Field lab: Organic Wheat Varieties

Final report

2019/20

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Organic Winter Wheat Varieties Year 3 Report 2019/20

Introduction

Having been bred in, and for, conventional high input farming, non-adapted varieties are probably one of the main drivers of organic wheat under-performance (Murphy et al. 2007). It has also been demonstrated that breeding programs focusing on cultivar evaluation in high-input environments do not result in the selection of cultivars suited to low-input environments (Loyce et al. 2008). This situation is made worse by the fact that these conventional high input varieties are seldom evaluated under organic conditions. The only recent publicly available varietal information is from conventional trials using full fertiliser and herbicide inputs with the untreated fungicide results the main indication of organic suitability. Organic farmers need better, more reliable information on varietal performance under organic husbandry and therefore need testing to take place under these conditions for the information to be of most relevance.

In Summary underperformance results from

(i) very limited access to environmental modification during the growing season, which means that variety is the main seasonal crop management choice.
(ii) suitable organic genotypes are neglected in conventional breeding and thus not on the market.
(iii) limited access to reliable information about commercial varietal performance under organic farming conditions exacerbating the information deficit.

Given this situation, in 2017/18 we started a field lab to test a range of varieties through a plot trial within a commercial organic farm rotation.

The main goals of the field lab were;

(1) to help provide farmers with reliable varietal comparisons and evidence of varietal performance under, and suitability for, organic cultivation to support their on- farm trials and decisions about variety selection.

(2) evaluate a range of current commercial varieties commonly grown by organic farmers as benchmarks, new lines, European varieties, an old UK cultivar, an English landrace, and Organically bred varieties from Europe.

(3) including a range of phenotypes (observable characteristics) in the trial to facilitate investigation of traits useful for organic farming, most notably traits likely to convey weed competitiveness such as crop height, ground cover, vigour, and tillering

Plot trials remain the most reliable and simplest way of comparing a large number of varieties in a robust replicated design. However, there is also evidence that under organic conditions the increased environmental variation means that the most relevant information on yield and quality performance will come from field scale, commercial production on farm. Therefore, the plot trial must be used in conjunction with farm field scale trials (Kravchencko et al. 2016). With this in mind steps have been taken towards the qualitative integration of the plot trial with field scale farm trials through the LiveWheat project.

This report details the key results and observations for the third year of the Organic Wheat Varieties Field Lab funded through the Innovative Farmers programme with support from the AHDB.

Materials and methods

Experimental site and crop management

The trial was carried out at The Bradwell Grove Estate near Burford, West Oxfordshire (51°46'01.8"N 1°41'32.8") in a typical Cotswolds brash field (shallow silty clay loam) with pH 8.1, 13.8mg/kg available N, 6.8mg/l available P (Index 0), 169 mg/l available K (Index 2-), 53 mg/l available Mg (Index 2), 8.4% organic matter (LOI) to a depth of 15cm.

The trial was drilled at a 520 seeds/m^2 with a plot driller on the 21st November 2019, after the soil was ploughed and harrowed. Harvest was performed with a plot combine on the 7th August 2020.

Climate

The season was characterised by a mild wet Autumn and Winter and a very dry, sunny Spring. Summer was slightly warmer and wetter than the long term average from 1981-2010. (Figure. 1).

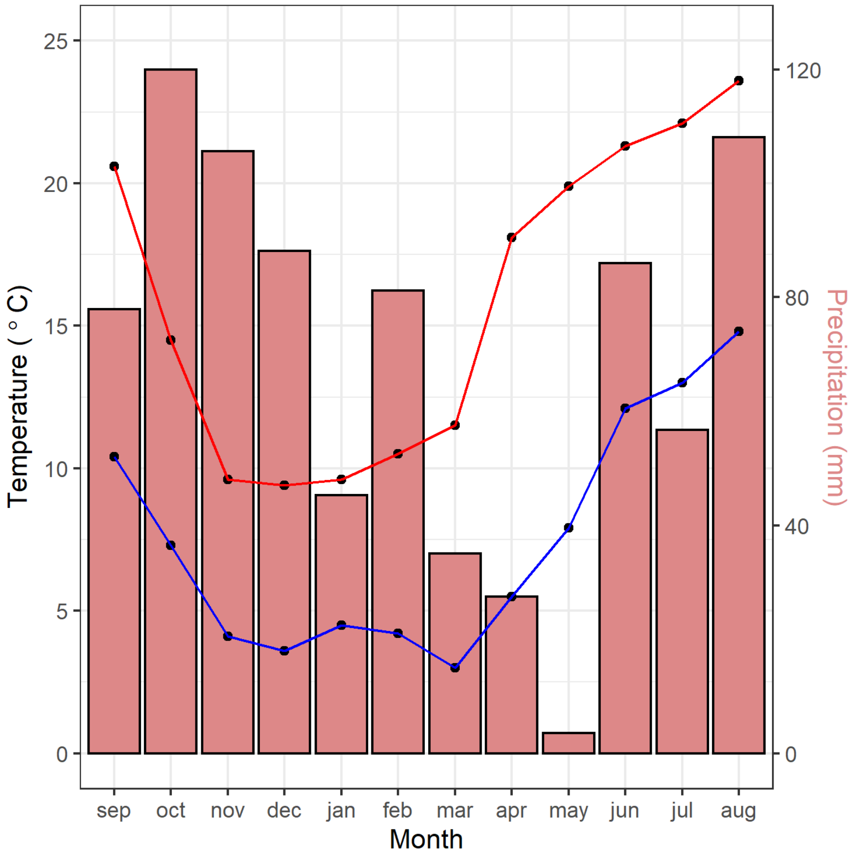


Figure 1. Average monthly min (blue line) and max (red line) temperature and total monthly precipitation. Source MET Office, Oxford station.

Variety List

Table 1.0 Variety list for 2019/20 season. Varieties with an asterix were commercially available in the UK at the time of drilling.

#	Variety	Information
1	Alabaster*	KWS variety, white grain and pale flour from bright white endosperm and pale seed coat. Hard milling with breadmaking potential
2	Ataro	GZPK bred biodynamic variety from Switzerland, lower quality feed type
3	AWC-17	Angus Wheat Consultants NL1 Evolution x Solace, hard milling feed wheat
4	AWC-19	Angus Wheat Consultants NL1 Skyfall x Crusoe, hard milling with bread making potential
5	Costello*	Senova hard milling, Group 4
6	Crispin*	KWS hard milling, Group 4
7	Effendi	German high quality E-wheat
8	Evolution*	LG hard milling, Group 4
9	Extase*	KWS hard milling with bread making potential, Group 2
10	Firefly*	KWS soft milling, Group 3
11	Gleam*	Syngenta hard milling Group 4
12	Hallfreda	Lantmannen variety from Sweden, new milling variety
13	Informer	German B quality, hard milling with bread making potential
14	Maris Widgeon*	PBI bred historic cultivar from 1964 milling wheat
15	Montana*	German high quality E-wheat
16	Mortimer	Secobra French variety hard milling Group 4 ukp
17	Pizza	GZPK bred biodynamic variety from Switzerland. Quality milling type
18	Red Lammas	Old English land race
19	Revelation*	LG soft milling, Group 4 uks
20	Royal	GZPK bred biodynamic variety from Switzerland. Lower quality feed type
21	Siskin*	KWS hard milling with bread making potential, Group 2
22	Skyfall*	RGT hard milling breadmaking, Group 1
23	Wiwa	GZPK bred biodynamic variety from Switzerland, quality milling type
24	Zyatt*	KWS hard milling breadmaking, Group 1

Assessments

- **Pre-trial soil** texture, chemical analysis (Olsen-P, extractable K and Mg, pH) and Organic Matter % (LOI) performed by NRM Laboratories.

A representative soil sample was collected from the trial area at drilling.

- **Crop Growth Habit** – on a plot basis pre stem extension.

A 1 to 5 scale from prostrate to erect to give an idea of crop morphology and canopy structure in April.

- **Growth cycle length** - crop phenological stage at key dates at or around the growth stages of stem extension , booting, flowering and early dough

The growth stage of each variety was assessed using the BBCH scale during site visits in April, May, June and July.

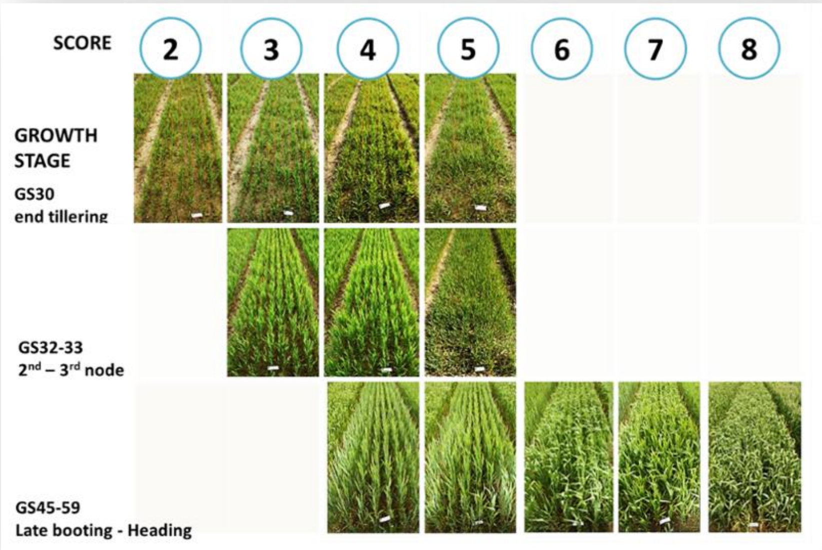
- **Crop canopy height** - on a plot basis, in correspondence of stem extension and flowering

The canopy height was measured using a ruler to give a representative canopy height across the plot.

- **Crop and Weed cover** – on a plot basis, at stem extension and flowering

A visual assessment of crop and weed ground cover % was taken at these key times.

- **Crop Vigour –** visual assessment on a plot basis in April, May and June using the scoring system from 1-9 developed by the French Institut Technique de l'Agriculture Biologique (ITAB).



- **Foliar Disease severity** – on a plot basis. Identification of main foliar diseases and estimated average percentage cover of flag leaf, leaf 2 and leaf 3 in correspondence of BBCH GS 45 and 65

A percentage leaf area showing symptoms for the two leaves described was performed

- **Ear Disease severity** – on a plot basis. Identification of main ear diseases and estimated average percentage cover of ear in correspondence of BBCH GS 79

A percentage ear area showing symptoms was performed.

- **Ear density** – on three row meters per plot at BBCH 75

count of fertile tillers on three randomly selected row meters in each plot converted to ears per m^2 using row width.

- **Spikelet number and grains per spikelet** – on the same rows as the ear density assessment at BBCH 75.

count of number of spikelets from 3 random ears .

- **Grain yield** – plot combine harvest of each plot at maturity, with grain weight adjusted at 15% moisture and converted to t/ha.

Each plot harvested to provide a t/ha grain yield and a moisture content to allow standardisation to 15% moisture.

- **Grain quality** – protein content, specific weight (hectolitre weight, HLW), Hagberg Falling Number (HFN) and Endosperm Hardness (NIR) measured in a lab by Angus Wheat Consultants Ltd.

  Samples were collected at harvest and analysed on a single bulked composite sample made up from all three replicates for each variety.

Statistical analysis

We adopted a Randomised Complete Block design with 24 treatments and three blocks. Data were analysed through ANOVA with Variety and Block as predictive variables to highlight effect of variety over any response variable. Validity of the model was checked graphically observing the diagnostic plot of residuals (quantile-quantile plot) and also through Shapiro Wilkes test for normality and Levene test for equality of variance. In the event of failure to meet assumptions for ANOVA, the non-parametric Kruskal Wallace test was used.

Differences of varieties from the grand mean were analysed as pairwise comparison through ANOVA. Analysis of differences between breeding classes was performed by ANOVA with pairwise class comparisons done through a T-Test. The relationship between yield and protein was analysed by regression analysis.

To visualise relationships between the tested variables, principal component analysis (PCA) was run in two steps. First, an interim PCA was run with all the variables included, and the quality of representation (Cos2) of each variable was checked. Second, a simplified PCA was run with those variables showing the highest contribution to the variance.

Dynamic stability was analysed according to Finlay and Wilkinson (1963)

All analyses were done by R version 4.0.2.

Results and Discussion

Yield

The grand yield for the Milling wheats assessed was 3.91±0.36 t/ha. Siskin was the highest yielding a 4.93±0.36 t/ha and Wiwa was the lowest at 3.22±0.19 t/ha.

Yield of the (potential) milling varieties shows a clear clustering of varieties by NABIM group with the group 2s highest yielding at 4.50±0.28t/ha. The group 1s (or equivalent) yielded on average 3.62±0.24 t/ha.

Comparing to the grand mean of the milling varieties tested shows Wiwa, Skyfall and Maris Widgeon performing significantly lower than the mean.

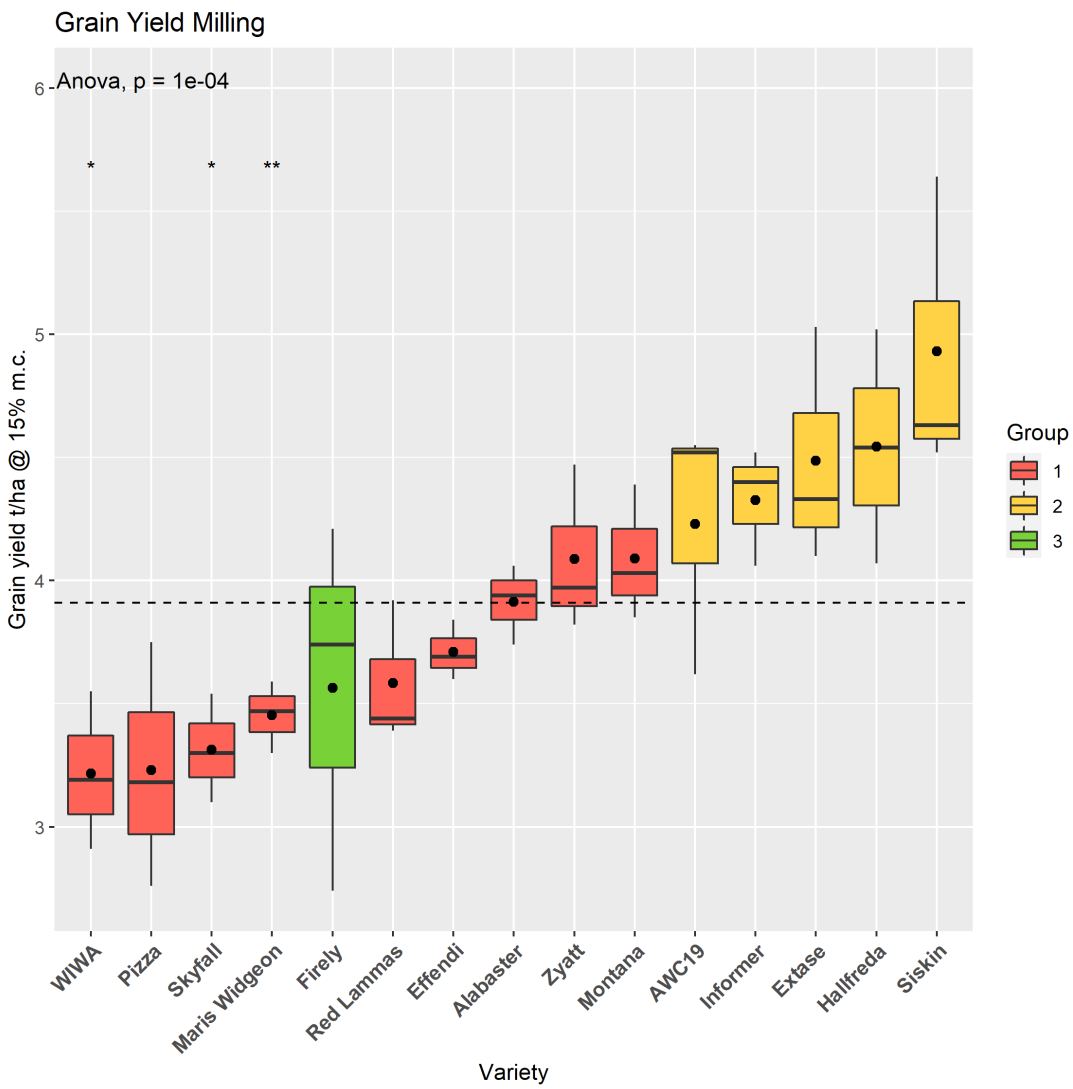


Figure 2.0 Boxplot of milling wheat yields for NABIM groups (or equivalent) 1-3 as compared to the grand mean yield (dotted line) for milling wheats tested. Black dots indicate mean variety yield. Stars indicate yield significantly different from the grand mean (* < 0.05, **p < 0.01, *** p < 0.001).

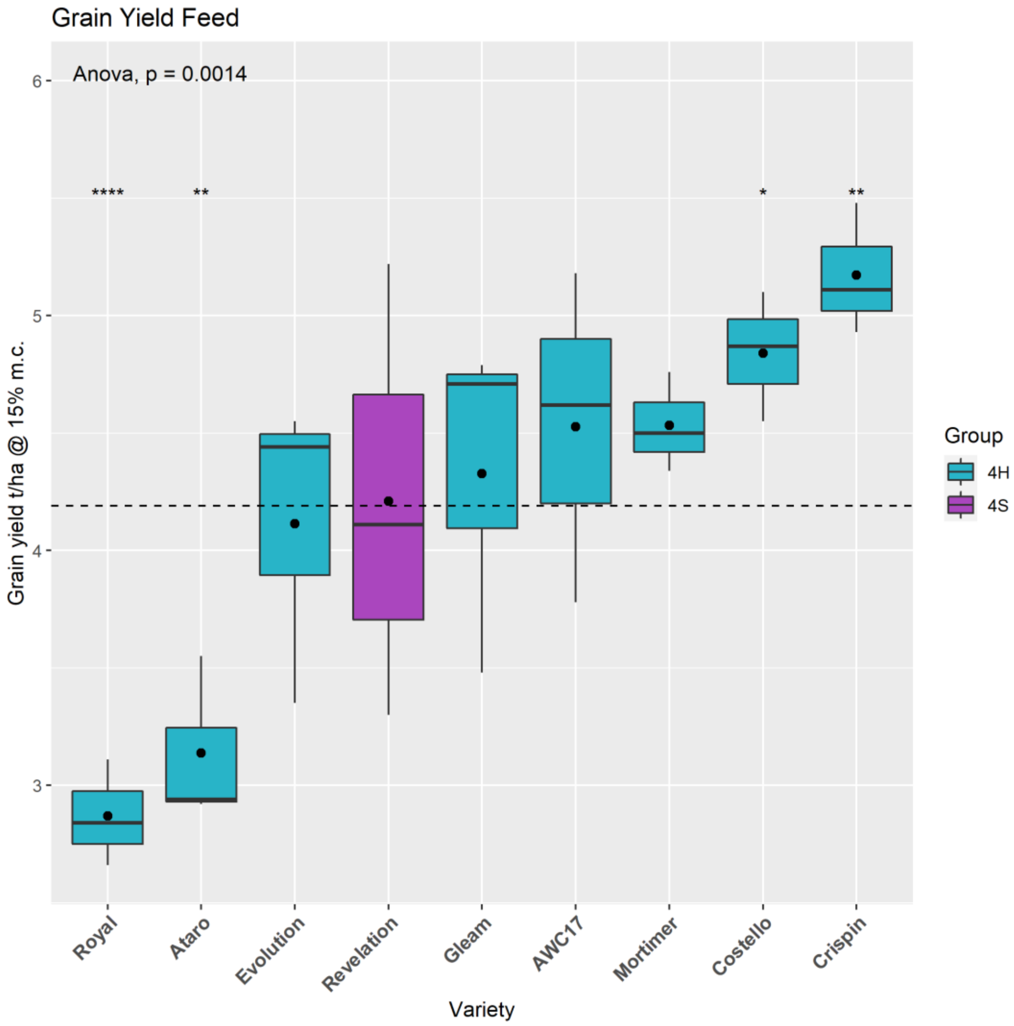


Figure 3.0 Boxplot of milling wheat yields for NABIM groups (or equivalent) 4H and 4S as compared to the grand mean yield (dotted line) for feed wheats tested. Black dots indicate mean variety yield. Stars indicate yield significantly different from the grand mean (* < 0.05, **p < 0.01, *** p < 0.001).

The grand mean yield of the feed wheats was 4.19±0.49t/ha. Crispin was the highest yielding at 5.17±0.16 t/ha and Royal was the lowest at 2.87±0.13 t/ha.

Of the group 4s the 4H group yielded on average 4.19±0.5t/ha. Only one variety, Revelation, represented the group 4 soft wheats which itself yielded 4.21±0.56t/ha.

Crispin showed an above average performance of the group tested along with Costello. Investigating the yield ranking from previous years shows Crispin and Costello consistently in the top yielding across three years.

Crispin is well suited to later sowing and shows early vigour and is quick to reach stem extension from late sowing. The typical later sowing of Organic farming and early vigour for increased competition with weeds could be two important factors that explain Crispin’s consistently strong yield performance. Although the variety looks set to be discontinued and is no longer on the RL it is one of the parents of a new variety Cranium that can be expected to exhibit similar traits and has been included in this year’s organic wheat variety trial.

Quality

Table 2.0 Standard grain quality measurements performed on composite samples from the plot trial

G	Variety	Yield t/ha	Protein %	Sp Wt kg/hl	HFN (s)	Relative Hardness (NIR)	TGW (g)
4H	**Crispin**	5.17±0.16	7.2	79.9	323	4.9	46.6
2	**Siskin**	4.93±0.35	7.2	79.6	347	4.1	50.4
4H	**Costello**	4.84±0.16	6.8	82	343	5.7	46.9
2	**Hallfreda**	4.55±0.27	8.1	82.2	347	8.1	47.3
4H	**Mortimer**	4.53±0.12	7.2	81.4	310	5.7	53.3
4H	**AWC-17**	4.52±0.41	7.3	78.4	283	5.8	50.1
2	**Extase**	4.49±0.27	7.3	79.9	312	3.8	54.5
4H	**Gleam**	4.33±0.42	7.4	78	247	4.6	52.4
2	**Informer**	4.33±0.14	7.9	80.9	368	7.2	58.3
2	**AWC-19**	4.23±0.31	7.7	78.7	239	4.2	51.7
4S	**Revelation**	4.21±0.56	7.2	77	272	0.8	49.7
4H	**Evolution**	4.11±0.38	7.4	78.5	220	7.3	51.3
1	**Montana**	4.09±0.20	8.6	79.6	360	5.7	44.7
1	**Zyatt**	4.09±0.16	8.1	79.8	301	5.4	49.7
1	**Alabaster**	3.91±0.09	7.7	80.2	341	4.2	46.3
1	**Effendi**	3.71±0.07	8.8	81.6	264	7	46.7
1	**Red Lammas**	3.58±0.17	9.7	82	260	0.9	42.2
3	**Firely**	3.56±0.43	7.5	77.2	216	-0.1	51.6
1	**Maris Widgeon**	3.45±0.08	9.4	81.3	222	7.5	52.6
1	**Skyfall**	3.31±0.13	7.8	77.6	317	5.5	43.6
1	**Pizza**	3.23±0.28	10.8	84.3	315	8.1	41.8
1	**Wiwa**	3.22±0.18	11	84	369	8.2	46.5
4H	**Ataro**	3.14±0.20	10.3	83.1	311	7.9	46.5
4H	**Royal**	2.87±0.13	11.3	84.8	298	9.9	50.5
	Grand Mean	**4.0±0.09**	**8.3**	**80.5**	**299.4**	**5.5**	**48.8**

Hallfreda appears to show the strongest set of standard quality parameters and with a positive relative yield performance suggestive of a NABIM Group 2 could be an interesting variety to test under commercial organic farming conditions at field scale. Informer, a German B wheat, is another variety falling into the NABIM group 2 equivalence but with superior grain quality to both Siskin and Extase in the 2020 trial.

One of the most surprising results is the apparent softness of the Red Lammas grain. The NIR analysis would classify it as a soft wheat with a NIR hardness similar to the group 4 soft wheat Revelation.

If the relative NIR scores for endosperm hardness are a good indicator of milling quality then the EU Biodynamic varieties along with Hallfreda, a modern Swedish variety and Maris Widgeon may be most suitable for bread making.

For milling varieties, testing protein quality, specifically Glutenin:Gliadin ratios may provide useful information on suitability for breadmaking at lower grain protein levels often experienced under organic farming with the suggestion that a higher ratio of glutenin can improve elasticity of the dough even with lower overall protein content. At present a single sample costs £150 making the cost prohibitive.

For Feed varieties, testing amino acid composition could be a useful addition for assessing feed value especially for the essential (and semi-essential) amino acids that some livestock diets are often short of including lysine and methionine (and cysteine).

Yield vs Protein

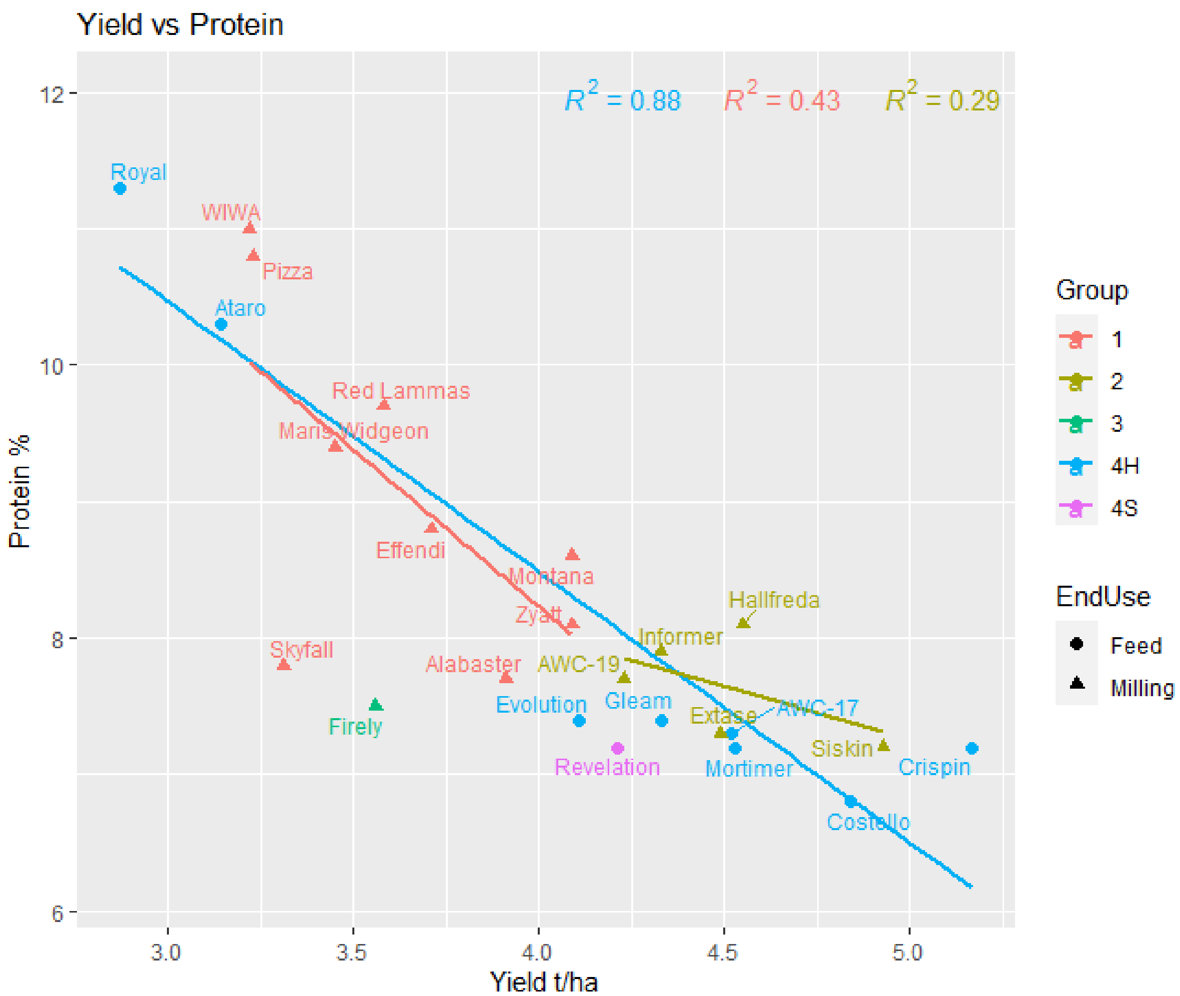


Figure 4.0. Relationship between grain yield and grain protein content of the tested varieties. Regression lines of grain protein as affected by grain yields are shown for each NABIM end-use group.

The classic yield protein trade-off is observed but with certain varieties outperforming the trend, notably Hallfreda with a higher than expected protein content for its yield within the Group 2s. Group 1 benchmark variety Skyfall underperformed in terms of the yield protein relationship with a lower than expected protein content for its yield compared to the other Group 1s tested. Of the groups 4s Crispin looks to have outperformed the trade-off but the relationship has been altered by the presence of the EU biodynamic varieties classified by the breeder as feed that actually perform more like heritage milling types (for yield and quality). This shows the importance of understanding breeding, classification and provenance when comparing the varieties.

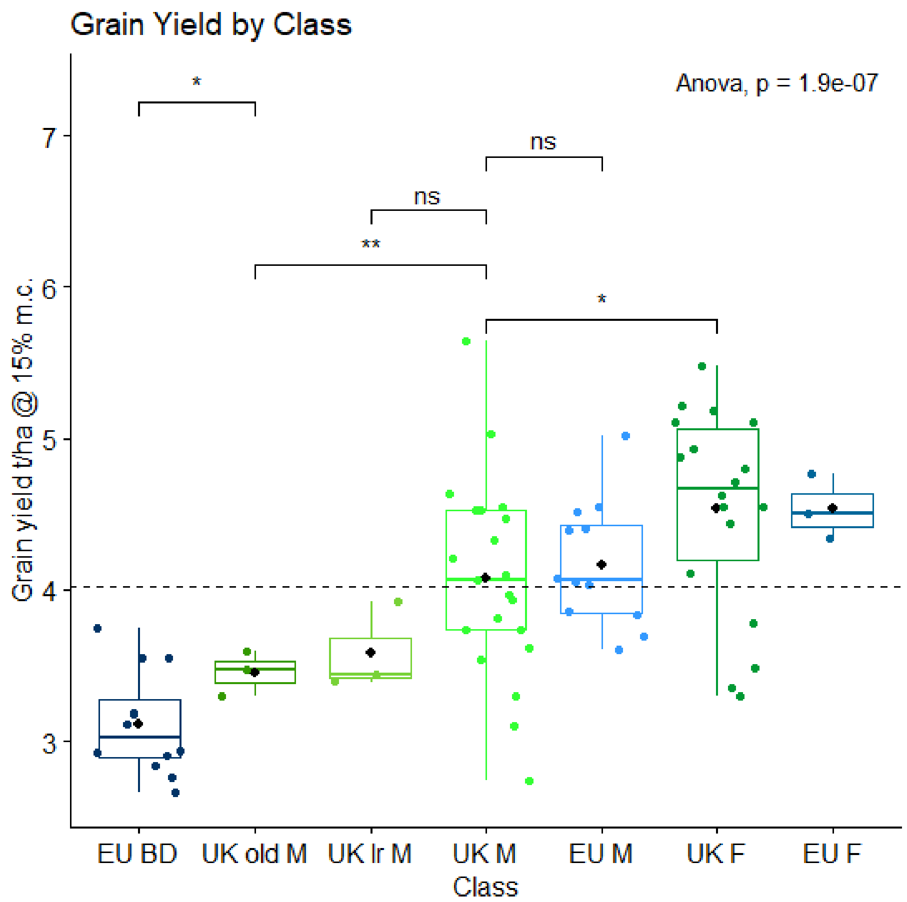


Figure 5.0 Boxplot showing yield comparison of wheats in different categories according to provenance and end-use, stars indicate significant difference between classes.

Splitting the varieties into categories determined by both provenance and end-use provides a fairer comparison of relative yield performance.

The four biodynamic varieties from Switzerland “EU BD” yielded significantly lower (3.1±0.1 t/ha) as a group than Maris Widgeon (3.45±0.08t/ha) an old UK cultivar “UK old M”, which itself yielded similar to the English landrace Red Lammas, “UK lr M” (3.58±0.17t/ha). As a group the modern UK milling wheats “UK M” yielded higher (4.07±0.14t/ha) than the old UK cultivar Maris Widgeon.

As a class UK feed wheat “UK F” yielded higher (4.53±0.16t/ha) than UK milling but with an overlap in yield performance largely due to the NABIM group 2s. There was no difference between conventionally bred modern UK and EU milling wheats suggesting there is an opportunity to explore more continental varieties for organic farming particularly those bred for similar latitudes and altitudes to typical British organic arable farming.

Disease

Foliar and Ear Disease

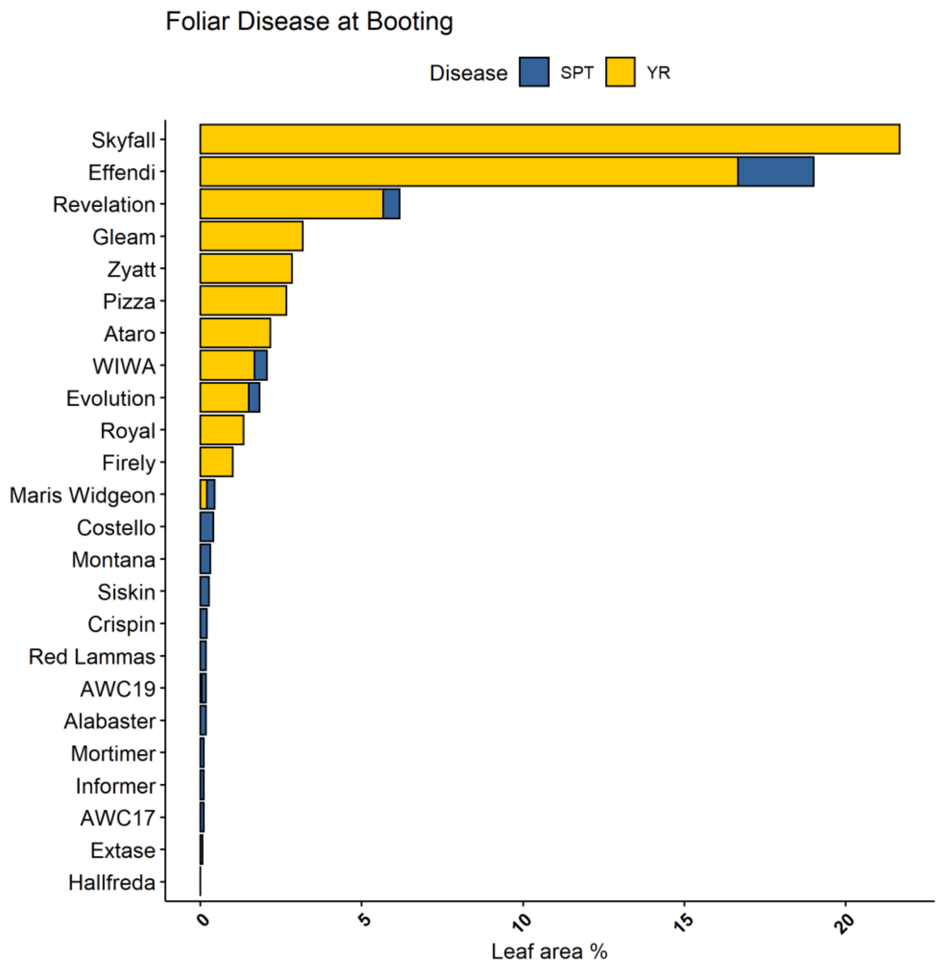


Figure 6.0 Main Foliar diseases present on top three leaves at BBCH45

There were very low levels of Septoria across the varieties during the season, most likely the result of the dry spring where the pathogen would normally be spread to new leaves via rain splash. In addition, under low nitrogen status of the experimental site, Septoria was not favoured. As has been observed in previous years, yellow rust was the most severe foliar disease with the RL variety Skyfall showing the most severe symptoms. Although levels in most varieties were low, certain varieties that would be expected to show high levels of resistance showed some susceptibility including Firefly, Gleam and Revelation although this particular variety is known to have seedling susceptibility but adult resistance. Other varieties to show relatively high levels were the German variety Effendi and the Swiss biodynamic varieties Ataro, Pizza and Wiwa. The dry, sunny spring weather meant overall disease development was low between booting and flowering.

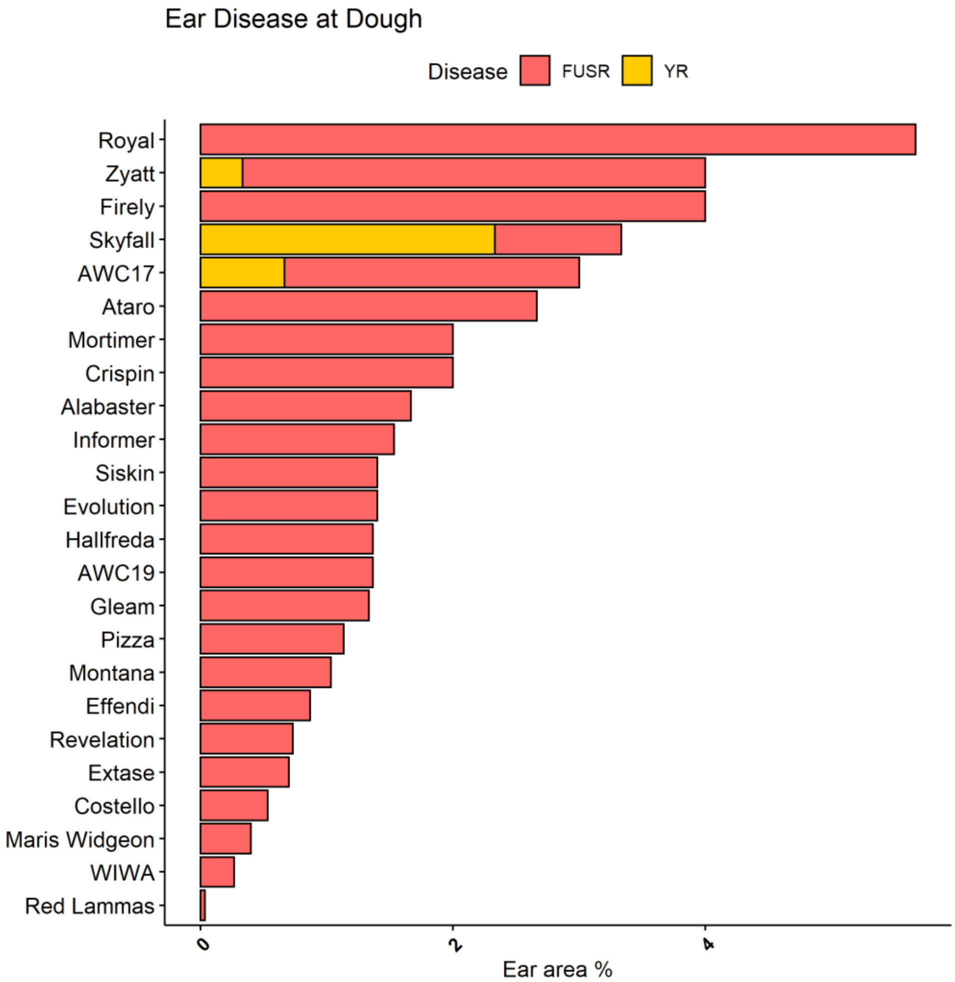


Figure 7.0 Main Ear diseases present at BBCH81

Zyatt and Firefly showed the highest levels of fusarium ear blight as expected given they have the lowest ratings of resistance for the RL varieties included. The Swiss variety Royal also showed relatively high levels but overall fusarium severity was low. The high levels of foliar yellow rust observed on the variety Skyfall resulted in relatively high levels on the ear between the grain and glumes.

Crop Height, Vigour and Cover

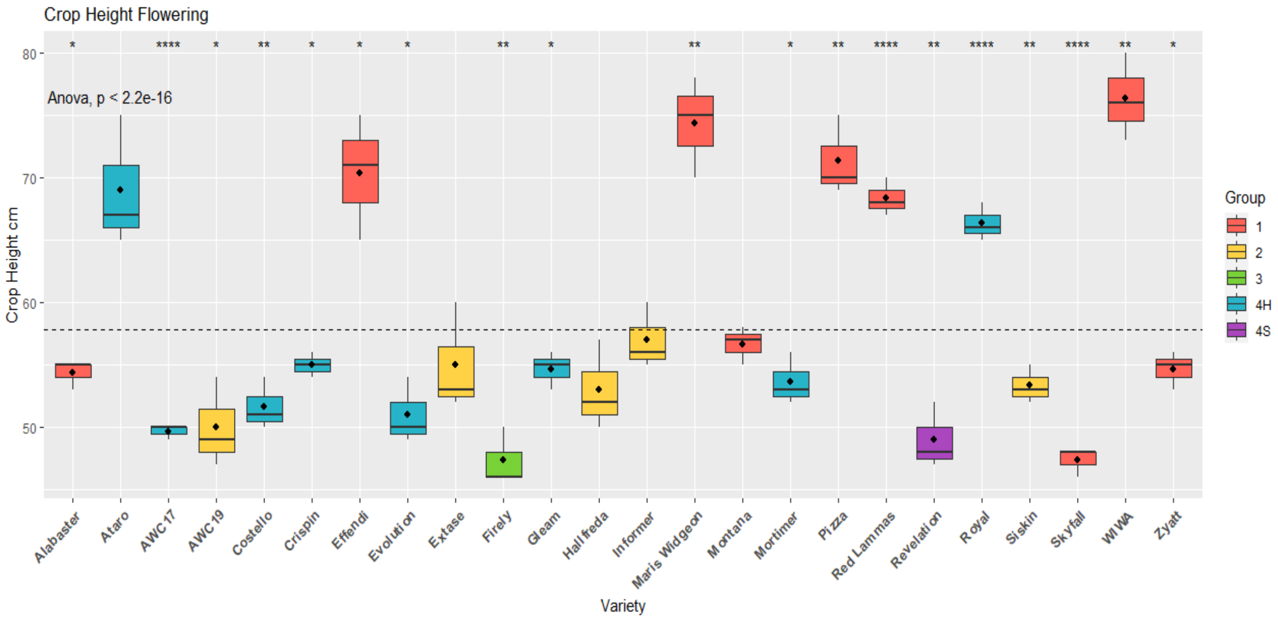


Figure 8.0 Crop height at flowering. Varietal height compared to grand mean (dotted line); stars indicate significant difference from the grand mean(* < 0.05, **p < 0.01, *** p < 0.001).

All varieties above the grand mean line are considered heritage phenotypes even if they are from modern breeding programmes, due to their height and lack of semi dwarfing genes in their genetics. This group is represented by the English land race Red Lammas, the old UK cultivar Maris Widgeon, four modern Swiss biodynamic varieties with historic parents (Ataro, Pizza, Royal, Wiwa) and the modern German variety Effendi.

None of these taller varieties exhibited any signs of lodging but this should be taken in the context of a low fertility site and a season in which nutrient uptake and therefore height was limited in spring by drought with varieties typically 70% of the height at flowering compared to the heights of the same varieties in 2019. Maris Widgeon was on average 105cm tall at flowering in 2019 and 74.3cm tall in 2020. Likewise, Crispin was 80cm tall at flowering in 2019 but only 55cm tall in 2020.

Height at flowering may not be as important as height earlier in the season when certain yield components are being determined and competition with weeds is at a more critical stage. This may be one of the traits of benefit to the varieties Crispin, Siskin and Mortimer and may indicate their vigour in reaching GS 31 quickly from a late sowing date with the varieties drilled on 22nd November. (Figure 9.0)

Crop height during growth and the rate of height increase may be more important than mature height for weed competition. However, height alone does not explain competitiveness, with cover and canopy architecture also of importance.

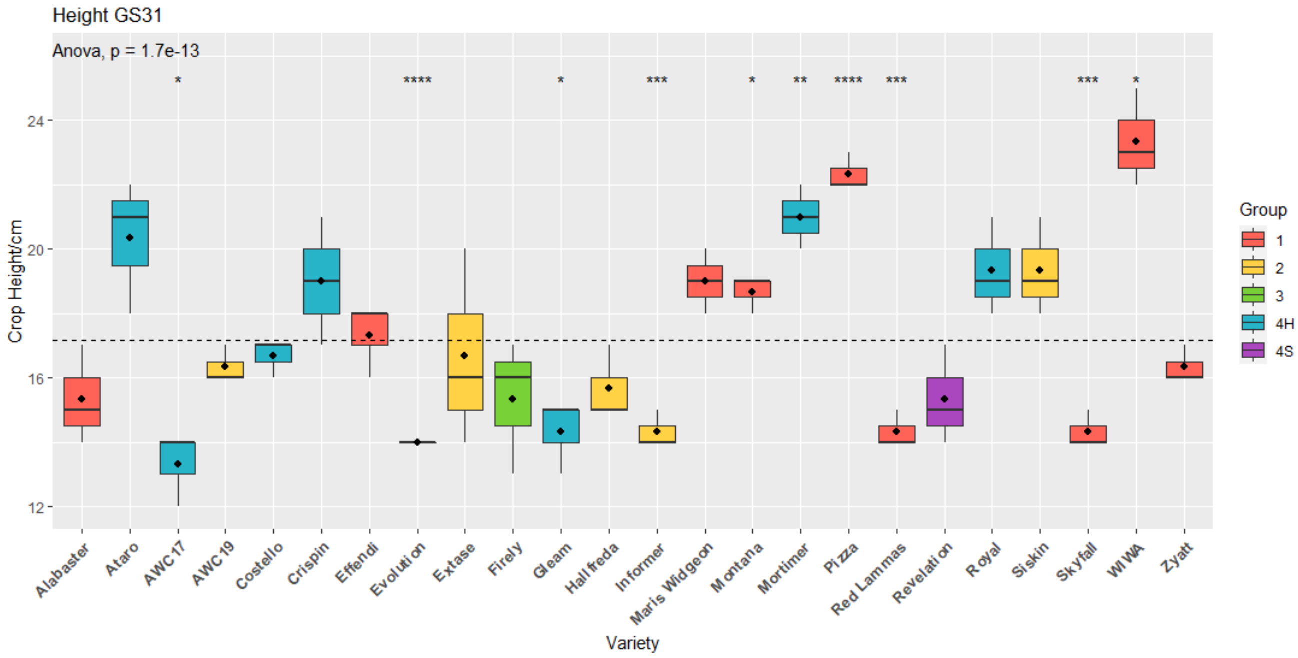


Figure 9.0 Crop height at stem extension. Varietal height compared to grand mean (dotted line); stars indicate significant difference from the grand mean (* < 0.05, **p < 0.01, *** p < 0.001).

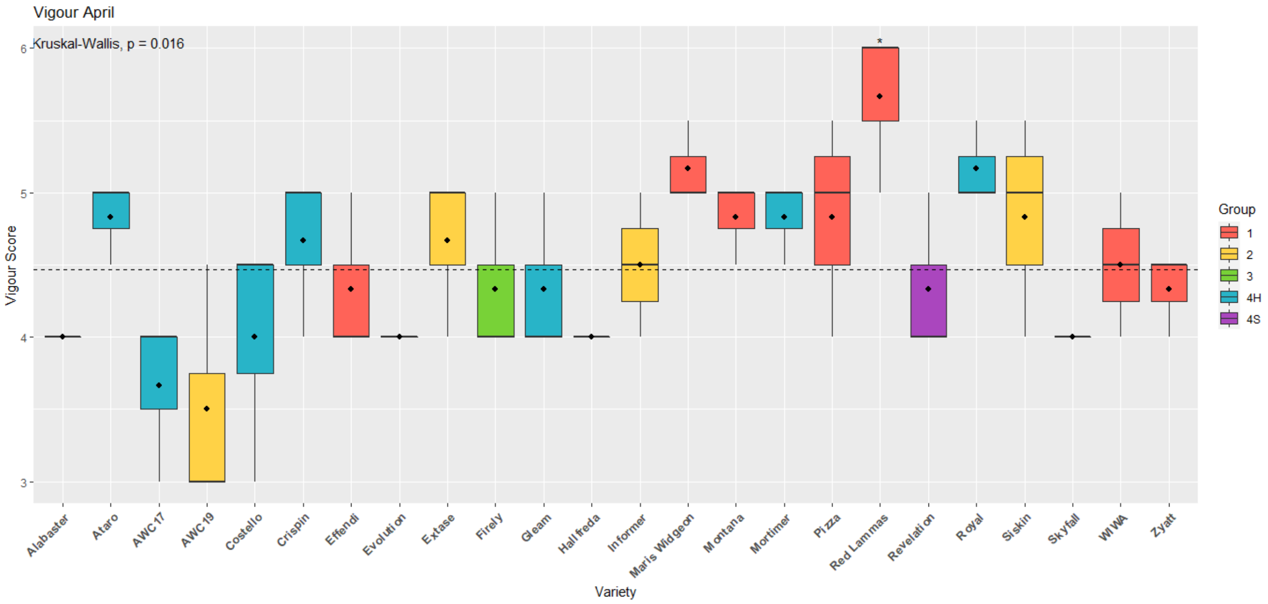


Figure 10.0 Crop vigour in April at early stem extension. Black dots so vigour average. Dotted line shows grand mean (* < 0.05, **p < 0.01, *** p < 0.001).

Crop vigour is measured through a ranking score 1-9 according to the ITAB method and takes account of height and cover to give an overall biomass score providing a three dimensional assessment of vigour. A ranking like this that is performed on the same calendar date will be affected by crop phenology with later varieties scoring relatively low. However, calendar date assessment may be as relevant with those varieties growing taller and covering more ground earlier, offering greater competition against weeds at an earlier stage of the season. Crop vigour at this stage could be considered a positive trait and varieties such as Crispin, Siskin, Mortimer, Montana and Extase, along with the heritage phenotypes of Mars Widgeon, Red Lammas and the Swiss Biodynamic varieties show good “early” vigour. Whilst this does not necessarily confer a yield advantage, especially for varieties with historic genetics and particularly in lower weed burden environments as the plots were in 2019/20, it is a positive trait of benefit for resource capture and competition against weeds. In weedier environments, this trait may improve weed suppression.

Figure 11.0. Vigour scoring example using 45° photos looking down the rows. Vigour scores assigned on 1-9 with 9 most vigorous, according to ITAB scale including reference pictures at different Growth Stages. Here Maris Widgeon would score 7, Skyfall would score 5.

This simple visual vigour scoring system can be easily carried out by farmers and offers a useful way to compare varieties and may offer a good indication of weed competitiveness.

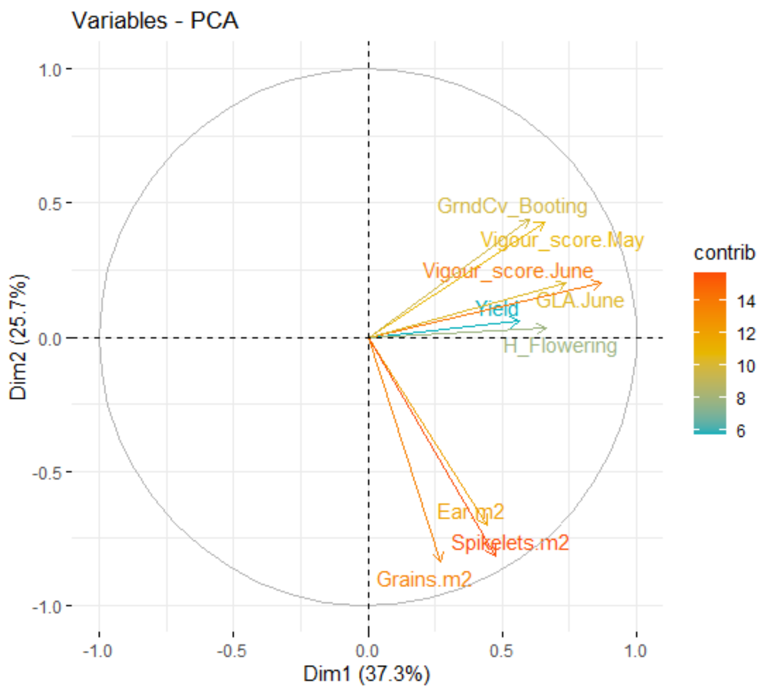


Figure 12.0 Principal component analysis of the variables measured on the 17 non heritage phenotype varieties in 2020 with the eight traits showing the largest contribution to variance of the two principal components, and yield.

There is a clustering of canopy traits along the one principal component (Dim1) and yield components along the other principal component (Dim2) showing that these two groups explain the maximal variation in the dataset and interestingly are orthogonal and therefore unrelated in the 2019/20 dataset. Perhaps more surprising is that although its contribution is low, yield is related to the canopy architecture (cover, height, vigour) rather than to the yield components of ears, spikelets and grain per m2.

Relative Yield Rankings 2018-2020

A simple varietal ranking for yield helps show varieties performing consistently well or poorly and is most reliable for varieties having appeared across all three years. Crispin ranks highest with its top yield performance in both 2018 and 2020. Costello has ranked consistently in the top 3 across all years. Evolution was the highest ranked in 2019 but only 12th in 2020 showing a strong interaction with the season suggesting the extreme conditions of the 2019/20 season had a relatively large negative impact on Evolution with a similar suggestion for Revelation. These two varieties may be susceptible to the extreme conditions experienced where late drilling, a very wet winter and a spring drought caused a relatively poor performance. The variety Skyfall also appears to have been quite negatively affected by the 2019/20 season. The variety Mortimer appears to show relative yield consistency even in extreme conditions of the 2017/18 and 2019/20 season. Despite a relatively poor performance in 2017/18 Siskin has performed well in the last two seasons, ranking 4th and 2nd respectively. This may suggest that Siskin is more vulnerable to a drought later in Spring experienced in 2018, than a drought earlier in Spring as experienced in 2020. Interestingly, Siskin showed severe drought symptoms of leaf rolling during the Spring of 2020 but was the 2nd highest yielding, with the symptoms perhaps an adaption to the drought conditions.

Organically/Biodynamically bred varieties from Europe have consistently ranked bottom for yield. (Table 3.0)

Table 3.0 Mean Yield Rank of Varieties tested each year from 2018-2020.

Average Yield Rank				
Variety	2018	2019	2020	Mean Rank
Crispin	**1**	**6**	**1**	**2.5**
Costello	**3**	**2**	**3**	**2.7**
Hallfreda		5	4	4.5
Dunston	5			5.0
Gleam	2		9	5.0
Mortimer	**4**	**7**	**5**	**5.2**
AWC-17			6	6.0
Sundance	6			6.0
Evolution		1	12	6.5
Siskin	**12**	**4**	**2**	**6.6**
Revelation	**7**	**3**	**11**	**7.0**
AWC2		8		8.0
Graham	8			8.0
Informer			8	8.0
Extase		10	7	8.5
Cougar		9		9.0
AWC-19			10	10.0
Gourmet	10			10.0
Skyfall	**9**	**11**	**20**	**12.9**
Olympus	13			13.0
Crusoe	14	13		13.6
Mv Fredericia	15	12		13.7
Montana		15	13	14.0
Maris Widgeon	**11**	**14**	**19**	**14.3**
Alabaster			15	15.0
Effendi			16	16.0
Moschus		16		16.0
Zyatt	**16**	**20**	**14**	**16.6**
Anapolis	17			17.0
AWC4		17		17.0
Red Lammas			17	17.0
Firely			18	18.0
Edelmann		19		19.0
AWC3		21		21.0
Pizza			21	21.0
Ehogold		22		22.0
WIWA			22	22.0
Ataro			23	23.0
Royal			24	24.0

Dynamic Stability

Across three years of the organic wheat variety trial eight core accessions (four feed and four milling) have been included across all years. A comparison of the regression slopes shows that three of the eight varieties differ significantly from the mean grand yield each season (slope=1) with Siskin showing improved yield performance in the higher yielding years but poorer performance in a lower yielding year whereas the varieties Skyfall and Maris Widgeon showed improved performance in an overall poorer yielding year but poorer performance in higher yielding years (chart 10.0). The variety Zyatt shows consistently poor performance whilst the varieties Crispin and Costello show consistently strong performance. The plot trial enables this kind of analysis across seasons but for varietal recommendations to be made for organic farming, varieties need to be tested across farm environments i.e., through a farm trial network to gain insight into how varieties perform under different weed burdens, soil types, local climates, and crop management conditions.

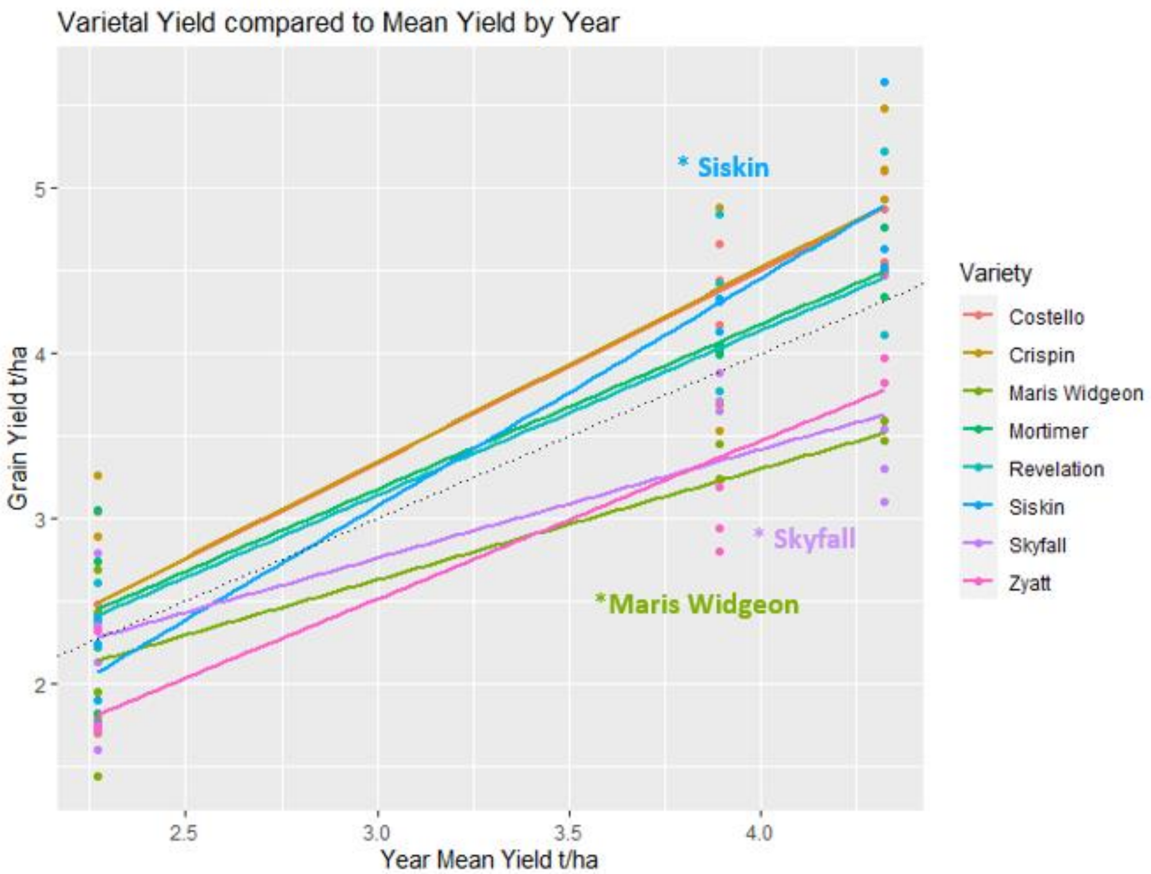


Figure 13.0 Grain yield of core 8 varieties across a gradient of three seasons with slopes compared to the grand mean yield (dotted line). Variety names with starts on graph show significant difference from grand mean slope with gradient 1.

Conclusion

The group 2 varieties tested in 2020 appear to offer a good option as high yielding (equivalent with the group 4s tested) but with breadmaking potential. Group 2 may represent a lower risk option compared with group 1 and group 4.

The Swedish variety Hallfreda has been tested for two years and has yielded consistently well and was also ranked favourite for a combination of desirable traits by a group of organic farmers in the

2019 trial. Hallfreda had a strong all round grain quality result and this season will be tested under the LiveWheat project on three organic farms to provide "real world" performance to assess its potential value for organic farming. The variety also has an additional desirable trait of bunt (*Tilletia tritici*) tolerance. Informer is another group 2 equivalent that will be tested again to confirm its potential for organic cultivation given a strong all round performance on yield and quality in 2020.

The French variety Mortimer has been included in the plot trial for three successive years and has shown a reliable and consistent yield ranking across years. It remains a variety with potential that requires validation through testing at a field scale on commercial organic farms.

Crispin is a hard group 4 variety that has shown adaption for organic farming not least due to its suitability for late drilling, its strong early vigour being quick to reach GS31, and its disease resistance. Performance across farms has shown reliability but the variety has now dropped from the RL meaning it is unlikely to be commercially available in the near future. The variety has been used to breed a successor with the new RL hard group 4 Cranium offering a potential alternative. With Crispin in its parentage Cranium appears to have the same traits that made Crispin a suitable variety for organic farming and has been included in this year's plot trial to gain insight into its potential for organic cultivation.

Whilst the yield performance of the organically bred varieties and the heritage types compared unfavourably to the modern varieties, it may be unfair to judge on a yearly yield basis given the additional positive traits these types possess. They should be thought of as making a rotational contribution with extra straw and root biomass adding organic matter to the farm and height and biomass offering greater weed competition which could see them used as part of an integrated weed control strategy, particularly where the weed burden may be high. In these environments the yield penalty for the heritage types is much lower and their competitiveness may help reduce the weed burden. In weedy environments, weed competitiveness of heritage types may actually lower the yield gap with those modern varieties lacking in weed competitive or weed tolerant traits. They may also possess enhanced grain qualities as indicated by protein, specific weight, HFN and endosperm hardness.

With respect to the plot trial approach the conclusion remains consistent, that it provides an opportunity to evaluate a large number of varieties free of additional variables for an accurate genetic comparison. Including novel lines can offer clues about varieties that may show suitability or desirable traits for organic farming but a single plot trial should not be used in isolation to make sector wide recommendations about varieties. A single plot trial, even run across multiple years, does not provide the information on the interactions between the varieties and farm environments (G*E) and the interaction of varieties and crop management (G*M) that is expected to be very significant in organic farming with limited external inputs to modify the environment, with particular respect to fertility and weeds. In addition, testing on farms is important because it is likely to be the first time commercial varieties are exposed to mechanical weeding, weed communities and low nitrogen availability. As stated previously, plot trial results may not be good predictors of actual on-farm field performance for organic farming (Kravchencko, 2017)

The plot trial should only be used for traits studies and for guidance to select varieties that need to be tested on and across farms to establish suitability for Organic cultivation. Actually, the only way for a farmer to truly understand which variety may suit their farm and management is to test themselves.

The varieties Mortimer, tested in three years and Hallfreda, tested in two years appear to be suited to organic farming but should not be recommended without testing across representative organic farms to establish suitability for commercial cultivation. This is also only based on field performance and agronomic merit but would need engagement from actors in the supply chain to establish end use suitability. Further quality assessments should be performed to help identify varieties that may show enhanced protein quality for bread making through their Glutenin:Gliadin ratios, or for feed through Amino Acid profiles.

Finally, even if all agronomic and quality criteria for organic suitability are satisfied, the variety will need to be commercially available and in high enough demand, both from organic and conventional farmers to warrant the investment in maintaining the variety, adding an additional barrier to successful introduction of varieties suited to Organic farming.

This plot trial supports work being carried out initially under the LiveSeed project and now under the LiveWheat project testing wheat varieties across a network of Organic and low-input farms.

Recommendations

For Farmers

- Take results from a single plot trial at a single location cautiously as evidence of potential but with the need for validation on your own farm under your environmental conditions and crop management.
- Try to use relative untreated yields from NL and RL trials and look for certain traits like suitability for late drilling and speed to GS31 to identify varieties with potential for organic/low input cultivation.
- Use the Vigour assessment in Spring to provide a simple method of weed competitiveness and as a predictor of crop performance.
- Select varieties not just for single year yields but as part of the cropping system.
- Consider diversification through varietal mixtures of the same end use categories to harness a range of positive traits, provide disease control, enhance yield stability and reduce risk.

For the Industry

- Organic farmers need data on varietal performance from organic environments.
- NL/RL trials to include “untreated with nitrogen” plots to establish varieties suitable for low/reduced nitrogen environments and to better understand the role of nitrogen in disease resistance/susceptibility.
- RL to include measures of “Spring Vigour” e.g., days to GS31 to provide organic and low input farmers with potential weed competitiveness.
- Carry out more trials under low input/organic conditions to help inform farmers wishing to reduce inputs while maintaining acceptable yields to improve the sustainability of wheat production.
- New varieties from Europe with limited data on performance in the UK under organic husbandry should be tested across a small representative network of commercial organic farms to validate suitability.
- Once varieties have been established as showing suitability for organic farming collective action by the sector is needed to ensure future seed supply.

- Involve more stakeholders including breeders, seed merchants, grain merchants, millers and bakers in organic variety testing.
- End users in the milling, baking and feed sectors sourcing organic wheat grain from overseas should consider supporting testing of additional quality parameters beyond commodity specifications such as protein quality and amino acid profiles to help identify varieties with "exceptional qualities" for a more holistic understanding of grain quality.

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