman period. Free threshing like modern wheat so does not require as much processing as the true ancient "hulled" cereals. Close relative of Durum wheat.	Seed saved from ORC trials, resulting from multiplication from a gene bank	Autumn 2020
Bean - var Maris Bead	*Vicia faba*	Heritage field bean bred in the 1950's and still used in commercial cultivation. Used in the intercropping field trials.	Commercially available from Church of Bures	Spring 2021
White Clover – var unknown	*Trifolium repens*	Herbaceous perennial, native to Europe. One of the most widely cultivated types of clover. Used in the under-sowing trials.	Seed from a French farmer, Swedish variety	Spring 2019

2.6 Sampling and Assessments

Crop assessment was aimed at covering the main aspects of crop development and performance through an agro-ecosystem approach. Details of the assessments made can be found in Table 2.6.

Table 2.6 List of crop traits measured and details of the measurement

Trait	How it was measured/recorded	When was it measured
Plant Count	Number of emerging plants approximately three weeks after sowing measured on a 0.25m2 area using a quadrat	Winter Wheat: November (2021) Spring Wheat: May (2019,2021)
Establishment Score	A visual score from 1-5 describing how well the crop established. (Annex A)	Winter Wheat: May (2021) Spring Wheat: June (2021)
Crop Growth Stage	Crop phenological stage – assessed using the BBCH scale (Annex B)	Winter Wheat: May & June (2021) Spring Wheat: June (2019,2021) & July (2021)
Crop Height	Average of five measurements per plot, measured in centimetres.	Winter Wheat: May & June (2021) Spring Wheat: June (2019,2021) & July (2021)
Crop Ground Cover	Visual assessment of crop ground cover as a % averaged over five measurements per plot	Winter Wheat: May & June (2021) Spring Wheat: June (2019,2021) & July (2021)
Crop Growth Habit	A 1-5 scale from prostrate to erect to give an idea early crop/canopy morphology	Winter Wheat: May (2021) Spring Wheat: June (2021)
Vigour Score	A visual score of above ground crop biomass, using the scoring system from the ITAB. Scored from 1-9. (Annex C)	Winter Wheat: May & June (2021) Spring Wheat: June & July (2021)
Tiller Number	Number of tillers additional to the main stem	Winter Wheat: May (2021) Spring Wheat: June (2021)
Clover Cover	Visual assessment of clover ground cover as a % per plot	Spring Wheat: July (2019)
Weed Cover	Visual assessment of weed ground cover as a % per plot	Winter Wheat: May & June (2021) Spring Wheat: June (2019,2021) & July (2021)
Foliar Disease Severity	Identification of main foliar diseases and estimated average percentage leaf cover of flag leaf, leaf 2 and leaf 3	Winter Wheat: May & June (2021) Spring Wheat: June (2019,2021) & July (2021)
Ear Density	Number of ears/M^2. Estimated using a count of fertile tillers on three randomly selected row meters in each plot, converted to ears per m^2 using row width.	Winter Wheat: June (2021) Spring Wheat: July (2021,2019)
Spikelet Number	Average number of spikelets per ear, using 3 randomly selected spikelets from the ear density measurement.	Winter Wheat: June (2021) Spring Wheat: July (2021,2019)
Lodging	Assessment of crop area (0-100%) and angle (0-90°) of lodging and calculation of lodging index from 0-1.	Pre-harvest 2019 and 2021
Grain Yield	Combine harvest of each plot at maturity, weight of grain in kg, adjusted to 15% moisture and converted to t/ha.	Winter Wheat: September (2021) Spring Wheat: July (2019), September (2021)
Grain Quality	Analysis of grain for moisture content, protein content, hectolitre weight and thousand grain weight	Post-harvest (2019, 2021)

2.7 Data Analysis

We used the R project for statistical computing version 4.1.1 "Kick Things" to create graphs for data visualisation using the ggplot package. Using the lme4 and lmer Test packages we performed linear mixed effects analysis of the relationships of interest between output variables and their interaction, for example yield, and the fixed effect factors of interest, Crop system and Crop. Random effects were specified in the model with random intercept, for example Farm. Below is an example of the type of full mixed effects model used.

Yield ~ Crop*Crop System + (1|Farm:Crop System)

The p-values were obtained by likelihood ratio tests of the full model with the factor in question against the reduced model without the factor present. If a factor resulted non-significant, the reduced model was preferred. In each case a visual inspection of residual plots was performed to check any obvious deviations from homoscedasticity or normality. Estimated marginal means were obtained for the levels of the significant factors and were then analysed using Tukey's Test to perform pairwise comparisons (pwc) to determine which treatment means were statistically different from each other ($p \leq 0.05$). P values close to but above 0.05 were considered to show a trend but still treated as non-significant (ns).

3.Results and Discussion

All three experiments provided novel insights into the cultivation of ancient and heritage wheats in Wales, as well as highlighting some of the issues surrounding the reintroduction of these cereals following on-farm research that seeks to explore some of the real-world challenges associated with crop diversification.

3.1 Spring 2019

The trial in 2019 was a preliminary investigation into growing ancient and heritage wheat, alongside a modern benchmark variety, as well as an opportunity to explore effective research methods and processes of farmer led research. The results give a good indication of what to expect from growing ancient and heritage crops and what they offer in terms of characteristics against a typical modern variety.

With a grand mean yield of 2.29±0.27 t/ha, the trial did not show significant yield difference by undersowing (Figure 3.10) or seed rate (Figure 3.12) and only highlighted varietal differences with the modern variety Mulika outperforming the Einkorn but yielding equivalent to heritage cultivar April Bearded. April bearded was found to have a significantly higher protein content than Mulika, with Einkorn showing a strong trend for higher protein than the modern variety (Figure 3.11). Differences between Mulika and the Einkorn and April Bearded were found in height, lodging index (Table 3.15)and foliar disease (Figure 3.14). Both the factors undersowing (Figure 3.15) and seed rate (Figure 3.16) were found to have an effect on weed cover with weeds reduced by undersowing with clover or by using higher seed rates. The heritage wheat April Bearded was found to be more weed suppressive than Mulika.

Crop Establishment

Table 3.10 Plant counts and germination % by Crop and Seed Rate

Crop	Seed Rate	Target Seed rate/m2	Plant Counts/m2	Germination %
April Bearded	Standard	400	273 ± 14	0.65
	Low	350	259 ± 13	0.76
Einkorn	Standard	600	408 ± 11	0.68
	Low	300	274 ± 8	0.93
Mulika	Standard	450	276 ± 20	0.58

Photo of heritage wheat April Bearded growing at Brynbank in July 2019.

In this experiment, there were some distinct yield differences, regardless of the treatments. Overall, the Mulika, despite being selected and bred to be a higher yielding variety, did not yield higher than the heritage wheat April Bearded, but did yield higher than the ancient wheat einkorn. The higher yield potential of the modern variety could not be met under the organic conditions of the trials and shows that under environments characterised by natural soil fertility and higher weed burdens that heritage crops can yield equivalent to high yielding modern varieties with important implications for sustainable production, biodiversity and breeding. Also observed, was that the Mulika has a lower protein content than both the heritage and ancient wheat. This is in part due to the yield-protein trade off that has been widely observed, crops with higher yields often have lower proteins contents (Michel et al., 2019) but cannot be fully explained by it since the April Bearded actually yielded equivalent to the Mulika but had a significantly higher protein content, an encouraging factor for its suitability for both cultivation and end use. April bearded appears to exhibit a trait known as grain protein deviation (Monaghan et al., 2001). April Bearded and Mulika showed higher Hectolitre weight (HLW) than einkorn, with the April Bearded having the highest HLW. Previous studies have shown older varieties to have had lower HLW than modern varieties, a trend that once again has not been followed by April Bearded (Løes et al., 2020). The study by Løes et al, also showed a trend of heritage and ancient varieties having lower Hagberg falling numbers and smaller kernels than modern varieties.

Yield by Cropping System and Crop

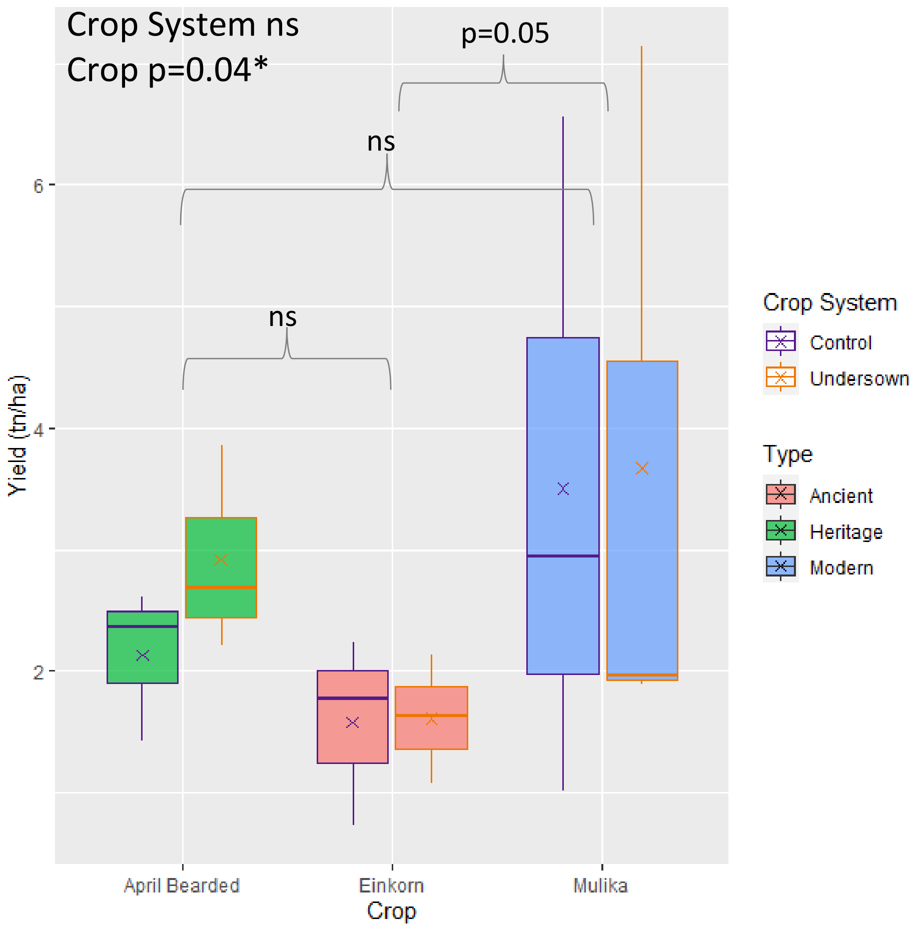

Figure 3.10 Boxplot of grain yield by crop and cropping system at standard seed rates. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

An analysis of the relationship between crop and undersowing on yield of the three crops sown at the standard seed rate showed no effect (p=0.72) of simultaneous undersowing with clover on the yield and no interaction between crop and system, but a significant effect for crop. The modern control Mulika (3.59±1.06 t/ha) yielded significantly higher than Einkorn (1.6±0.24 t/ha). No significant difference (p=0.35) was found between the yield of Mulika and heritage wheat April Bearded (2.52±32 t/ha) or between the yields of April bearded and Einkorn (p=0.44)

Table 3.11 Comparison of crop yields grown under organic (3) and non-organic (1) farm systems

Crop	Farm System	Yield ± SE (t/ha)	% of organic
April Bearded	Organic	2.13 ± 0.16	-
	Non-Organic	3.27 ± 0.47	+53.5
Einkorn	Organic	1.21 ± 0.18	-
	Non-Organic	1.85 ± 0.10	+52.9
Mulika	Organic	1.96 ± 0.39	-
	Non-Organic	6.85 ± 0.29	+249.5

In these trials, one of the farms included was not organic. All three crops, especially the Mulika, yielded higher under the non-organic compared to the organic conditions. In fact, the Mulika, which, due to breeding efforts has the highest grain yield potential of the crops studied, yielded 249% higher under the non-organic conditions compared to more modest increases for April Bearded of 54% and Einkorn of 53%. Comparing the yields across different farm systems highlights the huge difference in yield for the modern control variety Mulika and more modest yield differences for the ancient and heritage crops. Mulika yielded higher than the other crops under non-organic conditions mainly due to the use of herbicides and the residual nitrogen carried over from previous seasons synthetic fertiliser applications. The result shows the suitability of heritage wheats for organic farming with April bearded yielding equivalent to the modern control variety on the organic sites ($p=0.69$).

This is not a surprising result as differences in yields between conventional and organic cropping systems are widely observed. Mayer et al., 2015, and Bilsborrow et al., 2013 found wheat grain yields in organic cropping systems achieved ~60% of the conventional wheat yields. In this experiment, although during the trial year no additional fertilisers and herbicides were used, the residual effects of previous applications may have affected the wheat crops and weed control. An important finding from the trial was that, whilst the modern Mulika crop outperformed the heritage and ancient crops under the non-organic system, under the organic system the yields for all three varieties were very similar. The yield penalty between the non-organic and organic systems was greatest for the modern variety, Mulika. Modern varieties such a Mulika are bred and selected for high input environments which means they often don’t reach full potential in marginal environments. In marginal conditions, in terms of yield, it appears to be just as valuable to use ancient and heritage varieties as it does to use modern varieties. However, the additional benefits of using ancient and heritage varieties, such as increased weed suppression, greater straw production, and increased agrobiodiversity, can make using these varieties a more attractive option.

Protein by Cropping System and Crop

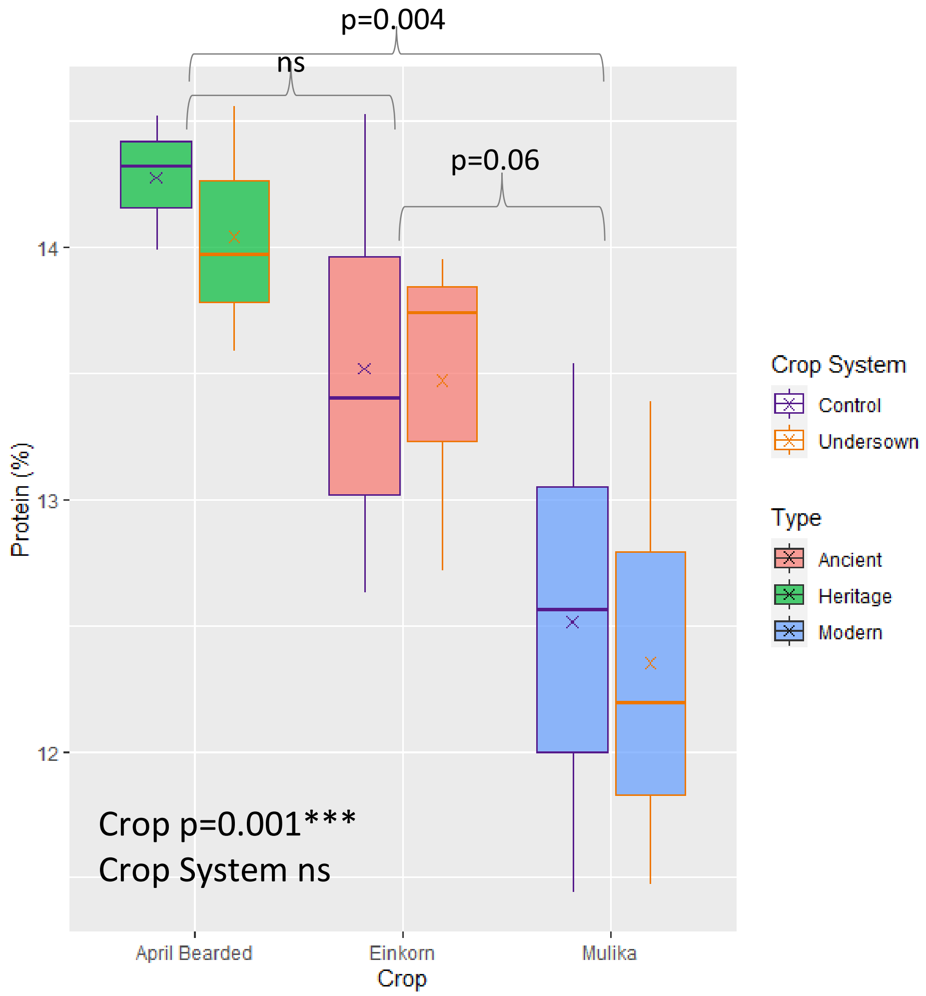

Figure 3.11 Boxplot of grain protein by crop and cropping system at standard seed rates. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

Analysis of the relationship between crop, cropping system and grain protein shows a significant effect of crop but no effect of crop system on protein content. Pairwise comparisons of the crop protein percentages show a significantly higher (p=0.004) protein content for April Bearded (14.2±0.15%) than for Mulika (12.4±0.37%) and a near significant (p=0.06) higher protein content for Einkorn (13.5±0.3%) than Mulika.

Table 3.12 Comparison of crop protein grown under organic (3) and non-organic (1) farm systems

Crop	Farm System	Protein ± SE (%)	% of organic
April Bearded	Organic	14.2 ± 0.11	-
	Non-Organic	13.6 ± 0.31	-4.3
Einkorn	Organic	13.3 ± 0.28	-
	Non-Organic	14.3 ± 0.23	+7.5
Mulika	Organic	12.6 ± 0.50	-
	Non-Organic	12.0 ± 0.55	-4.8

Grain Quality by Crop and System

Table 3.13 spring crop average grain quality results (±SEM) System and Crop effect shows p value obtained through likelihood ratio tests of the model

Crop	**Protein %**	**HLW kg/hl**
April Bearded	14.0 ± 0.1	66.4 ± 1.6
Mulika	12.4 ± 0.4	66.0 ± 3.9
Einkorn	13.7 ± 0.2	45.1 ± 2.0
System Effect	p=0.63	p=0.67
Crop Effect	p=0.001	p=0.001

Undersowing was not shown to affect hectolitre weight. A significant effect of Crop on hectolitre weight was found with Tukey's test showing that both April Bearded with a HLW of 66.1±2.4kg/hl (p=0.0003) and Mulika with a HLW of 65.7±3.2kg/hl (p=0.0004) had a higher HLW than Einkorn at 47.0±3.1kg/hl.

Photo of spring wheat ear morphology from Spring 2019 trials, from left to right April Bearded, Mulika, Einkorn, Emmer.

Yield by Crop and Seed Rate

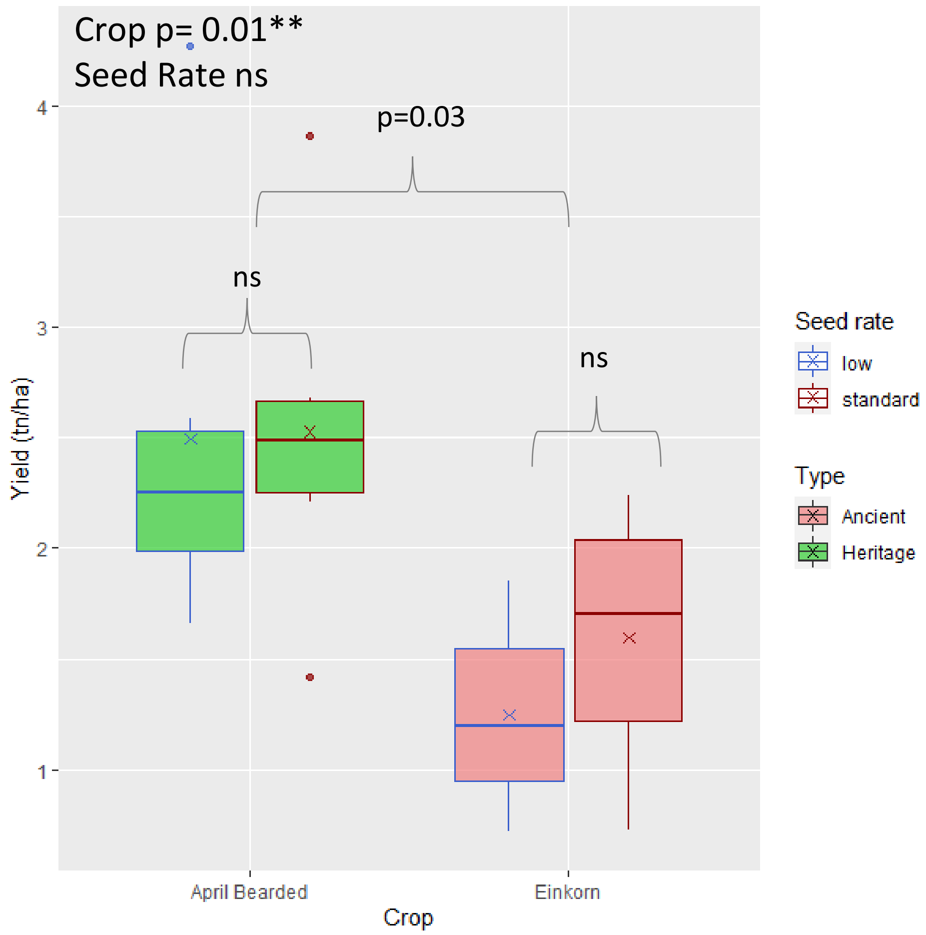

Figure 3.12 Boxplot of grain yield by crop and seed rate. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

An analysis for the relationship between seed rate and yield for the Einkorn and April Bearded crops show a significant effect of crop but no effect (p=0.14) of seed rate on yield and no interaction of crop and seed rate. April bearded yielded an average of 2.52 ± 0.32 t/ha at the standard seed rate compared to 2.49 ± 0.38 t/ha at the lower seed rate. Einkorn yielded 1.60±0.24 t/ha at the higher seed rate and 1.25 ± 0.18 t/ha at the lower seed rate.

Grain Quality by Crop and Seed Rate

Table 3.14 spring crop average grain quality results (±SEM) Seed Rate and Crop effect shows p value obtained through likelihood ratio tests of the model

Crop	**Protein %**	**HLW kg/hl**
April Bearded	14.0 ± 0.1	66.4 ± 1.6
Einkorn	13.7 ± 0.2	45.1 ± 2.0
Seed Rate Effect	p=0.45 (April Bearded) p=0.74 (Einkorn)	p=0.35
Crop Effect	p=0.10 (April Bearded) p=0.11(Einkorn)	p=4.28e^{-5}

Seed Rate*Crop Interaction found to be significant for Protein, so analysis done separately by crop.

Analysis of the effects of seed rate on grain protein shows a non-significant effect of seed rate and crop but a significant interaction (p=0.02) between crop and seed rate. Analysis comparing protein at each seed rate within each crop showed non-significant effects of seed rate for April Bearded (p=0.10) and Einkorn (p=0.11) with a slight trend for higher protein at higher seed rate in the April Bearded and lower protein at higher seed rate in the Einkorn. Seed rate was not found to affect hectolitre weight.

Crop Height and Lodging

Table 3.15 spring crop height and lodging index with p values obtained by likelihood ratio tests of the model.

Crop	Seed Rate	Height ± SE (cm)	Lodging index (0-1)
April Bearded	Standard	138 ± 5.6	0.54 ± 0.11
	Low	136 ± 6.6	0.39 ± 0.08
Einkorn	Standard	114 ± 6.4	0.58 ± 0.16
	Low	115 ± 7.6	0.51 ± 0.14
Mulika	Standard	87 ± 5.4	0
Crop Effect		$p=1.08e^{-9}$	$p=1.88e^{-6}$
Crop System		p=0.96	p=0.86
Seed Rate		p=0.71	p=0.004

Analysis of the relationship between the variable crop height and the factors crop, crop system and seed rate showed a significant effect of crop but non-significant effects for crop system(p=0.96) and seed rate (p=0.71). The tallest crop was April Bearded at an average height of 137±4.1cm, with Einkorn 114±4.7cm and the shortest crop Mulika at 87±5.4cm. Both the heritage (p=0.004) and ancient (p=0.05) wheats were significantly taller than the modern variety. A consistent trend was observed for crops to be taller under the non-organic conditions with grand mean crop height of 130±7.0cm compared to 112±5.1cm under organic conditions and with the individual crops ranging on average between 12-19% taller under the non-organic farm system. Lodging was observed in the heritage and ancient wheats but not in the modern wheat with both April bearded and Einkorn found to have significantly higher (p<0.0001) lodging index than Mulika. The increased height of the non-organic crops was associated with a higher lodging index for the ancient and heritage crops but not for the modern variety.

Ancient and heritage wheats, compared to the modern varieties, do not contain the height-reducing (Rht) genes, therefore they are generally much taller than modern varieties, as is shown in our results. This height can play an important role in the competitive ability of wheat against weeds (Mason & Spaner, 2005). Without under sown clover, the Mulika, a shorter modern variety, showed significantly higher weed cover than the heritage wheat April bearded. An increase in crop height is usually associated with an increased risk of lodging, which is once again confirmed in our results, with the taller ancient and heritage wheat displaying significant lodging, compared to no lodging in the modern Mulika. In terms of disease, the modern varieties are bred and selected for foliar disease resistance, and this is demonstrated in our results, with the Mulika displaying significantly less Septoria and Yellow Rust than the April Bearded. Foliar disease was slightly lower in Einkorn than the modern Mulika, and significantly less than the April Bearded. Studies have shown that Einkorn has significant disease resistance, particularly to fungal disease, which would explain the lack of yellow rust on the Einkorn (Zaharieva & Monneveux, 2014).

Foliar Disease

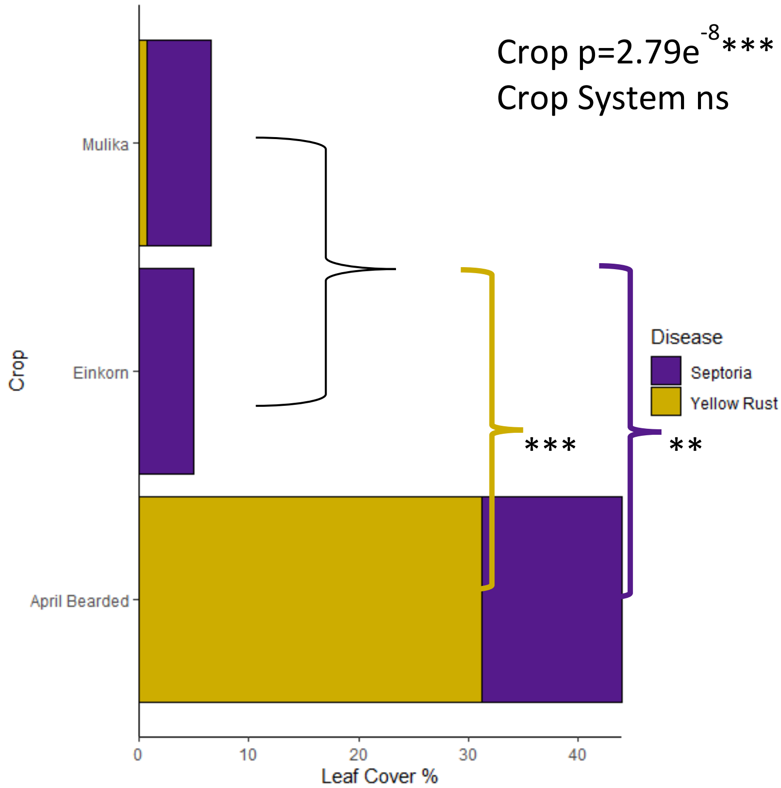

Figure 3.14 Bar chart of foliar disease at GS65 by crop. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test showing significantly higher yellow rust and Septoria in April Bearded compared to Einkorn and Mulika.

Analysis of the relationship between crop and crop system and the two key foliar diseases at crop anthesis showed a significantly higher yellow rust and Septoria leaf cover in April Bearded compared to Einkorn and Mulika. Crop system was not significant with the clover not shown to have an impact on foliar disease. When the relationship between seed rate and foliar disease was analysed, a significant effect of seed rate was found for Septoria (p= 0.02) but not for yellow rust (p=0.36), with Septoria levels lower under lower seed rates.

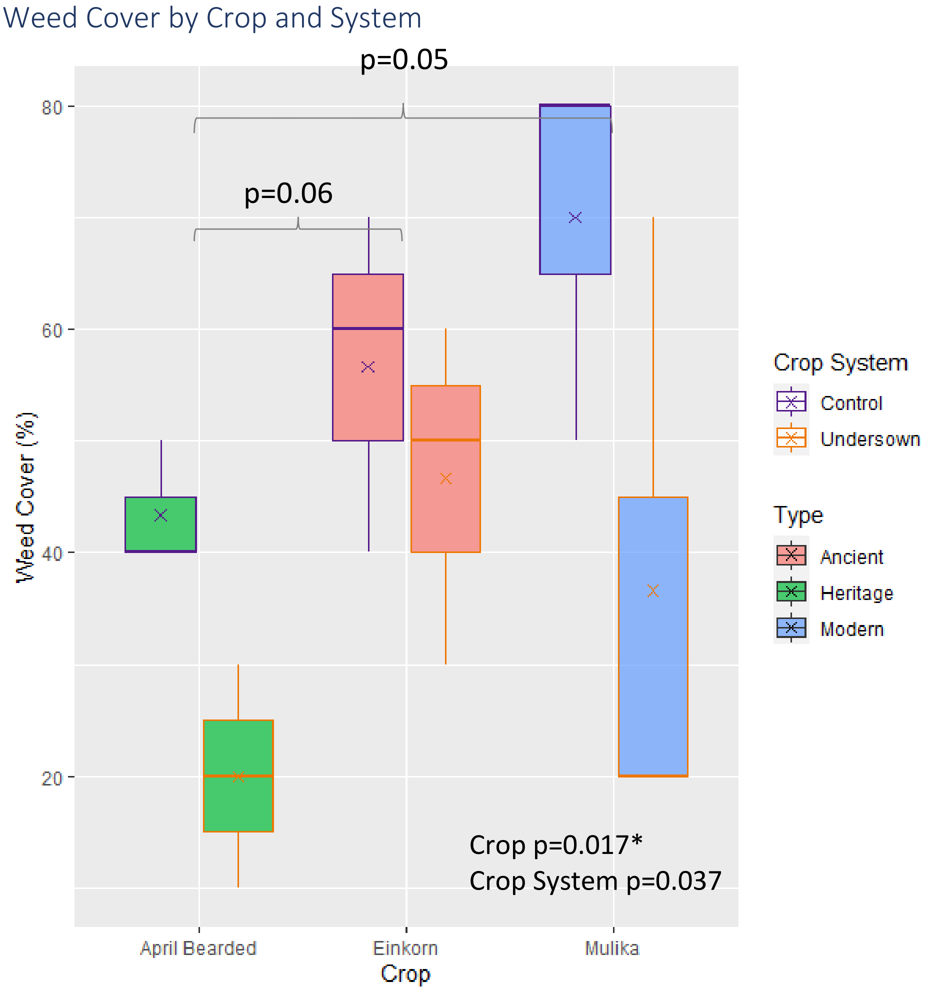

Figure 3.15 Boxplot of weed cover by crop and crop system. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

Analysis of weed cover revealed a significant effect of crop (p=0.017) and crop system (p=0.037). Weed cover was found to be significantly lower (36.7±5.1%) in the system under sown with clover compared to the control (58.7±4.1%). April Bearded was found to have a significantly lower weed cover at 35±4.9% than Mulika at 53.3±11.5% and a very strong trend for lower weed cover than Einkorn at 57.5±4.3%. April Bearded under sown with clover was found to have the lowest weed cover at 23.3±6.2% whilst Mulika control was found to have the highest weed cover at 70±10%.

Our results showed no significant difference in yield, protein, or disease between the under sown and control treatments, a result also found in a study by Fuchs et al., 2008. However, there was a significant effect on weed cover, with the undersown treatment showing significantly less weed cover than the controls. Gerhards, 2018 found that undersowing with clover significantly reduced weed density in cereal crops in Germany. In addition, the yields in all treatments were unaffected by the undersowing, as was found in our trials. These results suggest that undersowing with clover can suppress weeds without competing with cereal crops. However, research by Sjursen et al., 2011 found that undersowing wheat with clover did not suppress annual weeds but in fact fertilised the weeds as well as the cereals. In addition, Sjursen et al., 2021 found that undersowing with clover resulted in a statistically significant increase in the grain yield compared to the control. With the ability to fix nitrogen, it might be expected that the clover would increase the yield and protein of the wheat. However, this relies on niche complementarity and facilitation with the clover releasing the nitrogen at the correct time. All these factors are influenced by management practices such as clover disturbance, seed rates and variety. Further research on these factors to determine the optimum use of undersown clover would be beneficial. A particularly interesting research area, which applies also to the clover undersowing, is the ability for nitrogen fixing crops to positively influence future rotations. It is important to evaluate the cumulative effect over several years and not a single season. Hauggaard-Nielson et al., 2021 found that yields of winter wheat were greater when following a treatment of undersown clover. Whilst our experiment did not show direct effects of clover undersowing on grain quality or yield, the potential positive implication on future rotations is certainly a factor to be considered.

Weed Cover by Seed Rate and Crop

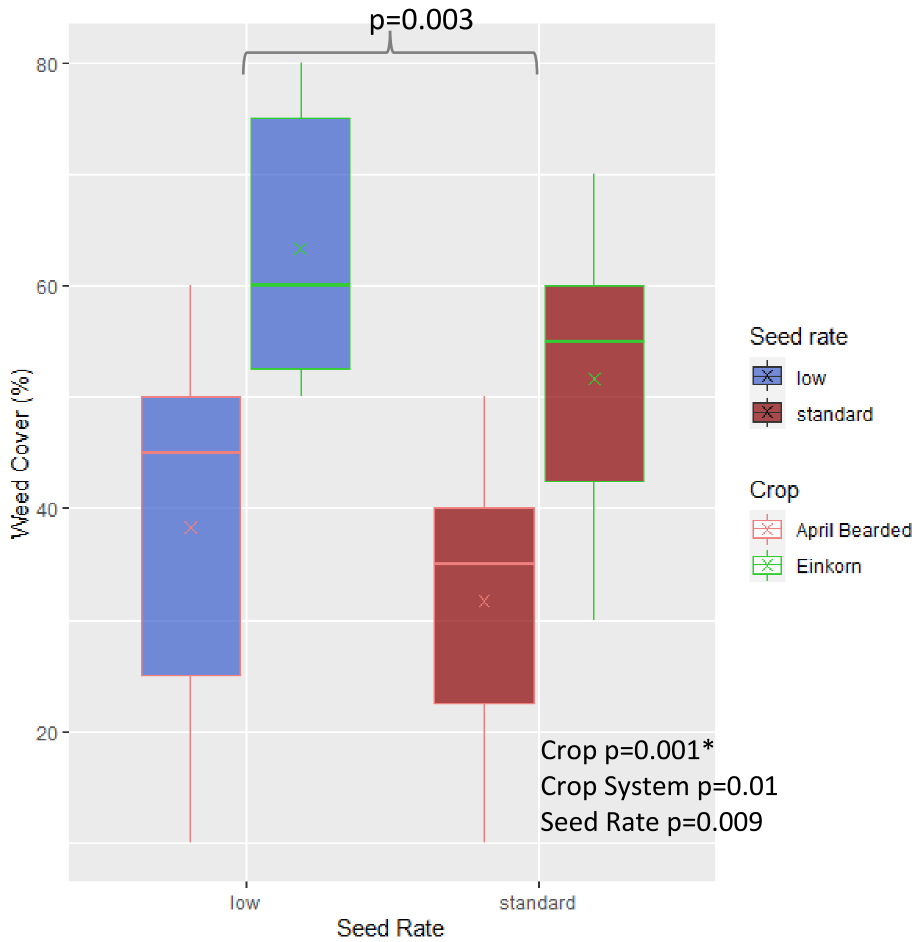

Figure 3.16 Boxplot of weed cover by seed rate and crop. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

Analysis of the relationship between seed rate and weed cover shows a significantly higher weed cover at the lower seed rate with a weed cover of 50.8±6.0% compared to a weed cover of 41.7±5.1% at the higher seed rate.

Our results showed that seed rate had no significant effect on yields, however higher seed rates did show greater weed suppression. Although the seed rate did not affect yield, the implication of reduced weed suppression can have longer term implications. For example, if the seed is being saved, the inclusion of weed seed in the grain can result in greater cleaning efforts and higher potential contamination during processing and in future crops, as well as increased weed burden on the farm the following season. On the contrary, lower seed rates have the potential benefit of reduced lodging risks. Our results both confirm and contradict previous studies. Studies by Baker 1982 found that higher seed rates led to the highest grain yield. Conversely, Matsuyama & Ookawa, 2019, found that decreasing the seeding rate of wheat did not significantly affect the grain yield. In fact, they found compensation effects, with the lower seed rates producing more spikelets per ear and an increased number of grains per spikelet. However, the seeding rate also affected the lodging index, with high seeding rates increasing the risk of lodging. Overall, there are several factors to consider when applying differing seed rates. Ancient and heritage wheats do tend to grow taller than their modern counterparts. Therefore, lodging is already an increased risk. As a taller variety, it can be argued that their weed suppression abilities are greater than those of modern varieties, therefore negating the weed suppression benefits of increased seed rates. Arable land that is exposed to harsh weather conditions, or particularly fertile soils that might encourage increased crop height, may be less suited to increased seed rates of the crops, as lodging risk is greater in these environments.

3.2 Winter 2020

Following difficult drilling conditions and poor seed quality results of the winter trial were generally unreliable with poor germination and establishment (Table 3.20) leading to poor over yields with a grand mean yield of 0.98 ±0.13 t/ha. Differences in crop yield were observed with Welsh landrace Hen Gymro and heritage cv Maris Widgeon yielding significantly higher than Ancient wheat Einkorn (Figure 3.20). Differences were also found for foliar disease (Figure 3.21) and crop height (Figure 3.22).

Crop Establishment

Table 3.20 winter crop establishment plant counts and spring establishment scores

Crop	Plants/m^2	Target seed rate	% Germination	Establishment Score
Hen Gymro	407 ± 47.7	450	0.90	4.6
Maris Widgeon	417 ± 25.6	450	0.93	3
Montana	0	500	0	0
Torth Y Tir	300 ± 15.6	450	0.67	4.9
Einkorn	151 ± 29.2	400	0.38	0.5
Emmer	194 ± 30.4	400	0.49	3.1
Rivet	301 ± 48.3	450	0.75	4.3

Crop establishment was generally poor with Hen Gymro and Maris Widegon establishing best with germination above 90% of the seed rate. Germination and establishment were low for Einkorn and Emmer, falling below 50% of the target seed rate. The modern control variety benchmark failed to establish. Establishment scores in the Spring show a general link with the % germination in the Autumn showing Hen Gymro and Torth y Tir had established best with Emmer and Maris Widgeon showing poorer establishment and Einkorn having the poorest establishment score other than the Montana crop that had failed.

Einkorn, Emmer and Rivet accessions were selected from seed stored for two years following the EU project Diversifood where trials had been conducted to investigate the agronomy of underutilised species with certain accessions selected for multiplication having yielded well under organic farming conditions. Of the commercially available varieties used, the modern benchmark Montana seed had been overwintered due to the difficult drilling conditions of Autumn/Winter 2019/20 and the suspension of the project until Autumn 2020 due to coronavirus. Montana has been shown to be a reasonable modern milling variety for Organic farming and was no longer commercially available by the start of the Autumn trials. The heritage wheat Maris Widgeon that remains in commercial cultivation as a seed crop was unavailable for use in the trials with overwintered seed again being used from ORC trials work. The best seed quality was from the Hen Gymro, provided by a farmer maintaining the crop and saving and managing seed stock each season, and Torth y Tir, the local farm crop, again being cleaned, stored, and saved each harvest for sowing the following season. Both farmers also treat saved seed with vinegar as an effective treatment for the seed-borne disease bunt (*Tilletia tritici*) which can be an issue in organic farming from saving seed.

Yield by Crop

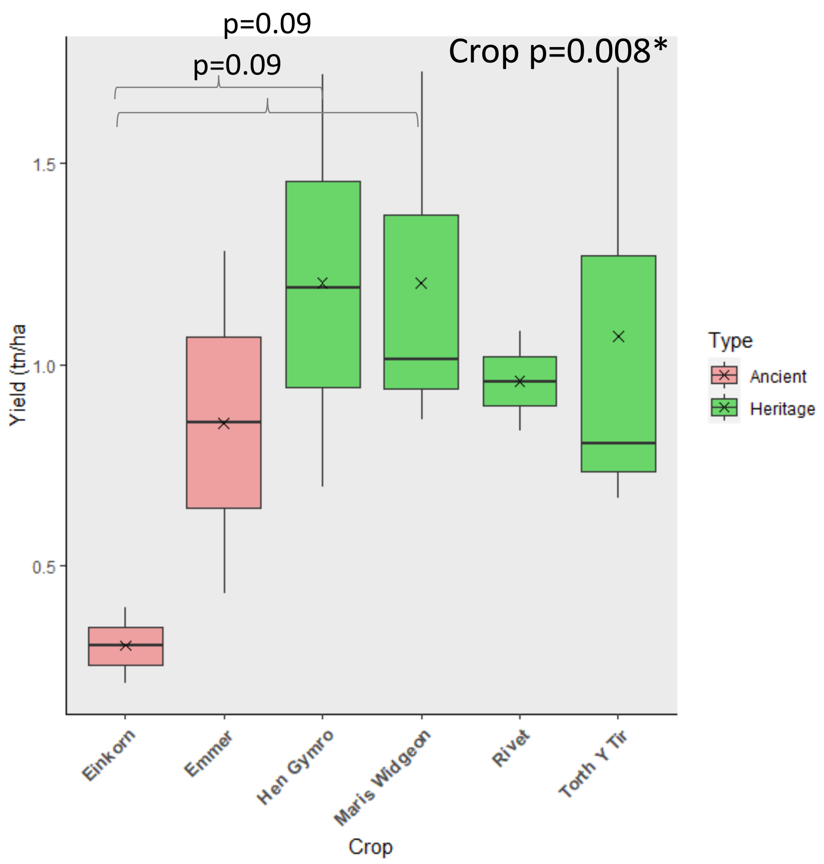

Figure 3.20 Boxplot of grain yield by crop. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

Analysis of the yield by crop revealed a significant effect of crop with the Tukey test revealing Einkorn to have yielded significantly lower than both Hen Gymro and Maris Widgeon. The three heritage bread wheats all yielded on average above 1t/ha with yields of 1.2±0.27 t/ha for Maris Widgeon, 1.2±0.30 t/ha from Hen Gymro and 1.07±0.34 t/ha for Troth y Tir. Rivet wheat was the highest yielding of the alternative wheat species with a yield of 0.96±0.12 t/ha, followed by Emmer at 0.86±0.43 and Einkorn yielding lowest at 0.30±0.09t/ha.

Average crop yields by Farm were 1.51±0.14t/ha at Bug Farm, 0.73±0.18t/ha at Caerhys and 0.69±0.08 at Brawdy, the reduced tillage site. Average weed cover at each trial site was 51.7±3.1% at Bug Farm, 56.5±3.7% at Caerhys and 95.8±1.3% at Brawdy.

Results of the 2020 Winter trials must be treated with some caution since a general poor performance of crops can be attributed to low seed quality and difficult conditions during drilling and establishment. Whilst every attempt was made to use the best quality seed available, in some cases, seed quality fell short of acceptable levels to provide good enough germination and establishment for the trials. This unfortunately means that certain results are less relevant with yields much lower than could be expected from growing ancient and heritage wheats under organic conditions. Under similar weed burdens as the farm sites in this project, trials conducted by The Organic Research Centre on an organic farm in Wiltshire in 2016/17 found an average Einkorn yield of 3.13±0.17t/ha, an average Emmer yield of 2.24±0.25t/ha, and an average Rivet yield of 2.91±0.30t/ha (Costanzo et al 2019). Although not published, this was in comparison to modern milling wheat yields of 1.99±0.18t/ha which showed that under more marginal conditions, ancient and heritage wheat can even outperform modern wheat varieties. A study in Hungary from 2016-2019 using some of the same accessions, showed average yields of around 3t/ha for a set of Einkorn and Emmer genotypes (Bencze et al. 2020). With regards to the 2021 Winter trials, yields by farm show that where the weed burdens were lowest, the soil fertility highest and the drilling conditions best, at Bug Farm, average yields were 1.5t/ha, over double the other two sites, with the Bug Farm yields 107 % and 119% higher than Caerhys and Brawdy respectively.

Grain Quality by Crop

Table 3.21 winter crop average grain quality results (±SEM) Crop effect shows p value obtained through likelihood ratio tests of the model

Crop	Protein %	HLW kg/hl	HFN /s	TGW /g
Hen Gymro	10.8 ± 0.72	68.5 ± 1.99	292.7 ± 10.1	35.3 ± 2.4
Maris Widgeon	10.6 ± 0.52	67.1 ± 2.5	277.7 ± 8.1	33.5 ± 2.4
Torth Y Tir	10.9 ± 0.54	69 ± 2.3	241.3 ± 15.9	34.7 ± 3.5
Einkorn	10.8 ± 1.41	67.1 ± 1.5	305.5 ± 6.5	34.6 ± 2.9
Emmer	10.8 ± 11.14	57.2 ± 1.1	247 ± 44	34.4 ± 3.3
Rivet	11 ± 1.31	65 ± 5.5	295 ± 1	32.8 ± 2
Crop effect	p=0.10	$p=9.1e^{-5}$	p=0.03	p=0.12

Analysis revealed a trend but non-significant effect of crop on protein content and thousand grain weight. Analysis of Hagberg falling number showed an effect of crop but Tukey pairwise comparisons found no significant difference between crops. There was a significant effect of crop on hectolitre weight with the pairwise comparisons showing Emmer to have a lower HLW than all other crops (Hen Gymro, p=0.003; Maris Widgeon p=0.005; Torth y Tir p=0.002; Einkorn p= 0.004; Rivet p=0.05). The einkorn result for HLW and TGW may be unreliable as the small grain would be expected to have the lowest HLW and TGW of all crops tested. Torth y Tir was found to have the lowest Hagberg falling number at 241.3 ± 15.9 seconds and the only crop to fall outside of the typical HFN specification of 250-350 seconds.

Results of grain quality may be unreliable due to contamination with some unexpected results. One result of note was the low Hagberg falling number of Torth y Tir but this may be linked to the fact that the crop was the earliest of the winter wheats grown, and therefore was particularly impacted by the delayed harvest and generally wet pre-harvest conditions that would have increased the risk of preharvest sprouting relative to the other crops.

Photo of winter wheat ear morphology from Winter trials 2020/21, from left to right Einkorn, Emmer, Rivet, Hen Gymro, Torth y Tir, Maris Widgeon.

Foliar Disease

Crop Septoria $p=6.29e^{-10}$***

Crop Yellow Rust $p= 3.35e^{-7}$***

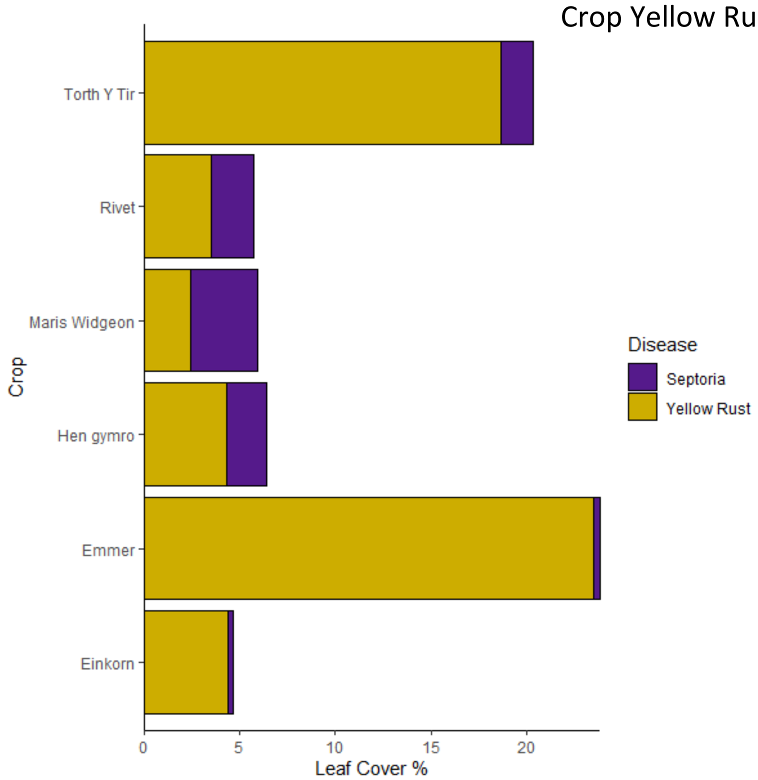

Figure 3.21 Bar chart of foliar disease at GS65 by crop. Global p values obtained by likelihood ratio tests of the model. Pairwise comparisons obtained through Tukey post-hoc test.

Analysis showed significantly higher Septoria in Torth y Tir, Rivet, Maris Widgeon and Hen Gymro compared to Einkorn and Emmer, as well as significantly higher Yellow rust in Torth y Tir and Emmer compared to Rivet, Maris Widgeon and Hen Gymro.

As well as yield, many measured variables linked to good establishment and target plant populations such as crop cover, vigour and weed cover were considered unreliable and not included in the report. There were however traits not so closely linked to plant population such as height and foliar disease that can still be informative. Generally low plant populations may also have reduced the risk of lodging with none observed for the winter trials despite an inclination for some ancient and heritage crops to lodge and with a strong correlation between crop height and lodging in wheat (Navabi et al.). The high weed burdens and low fertility of the trial sites also contributed to lower crop heights than may have been expected. The study by Costanzo et al. showed that the traits of ancient wheats are affected by differences in fertility and by reduced tillage, with the increased weed pressure and lower fertility associated with second cereal position in the rotation and reduced tillage leading to shorter crops. The results in our experiment show that the Emmer had the highest severity of yellow rust which is consistent with other research on the crop with the study by Bencze et al finding a consistent susceptibility to yellow rust from all the Emmer cultivars tested. The Torth y Tir population also showed quite high levels which might be a result of its origins from France, where it was exposed, and hence adapted to, specific strains of pathogens and hence shows a general susceptibility to the specific yellow rust races encountered in Britain.

Crop Height

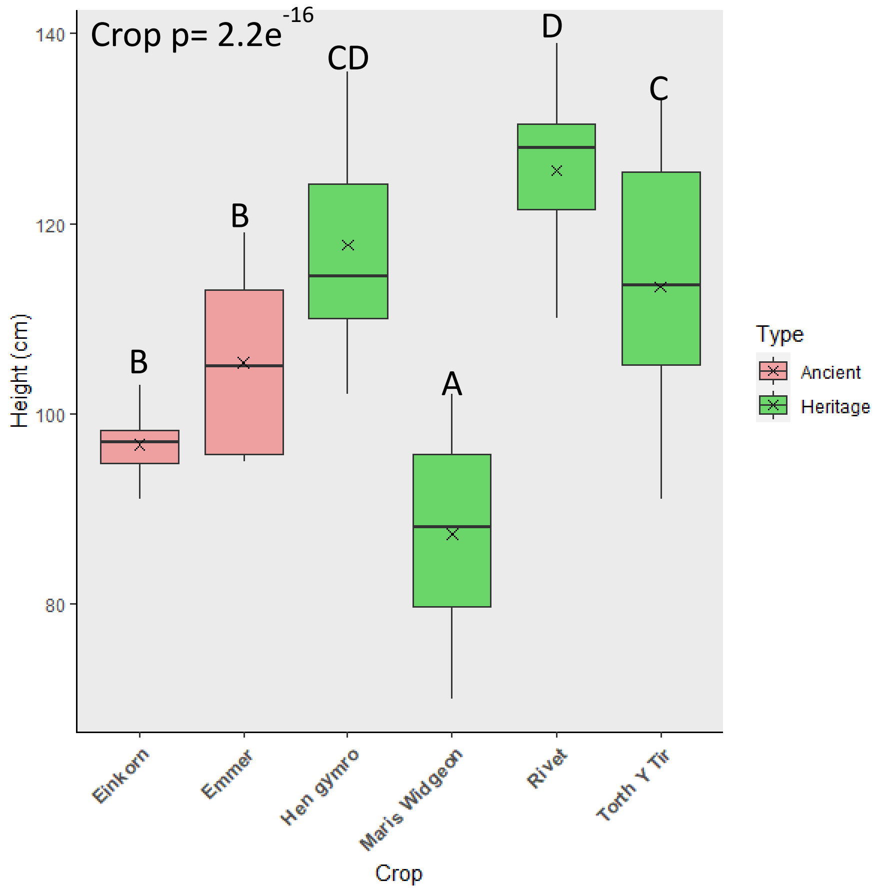

Figure 3.22 Boxplot of crop height. Global p value obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test and represented on the plot by letters. Crops with different letters are significantly different from each other.

Analysis of the crop heights showed a significant effect of crop with Maris Widgeon, the only variety, the shortest of all the crops grown at 87.3±3.0cm. Rivet was found to be the tallest crop at 126.1±3.7cm. The three wheat landraces Hen Gymro, Torth y Tir and Rivet were taller than the variety Maris Widgeon and the two ancient wheats Einkorn and Emmer. Average crop heights by Farm were 121±3cm at Bug Farm, 102±3cm at Brawdy and 99±3cm at Caerhys.

3.3 Spring 2021

The results from the trial provide a reasonably reliable indication of what to expect from ancient and heritage crops in terms of yield and quality and certain other traits. The ancient and heritage wheats were significantly taller than the modern benchmark variety, Mulika. Lodging only appeared to occur at one site and uncharacteristically in the Mulika crop which was completely flattened alongside the Atle. This result is an anomaly and likely due to animal damage or other undescribed factors, therefore these lodging results were not included in the report. Weed suppression was also highest amongst the ancient and heritage crops, apart from Emmer. This result is likely due to the poor germination from the Emmer crop owing to low seed quality, with a lower density of plants meaning that crop competition was reduced allowing for greater weed growth and cover. The heritage wheat April Bearded showed a greater level of foliar disease than the modern variety Mulika, consistent with the results in 2019, although yellow rust severity was much lower generally in 2021.

With a grand mean yield of 1.97±0.30 t/ha, the trial did not show significant yield difference by intercropping or by crop (Figure 3.30) with modern variety Mulika yielding equivalent to heritage cultivars April Bearded and Atle and ancient wheat Emmer. No effect of intercropping with beans was found on grain quality but crop differences were observed. April Bearded and Emmer were found to have a significantly higher protein content than Atle, with Emmer also showing higher protein than the modern variety (Figure 3.31). Differences between Crops were found for foliar disease (Figure 3.32) and crop height (Figure 3.33). The factors of intercropping and crop were found to have an effect on weed cover (Figure 3.34)

Crop Establishment

Table 3.30 spring crop establishment plant counts and spring establishment scores

Farm	Crop	Target seed rate/ m2	Plant count/m2	% Germination	Establishment Score
Caerhys & Bug	April Bearded	500	353 ± 3.12	0.71	5
	Atle	500	440 ± 47.9	0.88	4.8
	Mulika	500	481 ± 20.8	0.96	5
	Emmer	400	237 ± 5.21	0.59	3.5
	Maris Bead bean monocrop	50	39.5 ± 3.5	0.79	4.8
Whitesands	April Bearded	500	60	0.12	1
	Atle	500	38	0.08	1
	Mulika	400	19	0.05	1
	Emmer	500	92	0.18	1
	Maris Bead bean monocrop	50	0	0	0

Crop establishment was generally good at Caerhys and Bug farm but was very poor at Whitesands with near crop failure. At the two sites where establishment was good, Emmer showed the poorest germination around 60% with April Bearded around 70% germination. The highest germination was observed for Mulika at 96%.

Yield by Crop and Cropping System

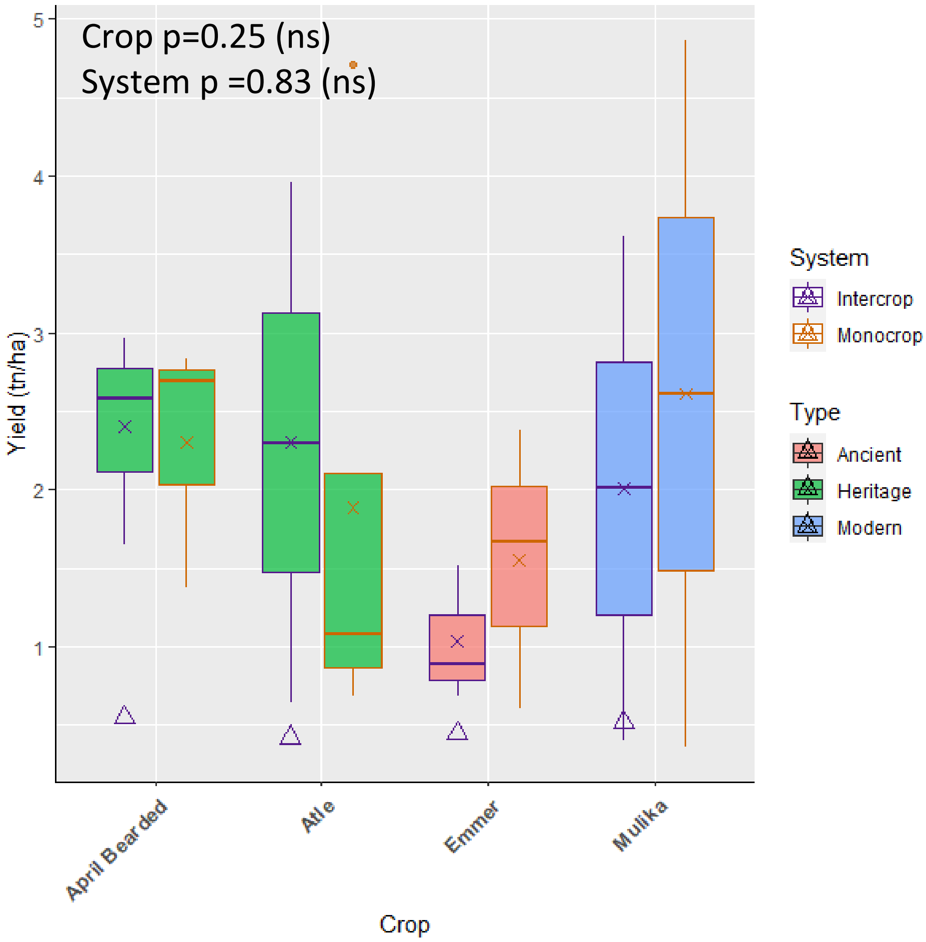

Figure 3.30 Boxplot of grain yield by crop and cropping system. Global p values obtained by likelihood ratio tests of the model. Purple triangles show additional bean yield in t/ha from the intercropping system.

Analysis showed no significant effect of crop or system on the grain yield of the spring wheats. The grand mean yield of the spring wheat was 1.97 ± 0.30 t/ha. The average yield of April Bearded was 2.35±0.27 t/ha, Mulika was 2.31±1.14t/ha, Atle was 2.03±0.74t/ha and Emmer was 1.29±0.28 t/ha.

The beans averaged a yield of 0.49±0.07 t/ha with yields ranging from 0.42 ± 0.17 t/ha grown with Atle to 0.55 ± 0.05 t/ha with April Bearded. The grand mean yield of monocropped wheat was 2.03±0.44t/ha and for intercropped wheat was 1.89±0.41t/ha. The addition of the bean yield to the intercropped wheat yield gives a total mean grain yield of 2.38±0.47t/ha for the intercropping system although the effect of the intercropping system on total grain yield was found to be non-significant (p=0.75) and wheat crop also had no effect (p=0.26).

The overall yield by crop showed that April Bearded, Atle and Emmer had similar yields to Mulika, with April Bearded yielding highest and Emmer lowest. The Emmer yield was most likely due to the poor initial germination of the crop linked to low seed quality, with the seed below specification grain from a mill in Wales. The result from Spring 2019 was repeated, with the April Bearded matching the yield of the modern variety under organic conditions. This provides evidence for its use in organic systems, particularly when accompanied with the associated height and vigour, both of which are good for weed suppression. The Swedish heritage variety Atle also yielded equivalent to Mulika.

Protein by Crop and Cropping System

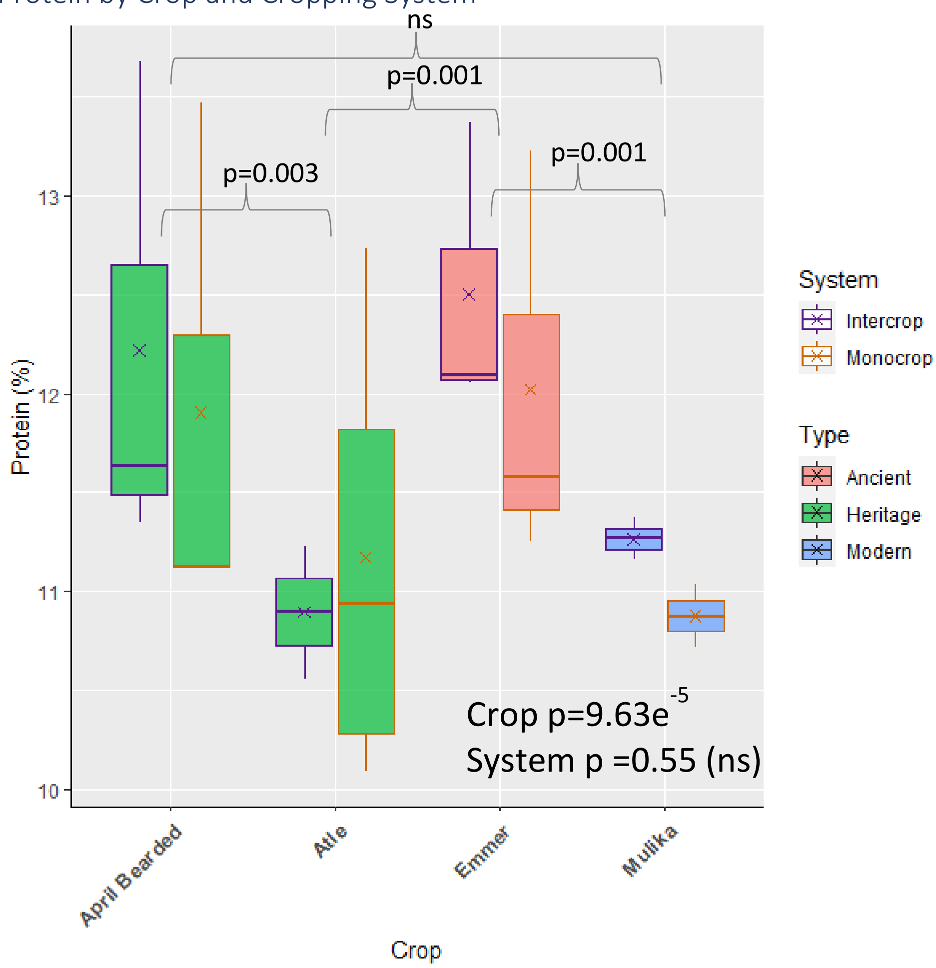

Figure 3.31 Boxplot of grain protein by crop ad cropping system. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

Analysis showed a significant effect of crop but not of system on the protein content of the wheat grain. April bearded had a significantly higher protein content than Atle ($p=0.003$) whilst the Emmer had a significantly higher protein than the Atle ($p=0.001$) and Mulika ($p=0.001$).

Grain Quality by Crop and Cropping System

Table 3.31 spring crop average grain quality results (±SEM) Crop and System effect shows p value obtained through likelihood ratio tests of the model

Crop	Protein %	HLW kg/hl	HFN /s	TGW /g
April Bearded	12.1 ± 0.485	72.7 ± 1.09	362 ± 8.39	38.3 ± 0.972
Atle	11.1 ± 0.397	73.2 ± 1.74	353 ± 10.5	35.8 ± 0.998
Mulika	11.1 ± 0.397	71.2 ± 2.07	335 ± 19.1	39.4 ± 0.603
Emmer	12.3 ± 0.353	52.2 ± 1.65	285 ± 13.3	36.5 ± 1.67
Crop Effect	$p=9.63e^{-5}$	$p=1.46e^{-10}$	$p=1.39e^{-5}$	p=0.04
System Effect	p=0.55	p=0.28	p=0.33	p=0.36

Analysis of all four grain quality metrics revealed a significant effect of crop but no system effect. For hectolitre weight pairwise comparisons using Tukey's test showed a significantly higher HLW for April Bearded (p=0.0001), Atle (p=0.0001) and Mulika (p=0.0001) than Emmer. A similar result was found for Hagberg falling number with April Bearded (p=0.001), Atle (p=0.003) and Mulika (p=0.016) all showing higher values than the Emmer wheat. Despite the likelihood ratio test showing a significant effect of crop, the pairwise comparisons using the Tukey test did not show any of the crops to have a significantly different TGW, although there was a strong trend for Mulika to have a higher TGW than Atle (p=0.07)

For the other grain quality factors, HLW, HFN and TGW, none were affected by the intercropping, but crop was significant. Emmer had significantly lower HLW and HFN than all other varieties and this result has been confirmed in the literature (Løes et al., 2020). None of the varieties had significantly different TGW. As in 2019, the April Bearded showed a high protein content, significantly higher than the Atle, despite similar yields which again suggest that April Bearded may show the trait of GPD. The Emmer also showed high protein values, significantly higher than Atle and Mulika, as the Emmer yielded poorly, this is likely due to the yield-protein trade off.

The yield in this experiment was not affected by the intercropping of beans, although the addition of beans provides an opportunity for increased overall cash-crop yield. The bean intercrop did not increase the protein content of the wheat, although as before, the presence of beans in the overall grain yield could increase the total harvested protein, which might be of relevance to livestock farmers. The presence of beans did have a significant effect on weed cover, with the lower weed cover under intercropping compared to the monocropping. This may have been due to a greater canopy architecture complementarity between crops offering enhanced competition and/or a slight trend in increased wheat crop height under intercropping that may have also contributed to greater weed suppression. This enhanced weed suppression from intercrops due to synergism has been found in other studies including Szumigalski, 2005.

The use and benefits of intercropping should not be determined by our experiment alone, with the typical benefits of cereal-legume intercropping well documented (Zhang et al.,2019); increased yields due to species complementarities, increased overall protein and reduced requirement for artificial N fertilizer. Reynolds et al., found the introduction of legume intercropping increased the productivity and nitrogen output of the wheat, in the absence of nitrogen fertiliser, with total biomass in the intercrops giving land equivalent ratios of as high as 1.54. This is supported by Xiao et al., who found the growth rate, biomass and yield of the wheat were all increased when intercropped with faba bean relative to the monocrop. In addition, Donwell et al., found that both nitrogen uptake and grain protein were increased in the intercropping system compared to the monocrop. Studies by Zhang et al., 2019 have also found that intercropping reduced disease incidence in both wheat and beans by

45% on average. In our experiment bean seed rates were low as wheat was the focus crop, but a greater density of beans may have influenced our results.

Foliar Disease

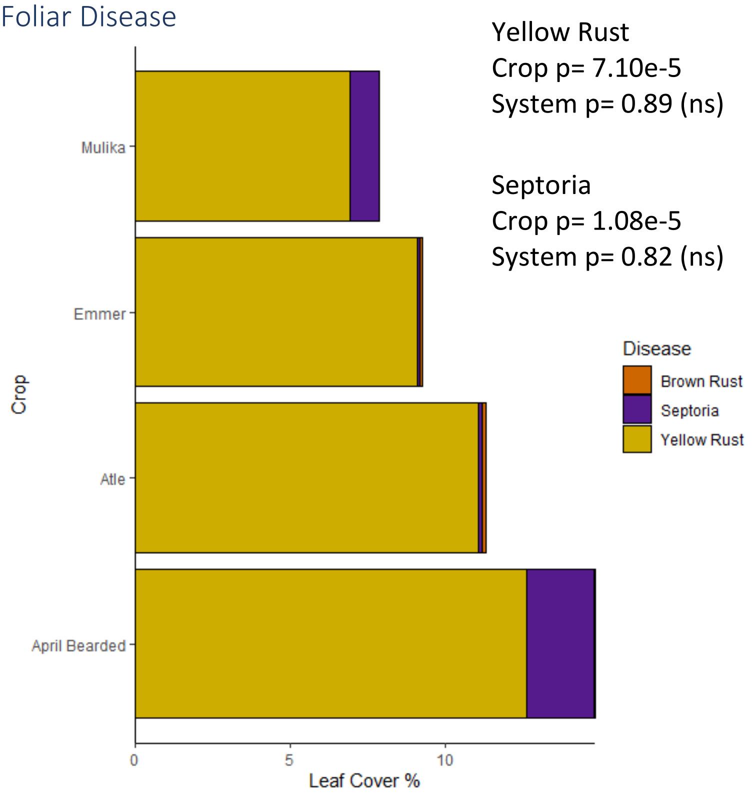

Figure 3.32 Bar chart of foliar disease by crop ad cropping system. Global p values obtained by likelihood ratio tests of the model. Pairwise comparisons obtained through Tukey post-hoc test.

Analysis shows April Bearded has significantly higher Septoria than the other crops (Atle, Emmer, p=0.0001; Mulika p=0.03) and higher yellow rust than Emmer (p=0.03) and Mulika (p=0.002). Tukey's test also shows Atle had higher yellow rust than Mulika (p=0.008).

Crop Height

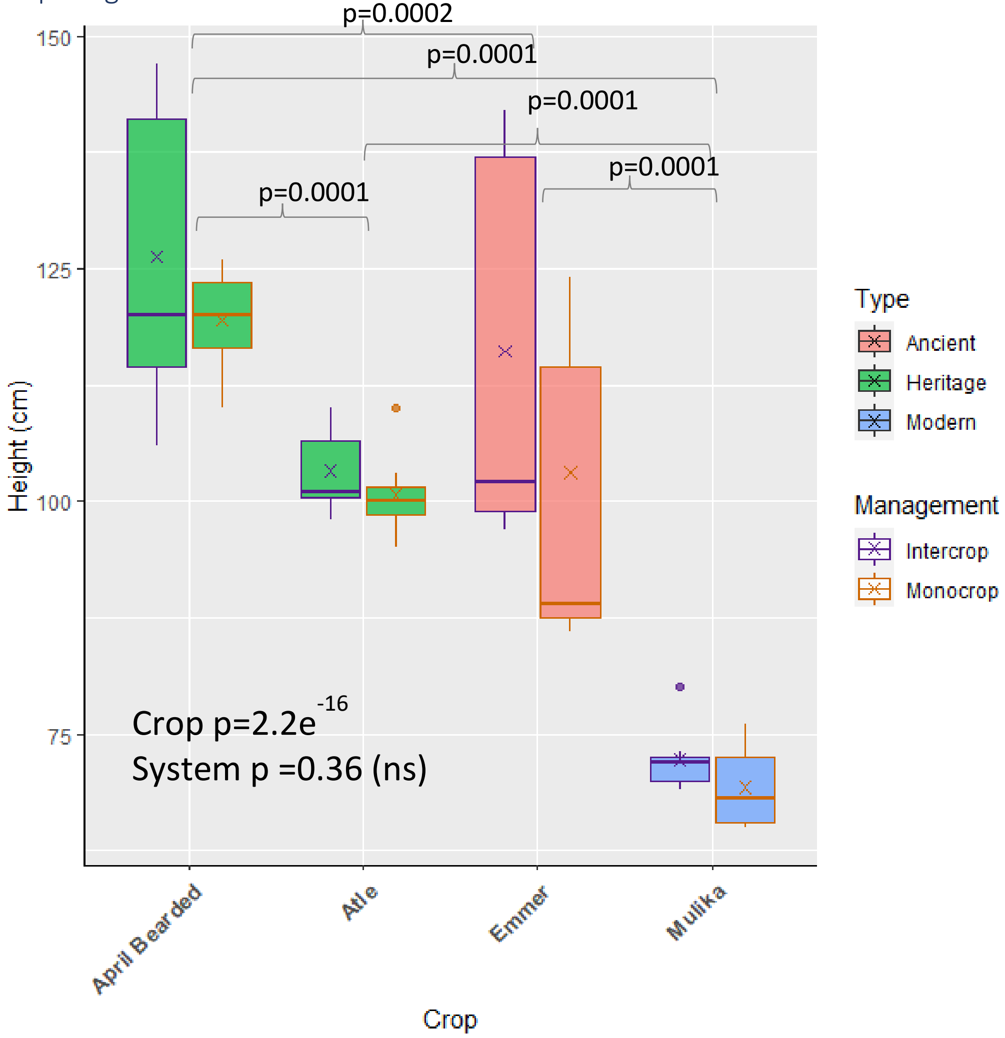

Figure 3.33 Boxplot of crop height by crop and cropping system. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

The mean height of April Bearded was 123±3.3cm and was found to be significantly taller (p=0.001) than the other heritage wheat crop Atle which was 102±1.3cm tall and the ancient wheat Emmer which was 108±5.4cm. Both heritage wheats and the ancient wheat were found to be significantly taller (p=0.0001) than the modern wheat Mulika. Cropping system was not found to affect crop height although there was a consistent observation that all wheat under intercropping conditions was on average taller than wheat grown in monoculture.

Although height was not significantly affected by the intercropping, in general the crops were taller in the intercrop system. This could be due to several factors: improved microclimates from the presence of bean plants, the height of the beans encouraging height competition from the wheat crops, or the addition of nutrients in the soil from the beans as nitrogen fixers. As with the clover undersowing, intercropping a cereal with a grain legume may have rotational benefits in terms of a legacy of fertility left from the legumes. In Eastern Europe, Babulicova 2016, found that the TGW of wheat grain was significantly higher when planted after intercropped peas in the rotation compared to after winter barley.

Weed Cover

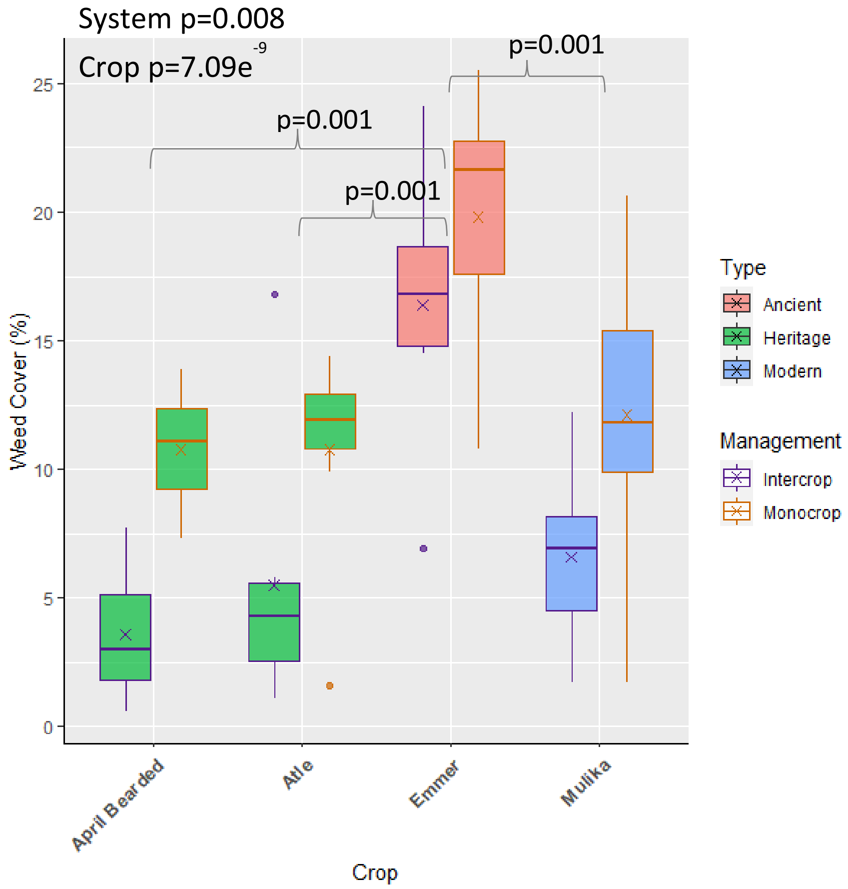

Figure 3.34 Boxplot of weed cover at anthesis by crop and cropping system. Global p values obtained by likelihood ratio tests of the model and pairwise comparisons obtained through Tukey post-hoc test.

There was a small but significant effect of crop system as a factor with weed cover significantly lower (p=0.008) for the intercrop, 8.0±1.2% than the monocrop, 13.4±1.1% although the Tukey's test found only a non-significant trend (p=0.095). An effect of crop was also found with Emmer having significantly higher weed cover than all other crops. The average weed cover of Emmer was 18.1±1.4% with weed cover of April Bearded 7.2±1.2%, Atle 8.1±1.4% and Mulika 9.3±1.5%.

3.4. Baking trials Spring and Autumn 2021

Baking trials were held in Spring 2021 at the Torth Y Tir bakery by Rupert Dunn. The grain used for the baking trials was not taken from the harvested field experiment in 2019, therefore the results are not directly linked to the field trials. However, several of the crops used in the baking trials were the same as those used in the field trials, notably; Mulika, Hen Gymro, Torth Y Tir and Atle. The results of these baking trials can be seen in Annex D although of note; Torth Y Tir had the top average score based on the six categories: Tastes and flavours, odours and aromas, crust, crumb, mouthfeel, and appearance. The modern variety Mulika ranked third of nine crops tested.

A second round of baking trials were completed in Autumn 2021, using the grain taken directly from the field trials to evaluate end use characteristics and suitability. These trials were carried out by Andrew Neagle from the Anuna Craft Bakery. The report of these trials is available in Annex D. The results of the trials showed that of ten crops tested, Mulika was found to be the highest-ranking variety in terms of baking and tasting, with Rivet second. The traditional Welsh landrace Hen Gymro came last in the Anuna baking trials. Feedback from the trial suggests some issues with contaminated grain which may have affected the results. Performance of some crops was consistent across the two baking trials but other crops were inconsistent performers, most notably the modern land race Torth y Tir and the old Welsh landrace Hen Gymro that ranked top and fourth respectively in the Torth y Tir bakery trial and seventh and last in the Anuna bakery trial. It should be noted that milling method, flour type and the bread making process all have a large effect on baking properties and this may account for some of the differences as well as the effect of growing environment on grain quality.

3.5 General Considerations

Beyond the specific field trial results there are several other points of consideration raised during the project.

Crop Diversity

An important point to stress is that for ancient wheat species there are many different genotypes and whilst there is some similarity and certain species traits, there exists a wide variation in traits and characteristics amongst them. There are studies for instance testing more than 100 different accessions of a certain species and that the Einkorn and Emmer used in the present study represent only a tiny fraction of genotypes that exist. The wide variation within species highlights the need for these underutilized crops to be properly evaluated in terms of agronomic performances of different genotypes, especially considering resistance to pathogens and adaptation to specific climatic environments since certain genotypes will be better suited to cultivation under specific environmental conditions. The main barrier to testing and evaluating different genotypes is the availability and access to seed.

Seed Supply

The trials have highlighted the issues of accessing seed and of seed quality when it comes to cultivating non-commercially available crops and from trying to implement short, local supply chains. Seed quality issues experienced for the trials show the risks of using non-commercially available seed for the project but more generally for those farmers wishing to cultivate ancient and heritage wheats. Gene banks offer one source of seed that can be accessed by farmers and comes with a Material Transfer Agreement (MTA) that outlines any restrictions and the rules associated with using such seed. The number of seed provided is small and may take several years before quantities are large enough for commercial activities on farm.

Infrastructure and Market

There are several logistical factors that need to be considered when growing ancient wheats. For example, the characteristic that sets them apart as ancient wheat also creates a need for additional processing, requiring de-hulling before they can be milled. This means the additional expense and maintenance of a de-huller. One consistent issue connected to the growing of ancient wheats in Pembrokeshire by the participating farmers in the project has been the difficulty in accessing an affordable small scale dehuller and the lack of dehulling capacity in the region. With the current low levels of arable farming and small grain production in Wales, there is also a general lack of suitable infrastructure to effectively clean, store and process the grain. Before the use of ancient and heritage grains can be scaled-up from an experimental scale, the infrastructure needs to be in place to ensure the grain can be stored and transported. In addition, one important aspect is to test grain entering the food chain for mycotoxins with legislation setting maximum levels to protect consumer safety. Testing can be expensive but is a legal requirement (Commission Regulation (EC) No 1881/2006).

Further along the chain, whilst the supply of grain can be created, the demand must also be in place. The baking tests and bakery involvement in the project has been invaluable in creating local interest as well as determining the suitability of ancient and heritage grains for bread making. Since this process is also vital in linking field performance to performance in the bakery thereby taking a whole chain approach to wheat production. There needs to be a concerted effort to encourage the widespread adoption of ancient and heritage wheat into everyday diets. Part of this process may be the promotion of the potential health benefits and nutritional qualities of these ancient and heritage crops although this was beyond the scope of this project.

Nutritional qualities

The nutritional benefits of ancient and heritage wheats against modern varieties are still a topic under some dispute. As aforementioned, one of the issues with categorising the health benefits of ancient grains is that they are not a homogenous category (Bordoni et al., 2016).

Studies by Dinu et al., 2018 on ancient wheat varieties have shown convincing beneficial effects linked to cardio-metabolic diseases such as lipid and glycaemic profiles, as well as the inflammatory and oxidative status. This is matched with a study by Hidalgo & Brandolini, 2013 that found Einkorn to be rich in antioxidants, zinc and iron and it showed anti-inflammatory benefits.

Although some health benefits have been found in ancient wheat species, Shewry 2018 concludes that further research is required on a wider range of genotypes of ancient and modern wheat species.

4. Conclusion

Ancient and heritage wheats do represent an opportunity for crop system diversification and have shown promising results from the trials in terms of grain yields, grain quality and beneficial crop traits such as weed suppression; however, they require adapted agronomy compared to modern varieties and management practices should be carefully considered. Despite their potential there come some risks in terms of lodging risk and susceptibility to disease, highlighting a need to test genotypes to find the best adapted to any given growing environment and testing genotypes should also include assessment of end use characteristics to confirm market suitability. The project highlighted seed supply issues and a lack of infrastructure as key barriers to the uptake of crop diversification using ancient and heritage wheats.

5. Recommendations

The project has confirmed the potential to successfully grow heritage and ancient wheat crops in Southwest Wales and through the farmer led approach has also revealed the key issues and barriers to be considered and addressed for wider scale uptake of the use of ancient and heritage wheat for crop system diversification. The project makes the following recommendations.

- Seed supply and maintenance should be considered carefully with sources of high-quality seed limited, risks from repeated seed saving and only small quantities of seed available from gene banks.
- The growing of ancient and heritage wheats should be focussed on marginal land and under organic and low input farming conditions where benefits of growing them can be maximised over the alternative modern varieties without loss of productivity.
- Numerous genotypes exist for ancient and heritage wheats and despite some within-species similarities, the wide variation of traits and characteristics necessitates testing to identify locally adapted genotypes.
- Management factors need to be refined on farm but the practices of undersowing with forage legumes and intercropping with grain legumes can be used to enhance agroecosystem services including weed suppression and improved soil fertility.

- Infrastructure needs to be in place in terms of storage and processing with small-scale de-hulling capacity a limiting step to the production of ancient wheats.
- Farmers should work with end users to secure a market and evaluate crops for end use potential and consumers should be engaged in product testing to help promote the demand for alternative crops
- Additional research should be focussed on the nutritional value of ancient and heritage crops compared to modern varieties and the effects of environment and crop management on the nutritional profile should be investigated.
- Ancient and heritage wheats represent a source of genetic diversity for cropping system resilience, enhanced agrobiodiversity and future crop breeding and cultivar development.

6. Acknowledgments

The project has received support and in-kind contributions from the following individuals/organisations; The Welsh Grain Forum representatives Steven Jacobs (OF&G), Anne Parry (Fen Ganol) and Andy Forbes (Brockwell Bake); Host farmers Wyn, Graham and Sarah for providing trial sites; Contractors James, Mike and Alun for drilling and harvesting the trials; Farmers Mark and Fred for supplying seed for research purposes.

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9. Appendix

Annex A - Establishment Scores

Establishment Score

This is a 1-5 visual score based on the germination and initial establishment of the crops.

1- Failed crop

2- Few patches of established crop

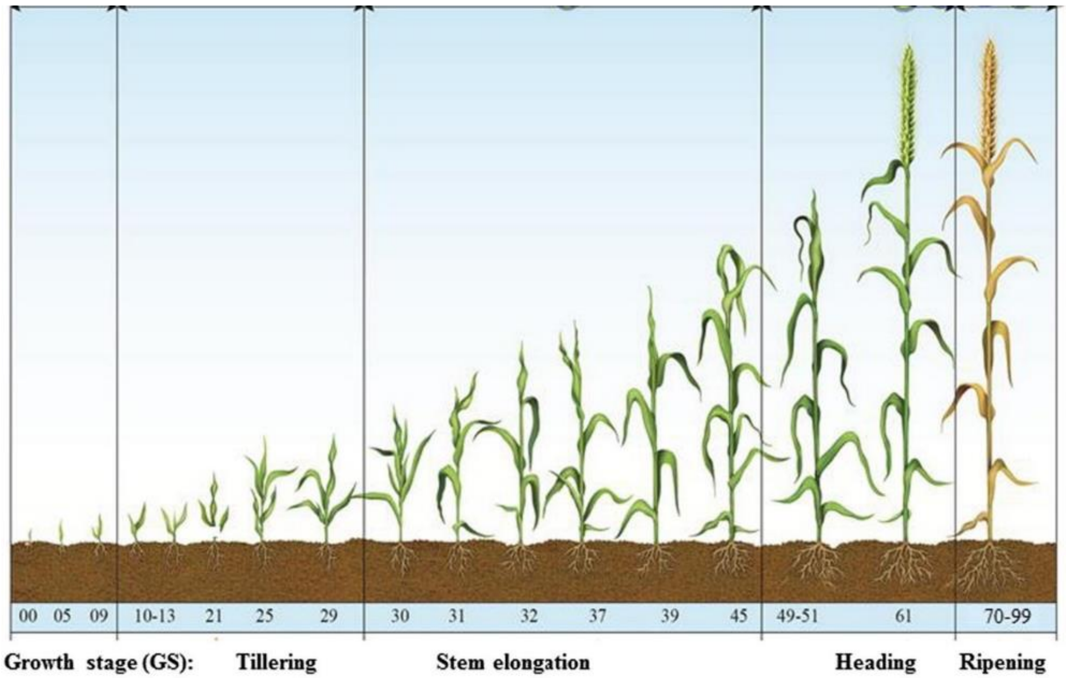
3- Patchy establishment

4- Few patches of poor establishment

5- Full establishment

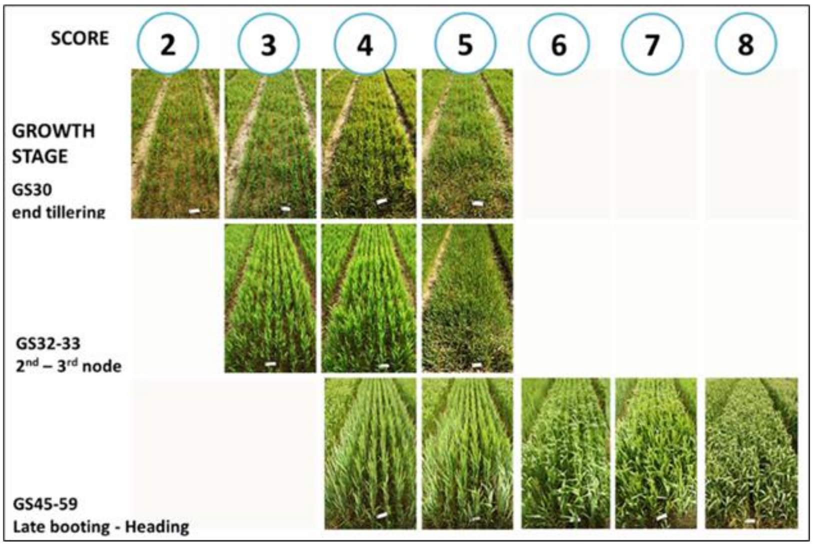
Annex B - BBCH Growth Stages

BBCH Growth Stage assessment



Annex C - Institut Technique de l'Agriculture Biologique (ITAB) Vigour scoring

ITAB Vigour score



This is a visual scoring system designed by ITAB to assess above ground biomass using a numerical scale from 1-9. In this assessment the crop height and cover are both taken into consideration. The score is determined whilst looking in the direction of the row at 45 degrees.

Annex D - Baking Trials

Baking trials Spring 2021

European Innovation Project

Baking Trials Report

Rupert Dunn

This report details the baking trials and conclusions from the EIP trials project.

Due to strategic challenges with the crop trials in 2020, the baking trials looked at a number of heritage varieties bought in. Most of these were grown in the UK with some from Italy. The baking trials took place on May 29th near St Davids, Pembrokeshire with the Torth y Tir bakery facilities hired for the occasion.

We trialled the following varieties:

1) Old Kend Hoary - An old English variety, see link above.

2) Millers Choice - A collection of old English varieties developed by Andy Frobes.

3) Mulika - A modern spring wheat

4) Tilimilia - An ancient Sicilian Durum wheat

5) Rusello - Balkan/Black Sea Durum

6) Perciasacchi - Ancient Khorrasan variety

7) Hen Gymro - Old Welshman

8) Atle - Spring heritage Swedish cultivar

9) Torth y Tir (TyT) population - Diverse winter population including French Varieties and Hen Gymro.

Baking trial and scoring methodology

All the grain was milled fresh on site with the same stone mill. All the doughs were made using their own sourdough leaven.

The scoring was made under the following headings:

- Tastes and flavours
- Odours and aromas
- Crust
- Crumb
- Mouthfeel
- Appearance
- Bread Harmony (bonus category)

The tasting was conducted blind, so each taster did not know which variety they were tasting.

For the full tasting results please click here

Via the link you will find results from each section and total score results. Hover over the icons to the right and you can enlarge: - pictures of the loaf - comments from tasters and a graph of results.

Overall, the Torth y Tir winter population bread was the most popular.

Results and Conclusions

The two overriding qualities we are looking for when trialling new varieties is flavour and crumb. These breads were made using artisanal techniques and are not considered suitable for large scale commercial manufacturing of bread.

Looking at the results, the two top average scores were the TyT wheat and the Perciassaci.

The flavours of both varieties are distinctive with the Perciassaci particularly distinctive in its flavour, aroma and yellow colour. Though it does not produce the volume of crumb that the TyT loaf did.

With regard to these results we need to keep two determining factors in mind:

1) Consumer compatibility

2) Agronomic versatility for our local area.

With regard to 2, the TyT is the clear leader due its ability to grow well in West Wales. The ability of the Perciassaci to do this is unknown as this seed was grown in Italy. It is highly unlikely that this variety would grow as well in West Wales as it is specifically adapted to Mediterranean conditions.

Regarding consumer compatibility, we are seeing a growing demand across the UK for more stoneground and speciality flours, especially during the lockdowns. This is demonstrated in this news article and many others.

It is worth noting that the modern variety Mulika showed up well in the trials coming third. People enjoyed the crust and there were good reports on the flavour too.

The conclusion from these trials therefore is that given we know the ability of the TyT heritage wheat to grow well in West Wales and combined with its high scoring in the trials, this would indicate that this wheat would be best placed for scaling up production and providing to more people in the area and further afield in Wales.

In the search for more localised, nutritional and distinctive foods in Wales, this is a valuable finding.

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Baking trials Autumn 2021

BECWS CREFFT ANUNA CRAFT BAKERY

Grawn Hynafol – Heritage Grain Trial

Milling and Bakery Report

September 2021

Prepared by Becws Crefft ANUNA Craft Bakery

Abstract

In September 2021, Becws Crefft ANUNA Craft Bakery was recruited to the Grawn Hynafol – Heritage Grain Trial, where we had the opportunity to mill, bake and taste test grains grown in Pembrokeshire. Ten grains were harvested, with nine of these suitable for testing as part of the trial. The grains included ancient, heritage, population, and modern varieties. The milling, dough production and baking was unblinded and the methods used were the same for each grain. The tasting trial was a blinded event, where members of the public were asked to view and sample each grain and complete a Score Card developed by Andy Forbes of Brockwell Bake.

The collated results of the tasting trial demonstrated that Mulika, a modern wheat suitable for organic production was most popular when collating scores for appearance, smell, taste, texture and overall rating. In second place was Rivet, a heritage grain. A number of recommendations have been detailed in the report, and it is our hope that this trial can act as catalyst for an emerging, vibrant, viable grain growing revolution in the west of Wales.

Introduction

Becws Crefft ANUNA Craft Bakery is based in Capel Dewi, near Llandysul. ANUNA has been supplying completely handmade sourdough breads and viennoiserie to residents and visitors for the last three and a half years. Working from our small farm we supply farmers markets and wholesale customers. We are keen to work with local farmers to enable short supply chain and local food sovereignty. The Heritage Grain Trial, we believe, supports learning and progress towards the development and reinvigoration of a west Wales grain economy.

ANUNA's role in the trial has been fourfold:

1. Milling the trial grains

2. Dough production

3. Baking

4. Running a tasting trial.

Through this report we will set out our aims, the methods used through the trial, our observations at each stage of our involvement, finishing with our conclusions and recommendations.

Aims

Our aim was to trial ten different grains, grown, harvested, and processed (dried) in Pembrokeshire. The grains were unblinded during the milling, dough production and baking phases, but were blinded for members of the public during the tasting trial.

The grains provided to be trialled were:

April Bearded

Atle

Einkorn

Emmer - Spring

Emmer – Winter

Hen Gymro

Maris Widgeon

Mulika

Rivet

Torth y Tir population

At each stage of the trial, we made no adjustments or interventions based on the characteristics of the dough. We maintained a consistent method throughout the trial and worked with 100% trial grain with no inclusions such as white high protein flour. Throughout the trial we used the sourdough long ferment retarded method, with no addition of baker's yeast.

Our aims were to test:

- The milling qualities of each grain, using a tabletop mill

- How the dough performed using our standard commercial dough making method

- How the dough performed during the baking process

- The public response to the appearance, smell, taste, texture, and overall view of the baked bread.

Method:

Milling the trial grains

Following collection from Real Seeds, Newport where the grain had been processed and dried, the grains were stored at ambient temperature in paper sacks in the bakery. Twenty-four hours prior to the dough production each grain was observed in its raw form, milled and then sifted to remove some of the coarse bran.

Prior to milling, notes were taken on the contamination with other seeds or chaff.

The grains were then milled using a Mockmill Professional 200 tabletop mill. This German made mill has a filling capacity of 1,300g and can produce 200g of flour per minute. The mill has an adjustable coarseness setting (0-20) and for the purposes of this trial we milled at level 1 (very fine). The grinding gear is a corund-ceramic composite. Each grain passed through the mill once.

Following milling, the flour was then sieved by hand, using a fine mesh sieve. The purpose of sieving was to remove some of the course bran and some contamination from the flour. The same sieve was used throughout the trial, and the extraction rate was recorded as a percentage. The extraction rate was determined by dividing the sieved flour by the weight of the un-sieved flour.

Dough production

The trial doughs were made according to our standard production method. As usual our sourdough starter (a 50/50 white organic wheat flour/wholemeal organic stoneground rye) was refreshed the night before. On the morning of the trial, we created a leaven with the starter and a 50/50 white/rye flour mix. Between 2-3 hours later, the doughs were started.

The dough consisted of filtered water at 29 degrees Celsius, leaven and flour. The ambient temperature of the bakery ranged from 20-22 degrees Celsius. The amount of water to flour was 70 %. The doughs were mixed by hand and then left to rest for 30 minutes (autolyse method). After 30 minutes, salt was added to the dough and integrated by hand, breaking the preformed gluten bonds. A further three stretch and folds were undertaken over the next two hours and fifteen-minute bulk fermentation period, before the doughs were ready for shaping.

It was planned that each dough would be enough to create two tin loaves and two freeform cane banneton loaves. This was to ensure there was enough bread for the trial to allow testing on appearance and smell/flavour. The doughs were weighed and then pre-shaped. Final shaping took place after fifteen minutes and then the doughs were left to prove at ambient temperature. Once the doughs had risen to an optimum size, the doughs were then transferred to the bakery retarder where they would slow ferment at a temperature between 2-4 degrees Celsius in preparation for baking the following morning.

Baking

On the morning of the tasting trial, the loaves were baked in a Rofco B40 oven. This is a semi-professional oven, with stone baking surfaces. The loaves were baked by type, free-form loaves separate to tin loaves. The loaves were removed from the bakery retarders and the free-form loaves were turned out of the cane banneton and onto a polytetrafluoroethylene (PTFE) coated glass fibre fabric. The tin loaves were placed directly onto the oven stone baking surface. Each stone surface was sprayed with unfiltered water to enable oven spring.

The tin loaves were baked for 50 minutes at 260 degrees Celsius. The ovens were vented after 25 minutes to develop the bread crust. The freeform loaves were baked for 30 minutes at 290 degrees Celsius. The ovens were vented after 18 minutes to develop the bread crust. Once baked, each loaf was transferred to a cooling rack before being transferred to a food grade crate for transportation to the tasting trial.

Running a tasting trial.

The trial was undertaken at the Marchnad Llambed – Lampeter Market, University of Wales Trinity Saint David, Lampeter Campus, Saturday 25th September 2021, 10:30-12:30. Details of the event were shared by flyer and social media. There were no selection criteria set for attendance of the event.

The loaves were blinded, by giving a number to each grain sample between 1-10. Two loaves (a tin and free-form) of each grain type were kept whole so those taking part could look at the overall appearance of the loaf. The remaining loaves were cut up into 5-7cm square pieces for attendees to taste the loaf and assess mouthfeel. The loaves and samples were set out on four tables. Three tables with three samples and the final sample on the main presentation table.

Tasters were asked to arrive at the event at 10:30. It was intended to be a short introduction to the trial by Tony Little, followed by comments from Andrew Neagle and Gabriele Landi of ANUNA. Tasters were then split into three groups and given the score card to complete by hand.

A copy of the score card used is set out as Appendix 1. The score card categories were developed by Andy Forbes, of Brockwell Bake. There were seven categories given, each with a weighting. Attendees were asked to score according to appearance, smell, taste, texture and overall rating of the loaf. Attendees completed a paper copy, with information in each category set out overleaf. Upon completing the trial, members of the public returned their completed score cards to members of the team. It was intended to then unblind the grains and share the result of the trial with attendees.

Observations:

Our observations are captured in the table below and in the results of the grain trial. It is important to note that there was not enough grain of the Emmer – Spring planting, so this grain had to be removed from the trial. We did, however, decide to combine the remaining flours and created a blended loaf. This loaf also formed part of the tasting trial.

Also, despite using the same milling equipment and settings, and the same sieve for all grains, the extraction rates varied considerably across the grains. This may be attributed to the dirtiness of samples, and/or significant contamination by vetch or arable weed seeds. High contamination was especially noted in the following: Maris Widgeon, April Bearded, Emmer – Winter, Einkorn and Torth y Tir. Alternatively, or in addition to, extraction rates may have been affected by the characteristics of the single varieties, such as thicker or thinner bran, or the ratio of bran to the endosperm.

Table 1: Milling, Dough Making and Baking Observations

Number	Name	Milling Comments	Extraction Rate	Dough Making Comments	Baking Comments
1	Mulika	High contamination. 60% Mulika/40% other varieties. Clean, little chaff in it.	91%	Very stiff dough. It became softer during bulk fermentation. Easy to handle and shape, not sticky.	Easy out of the banneton and to score.
2	Atle	Contamination with seeds from other wheats (less than 20%). A few vetch seeds and chaff.	88%	Good structure was developed during the mixing stage. Easy to shape, with reduced stickiness.	
3	Hen Gymro	Quality of the grain was very consistent in terms of size, shape and colour. Some vetch and chaff as for the Atle.	80%	The dough did not show any elastic quality. Too much extension in the dough and the inability to retain water caused significant problems at the time of shaping. The dough was extremely liquid, sloppy and sticky.	Freeform stuck to banneton and immediately slumped on the peel. Virtually no oven spring exhibited.
4	Maris Widgeon	Quite dirty in terms of chaff, oats and vetch. Consistent size and shape.	81%	Dough was not easy to handle. However, it produced a decent freeform loaf, despite its stickiness.	Pea flavour aromas. Freeform stuck to banneton and slumped during baking.

5	Torth y Tir	Highly contaminated with vetch.	75%	Intense smell of peas and legumes during the mixing. Incredibly sticky, probably because of the presence of vetch. Lack of strength, which caused difficulty during final shaping and a poor freeform loaf.	Pea flavour aromas. Freeform stuck to banneton and immediately slumped on the peel.
6	April Bearded	Contaminated with vitreous seeds (possibly Mulika or Emmer), and with seeds possibly belonging to the buckwheat family.	80%	Despite contamination, the dough showed some good technical qualities, and good balance between elasticity and extensibility.	Good oven spring exhibited
7	Emmer - Winter	High contamination from oats (white and black) and some other wheat.	65%	Poor water retention and hard to shape into a freeform loaf.	Dough immediately slumped on the peel
8	Einkorn	High contamination from oats (white and black).	70%	Poor water retention and hard to shape into a freeform loaf.	Pea flavour aromas. Freeform stuck to banneton and immediately slumped on the peel.
9	Rivet	Grains looked consistent in shape, colour and size.	80%	From the early stages of mixing, it was clear there was some decent strength to the dough.	Dough turned out of banneton easily and good oven

				Not an easy flour to work with, but it displays an interesting balance between extensibility and elasticity. Not extremely sticky.	spring achieved.
10	Blended	na	na		Dough turned out of banneton easily and good oven spring achieved.

Table 2: Blinded Baking Trial Results

	Criteria Weighing	**3**	**3**	**3**	**5**	**5**	**1**	**2**		
Ranking	**Name**	**A. Appearance**	**B. Crust**	**C. Crumb**	**D. Odours & Aromas**	**E. Tastes & Flavours**	**F. Mouthfeel**	**G. Bread Harmony**	**Total**	**Blinded No.**
1	Mulika - raw average	4.32	4.12	3.77	3.63	4.14	3.90	4.00		1
	Mulika - weighted	**12.97**	**12.35**	**11.30**	**18.13**	**20.68**	**3.90**	**8.00**	**87.32**	
2	Rivet - raw average	4.13	3.77	3.83	3.77	3.94	4.03	3.94		9

	Rivet - weighted	**12.40**	**11.32**	**11.50**	**18.83**	**19.71**	**4.03**	**7.88**	**85.66**	
3	Blended - raw average	3.93	3.66	3.62	3.72	3.90	3.74	3.70		10
	Blended - weighted	**11.79**	**10.97**	**10.86**	**18.62**	**19.48**	**3.74**	**7.40**	**82.86**	
4	Einkorn - raw average	3.50	3.76	3.79	3.64	3.71	3.66	3.81		8
	Einkorn - weighted	**10.50**	**11.27**	**11.36**	**18.20**	**18.53**	**3.66**	**7.61**	**81.14**	
5	April Bearded - raw average	3.87	3.74	3.75	3.50	3.66	3.54	3.85		6
	April Bearded - weighted	**11.61**	**11.21**	**11.25**	**17.50**	**18.29**	**3.54**	**7.70**	**81.10**	
6	Atle - raw average	3.85	3.74	3.70	3.41	3.53	3.53	3.64		2
	Atle - weighted	**11.56**	**11.23**	**11.09**	**17.05**	**17.65**	**3.53**	**7.27**	**79.37**	
7	Torth y Tir - raw average	3.50	3.42	3.59	3.48	3.69	3.61	3.59		5

	y Tir - weighted	**10.50**	**10.27**	**10.76**	**17.42**	**18.43**	**3.61**	**7.18**	**78.18**	
8	Emmer - Winter - raw average	2.97	3.32	3.53	3.61	3.79	3.49	3.52		7
	Emmer - Winter - weighted	**8.91**	**9.95**	**10.59**	**18.03**	**18.93**	**3.49**	**7.05**	**76.95**	
9	Maris Widgeon - raw average	3.23	3.26	3.40	3.41	3.47	3.30	3.38		4
	Maris Widgeon - weighted	**9.69**	**9.79**	**10.19**	**17.05**	**17.36**	**3.30**	**6.76**	**74.14**	
10	Hen Gymro - raw average	2.93	3.25	3.38	3.36	3.51	3.29	3.29		3
	Hen Gymro - weighted	**8.78**	**9.75**	**10.14**	**16.80**	**17.57**	**3.29**	**6.59**	**72.92**	

Description for each category

a) Appearance: What is the appearance of the loaf to you? Do you find it attractive? Does it make you want to buy or try the loaf?
b) B) Crust: Do you like the look of crust? Is it what you’re looking for in terms of colour and thickness of crust?

c) Crumb: What does the crumb look like to you? Is it attractive? Is it open, light and spongy? Or dense, doughy and damp?
d) Odours and aromas: What does the bread smell like? Does it have a pleasant smell or not? Does it make you want to eat the loaf?
e) Tastes and flavours: Are there good flavours? Is there a depth of taste? Do you want to carry on eating the loaf because of the taste?
f) Mouth feel: What does it feel like in your mouth? Do you like the texture? Is it light or claggy?
g) Bread harmony: Having considered each category in turn, what is your overall rating of the loaf?

Conclusions:

The observations show that Mulika, a modern wheat variety was the most popular grain in the tasting trial. This variety also showed good milling, dough, and baking properties. In some ways this is not surprising given the level of investment in modern hybrid seeds and that our tasting palettes are developed to recognise such grains as pleasing. There is a balance to be struck with having the consistency of a modern wheat variety, which is well suited to organic growing conditions, and the annual reliance on a plant breeder to access seed.

Rivet, an older variety performed well in the milling, dough and baking trials and proved to be the second most popular grain of the tasting trial. Along with Mulika, we would be interested to see further trialling of this grain in west Wales, and the possibility of developing a population.

We used the sourdough method and did not add any high protein white flour to improve the performance (notably rise) of the bread. Unsurprisingly, given the maritime conditions of the UK and especially west Wales, the doughs did not display a strong rise in the freeform banneton. The loaves fermented and baked in a tin were much more successful. If seeking an aesthetically pleasing "standard" loaf, we would recommend the use of a tin, when using 100% wholemeal heritage grain.

Recommendations for future trials:

- Contamination of the samples

All samples were contaminated with arable weeds and chaff to a greater or lesser extent. Unfortunately, some such as the Torth y Tir population grain and the Einkorn were particularly affected by vetch. Both samples ended up with strong "pea' aromas and flavours, which will have affected the tasting trial and the performance of the flour during the trial. Further exploration is probably required as to how samples can be cleaned prior to milling, and suitable equipment would need to be sourced to enable this to happen.

- Time to season the flour

Due to time constraints of the funding period, the time from harvest to the tasting trial was suboptimal. Flour performs best if it can be aged for 10 to 21 days after milling. Aging can improve the characteristics of the protein, thereby improving the raising abilities of the dough. We sifted some of the bran to try and improve the lightness of the dough, but the dough will have been denser than if we had let the flour age. If the trial is run again, it is recommended that the funding window be extended until the end of October, so that the tasting trial can take place in October.

- Variation in the quantity of grain supplied

For some grains there was limited quantity of grain to work with. This meant that for the case of Emmer – Spring grain, there was not a viable quantity to be able to produce any loaves, so this particular grain was taken out of the trial. In other cases, notably the Einkorn and Emmer – Winter grains, we were only able to produce tin versions of the loaves.

Following on from what was learnt during this trial, the recommended minimum viable quantity of grain is 3kg per grain type.

- Dough adhesion to bannetons

Due to the presence of contaminants (especially vetch), the dough for some of the grains was especially tacky, which caused the doughs to unduly adhere to the banneton and therefore release more slumped than would have otherwise been the case if the banneton was double-floured beforehand. It is recommended that future trials consider the risk of excessive dough adhesion and take appropriate precautions by flouring the bannetons accordingly.

- Sequencing of taste testing

Mulika was the first grain that most testers tried, and Rivet was the ninth. It may be the case that results were affected by the positioning in the tasting process. In future, it is suggested that testers taste randomly and not follow the same sequential order.

- Repetition on an annual basis

ANUNA Craft Bakery has enjoyed being part of the trial and having the opportunity to test Welsh grown grains. We hope this trial inspires further trials and grain growing in west Wales. We would also welcome the opportunity to test and feedback our findings with subsequent harvests. It is our desire to be part of a growing sustainable grain economy.

Andrew Neagle

Gabriele Landi

Elizabeth Neagle

October 2021

Annex E - Publicity

Open Day

In July 2021 an open day event was held at Caerhys Farm where farmers and other stakeholders were in attendance. Background information and results from the 2019 trials were shared and there was a tour of the trial fields. This resulted in an informative press release in Farming UK (See below). In addition, Farming Connect and EIP Wales created a video and article, with an associated article, which provided and update and overview of the ancient cereals. See the video here: https://www.youtube.com/watch?v=R-wUZyi_oG0 and the associated article here: https://businesswales.gov.wales/farmingconnect/business/european-innovation-partnership-eip-wales/approved-eip-wales-projects/organic-ancient

Farming UK press release.

Written by Debbie James. Photographs also by Debbie James.

A link to the article can be accessed here: https://www.farminguk.com/news/crop-trial-shows-benefits-of-growing-ancient-wheat-varieties_58793.html

Annex F Photos from the EIP Project

Photo of drilling at Brynbank May 2019.

Photo of emergence counts Rhodiad May 2019.

Photo of harvest at Brynbank September 2019.

Photo of bakey visit and trial planning October 2020.

Photo of drilling winter 2020 trials Brawdy Farm, October 2020.

Photo of drilling of spring 2021 trials at Caerhys Farm April 2021.

Photo of drilling of spring 2021 trials at Whitesands April 2021.

Photo of plant counts at Caerhys Farm May 2021.

Photo of Atle strip at Bug Farm, May 2021

Photo of spring wheat trial strips at Caerhys farm, July 2021.

Photo of Torth y Tir crop growing at Bug Farm, July 2021.

Photo of Hen Gymro crop growing at Bug Farm, July 2021.