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United Kingdom Cereal Pathogen Virulence Survey 2022 Annual Report

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1 Grower summary

Wheat yellow rust

UKCPVS received far fewer samples in 2021 compared to the previous year, when disease pressure was higher. In 2021, the UK experienced adverse weather that impeded rust development. April was colder and drier than usual. In some parts of the country, heavy rainfall was not seen until early May.

Although the wheat yellow rust population remains diverse, no major disease-resistance breakdowns were observed. Most Recommended Lists (RL) varieties continued to perform as predicted from their RL rating. In 2022 adult plant trials, KWS Zyatt was the most susceptible current RL variety, followed by Skyfall.

Most RL varieties and candidates were resistant to all five isolates in seedling (young plant) tests. Although some infected KWS Siskin samples were received by UKCPVS, the variety remained resistant in all 2021 seedling virulence test and 2022 adult plant trials.

Wheat brown rust

Results from the 2022 adult plant trials aligned with RL results, with most varieties showing moderate-to-high levels of disease.

In seedling (young plant) tests, only Theodore was resistant to all five isolates. However, RGT Zinzan and RGT Wolverine also performed relatively well against the isolates in adult plant trials.

During the 2022 field season, UKCPVS received a report of higher-than-expected levels of brown rust on Theodore*.

Wheat and barley powdery mildew

UKCPVS seedling (young plant) tests continue to detect variation in powdery mildew populations. This variation does not appear to result in meaningful differences at the adult plant stage, because no reports of unexpected outbreaks of wheat or barley powdery mildew during 2021 or 2022 were received by UKCPVS.

***Monitoring disease in 2023**

Many factors affect disease development, including local environment, the global climate and variety choice. During the season, pathogen populations respond to conditions. In-season monitoring is critical to rapidly detect any changes in the pathogen population. Farmers and agronomists are advised to report unusual disease levels to the UKCPVS.

Access sampling details via the AHDB website: ahdb.org.uk/ukcpvs

2 Scientific summary

The UKCPVS monitors the populations of the important cereal pathogens *Puccinia striiformis* f.sp. *tritici* (*Pst*), causing wheat yellow rust, *Puccinia triticina* (*Pt*) causing wheat brown rust, *Blumeria graminis* f.sp. *tritici* (*Bgt*) causing wheat powdery mildew and *Blumeria graminis* f.sp. *hordei* (*Bgh*) causing barley powdery mildew.

Wheat yellow rust

The UK *Pst* population continues to show high levels of diversity since the incursion of the Warrior population in 2011. The current population remains dominated by isolates from the Red group and within that group there are a broad range of virulence profiles which continue to change. Several new combinations of virulence were detected in 2021, with one novel isolate showing virulence for *Yr8*. Five isolates displaying novel and existing pathotypes were investigated in the adult plant trials. Genotyping has been established and improvements in methodology are ongoing. The genotyping results confirmed that all isolates tested in 2021 belonged to the Red group.

Wheat brown rust

A new differential set was used for the sixth year to analyse the *P. triticina* population. As seen in previous years, virulence was detected for many of the *Lr* genes tested. Some changes were found, for example, virulence for *Lr20, Lr23* and *Lr28* increased, while virulence for *Lr3ka* and *Lr26* declined although no major changes in varietal performance were reported. Variety seedling tests highlighted that all RL varieties except Theodore were susceptible to at least one of the five races under evaluation.

Wheat and barley powdery mildew

Major changes in the *Bgt* population were seen accompanied by small changes in the *Bgh* population, but these results should be interpreted with caution due to the limited number of isolates tested. As in previous years no unusual outbreaks were reported so it is unlikely that these changes have translated into detrimental effects on variety performance.

3 Glossary

AIT	Average Infection Type score
APR	Adult Plant Resistance – some varieties have resistance that is effective at later growth stages.
Avirulence	Lack of virulence. The pathogen is unable to infect a host. Pathogen isolates can be virulent or avirulent.
Differential	Varieties/accessions that have known resistance genes. If an isolate (pathogen) can infect a particular differential then it is said to carry the corresponding virulence gene, it has overcome the resistance gene carried by that differential. Some differentials have more than one resistance gene.
Epidemic	Widespread occurrence of an infectious disease at a particular time.
Genotyping	Determination of the differences in genetic make-up (DNA) of an individual.
Genetic group	Groups together races of yellow rust based on how genetically related they are. The UKCPVS naming system uses a colour to denote each different genetic group.
Growth stage (GS)	Using the Zadoks scale. The Zadoks scale is a cereal development scale proposed by the Dutch phytopathologist Jan Zadoks that is widely used in cereal research and agriculture.
Host	The living organism (plant) on which the pathogen lives.
Inoculated	Infected by a pathogen.
Isolate	A strain or culture isolated for study. Individual isolates are created from infected leaf samples.
Pathogen	A bacterium, virus, fungi or other micro-organism that can cause disease.
Pathotype	A disease-causing variant of a microorganism. Distinguishable from other members of its species by its virulence profile and/or unique molecular markers. UKCPVS pathotypes list the virulence genes the isolate carries and includes abbreviations of other additional test cultivars infected at seedling stage in the differential test. The pathotype is sometimes referred to as the virulence profile.
PCR	Polymerase chain reaction, a laboratory technique used to rapidly make copies (amplify) a DNA sequence.
Race	Strains of a single pathogen species that differ in their ability to attack different varieties of the same host species.
Resistance	The ability of the host plant to hinder or arrest the development of the pathogen. Host cultivars can be resistant or susceptible. Partial resistance gives incomplete resistance against all genotypes of a pathogen.
Resistance gene(s)	Genes in plant genomes that convey plant disease resistance against pathogens. NB: many varieties carry a combination of resistance genes to help them defend themselves against pathogen invasion.
Seedling	In the case of UKCPVS seedling tests this refers to seedlings infected at the first-leaf stage (when the first leaf is fully expanded). Subsequent leaves are ignored.
Spores	Shortened name for urediniospores. Urediniospores are thin-walled spores produced by the uredium, a stage in the life-cycle of rusts. Rust pustules seen on the surface of leaves contain urediniospores.
Susceptible	Likely or liable to be harmed by a particular thing. Host cultivars can be resistant or susceptible.
Variety	Variety or cultivar always refers to the variety of the host plant, never to the pathogen.
Virulence	Refers to the pathogen's ability to infect or cause disease to a host. Pathogen isolates can be virulent or avirulent.
Virulence gene(s)	The gene whose presence in an organism genome which is responsible for the pathogenicity of an infective agent. If an isolate of rust carries a particular virulence gene then it is able to infect a host cultivar which carries the corresponding resistance gene.

4 Introduction

4.1 General introduction to the United Kingdom Cereal Pathogen Virulence Survey (UKCPVS)

4.1.1 Establishment of the survey

Wheat production in the UK is threatened annually by a number of pests and diseases. In our cool maritime climate the foliar diseases Septoria leaf blotch and yellow (stripe) rust are easily found. Warmer summers have also led to an increase in brown (leaf) rust which prefers warmer temperatures and can be serious if left unchecked on susceptible varieties. Current methods of control are based principally on fungicidal inputs, however for the latter two diseases host resistance plays an important role due to the high levels offered in some UK wheat varieties. Host resistance to the rust fungi is however subject to change and should be monitored as part of a virulence survey due to the ability of the pathogen to mutate and overcome some kinds of resistance. For this reason, the UK Cereal Pathogen Virulence Survey was established in 1967 following an unexpected outbreak of yellow rust on the previously resistant variety Rothwell Perdix.

4.1.2 Targets of the survey and pipeline for pathotyping

4.1.2.1 Targets

Known originally as the Physiologic Race Survey of Cereal Pathogens, the survey was conducted by a group of organisations including NIAB. The list of target diseases was longer and included wheat yellow rust, wheat and barley mildew, barley brown rust, barley leaf scald (*Rhynchosporium*), barley net blotch, oat crown rust, oat leaf spot and oat mildew. Over time the list of target species has reduced but the principals remain the same and in its 55th year the survey continues to provide information to growers, breeders and other interested parties on the population of these important pathogens. The survey currently limits its activities to monitoring the pathogens causing the diseases wheat yellow and brown rust and wheat and barley powdery mildew (**Figure 1**). A close eye is also kept on the incidence of barley yellow rust, which although rare currently, has been a problem in the past.

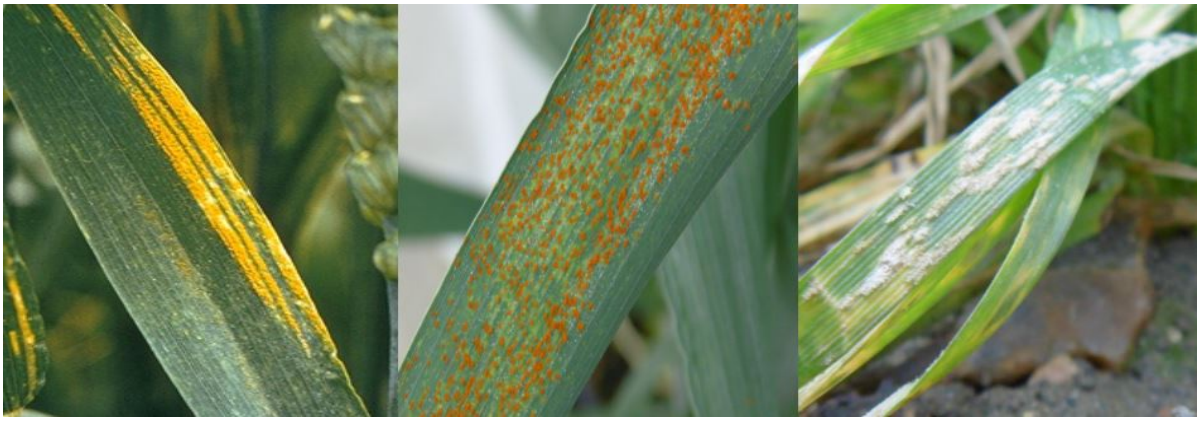

Figure 1: Classic symptoms of the cereal foliar pathogens yellow rust (left), brown rust (middle) and mildew (right).

4.1.2.2 Timescale of characterisation

Once a sample is received by the survey the causal agent is multiplied and stored for further testing. At the end of July when all the samples have been received the list is scrutinised and

at least 25 samples are selected per disease for further characterisation using a differential test. The differential tests follow a worldwide standard procedure where the different isolates of rust or mildew are inoculated onto a set of different varieties ("differentials") whose underlying resistance gene(s) are known (designated *Yr, Lr, Pm, Ml* or similar for yellow rust, brown rust, wheat mildew and barley mildew, respectively). Other varieties carrying uncharacterised sources of resistance are also included in these tests. By assessing whether the isolate can cause disease on the individual varieties (termed as virulent) or not (termed avirulent) allows the isolate to be characterised and compared with isolates previously identified within the UKCPVS and with colleagues elsewhere in the world. A new race is declared when virulence for a particular resistance gene, gene combination or variety is detected which has not been seen before in the UK.

4.1.3 Key virulence changes over the years: wheat yellow rust

In 2011 a new race of yellow rust, the Warrior race, was identified that appeared to be similar to previous races, but with additional virulence for the resistance gene *Yr7* and the variety Spaldings Prolific. It is important to note that virulence for the resistance gene *Yr7* had been seen before, but not in combination with virulence to the resistance genes *Yr6, Yr9, Yr17* and *Yr32.* There were, however, other pieces of evidence to suggest that the Warrior race was different to previous races, with abundant production of the sexual stage spores (teliospores) and multiple sightings of the new race across Europe in the same year. Further molecular genotyping of the Warrior race has shown that this new race was a foreign incursion and not a mutation of the existing population (Hovmøller *et al*., 2016; Hubbard *et al*., 2015). The Warrior race was also characterised by its high population diversity, indicating that it was likely to be derived via sexual recombination, and not the asexual mutation that previously characterised the UK population (Ali *et al*., 2014; Hovmøller, Justesen, and Brown 2002). The population diversity identified in the Warrior race highlighted that the incursion was of multiple isolates, in effect a population, rather than a single isolate or race.

Since the arrival of the Warrior group of isolates in 2011, existing European populations have been replaced so that the population is now dominated by isolates classified as members of the Warrior group (Hovmøller *et al*., 2016; Hubbard *et al*., 2015). In 2015 the UKCPVS confirmed that an additional race had arrived in the UK, the Kranich race (since renamed Purple 3) and later that year the Blue 7 group of isolates were detected (Hubbard, Pritchard, and Holdgate 2016). An epidemic year followed the arrival of these two groups of isolates, although it was later found that another group, Red 24, first detected in 2016, was the most likely culprit for substantial changes to Recommended List (RL) ratings that year (Hubbard, Wilderspin, and Holdgate 2017). An unusual outbreak on KWS Zyatt and Dunston in some parts of the country was identified during 2019. After close examination of UKCPVS adult plant trials carried out in 2019, a Red 27 isolate was identified as the likely cause of the outbreak. In 2021 three isolates were found to carry virulence for *Yr8* and one isolate carried virulence for Crusoe. The most common pathotypes identified from the seedling differential test data were Red 36, Red 37 and Red 41.

4.1.3.1 Changes in naming of races

With the recent race changes affecting the UK and across Europe, the UKCPVS has sought to redefine the naming system for new races. A meeting between virulence surveys from across Europe in 2016 failed to reach a consensus of how to deal with such a diverse pathogen

population. In the UK a system has now been proposed to take into consideration the genetic data produced by the John Innes Centre as well as the pathotype data generated by the UKCPVS. The races are now assigned a colour to divide the races into their genetic groups using the genotype data and then a number to divide the isolates according to the pathotype data. The colour group is based on that produced in the STRUCTURE programme used to analyse the data and the number is assigned sequentially. So, for example, the race Blue 1 will have been discovered in advance of Blue 2. Using this system it will be possible to separate races that may otherwise look similar. During this renaming process, colleagues at the Global Rust Reference Centre also developed a new naming system which groups races into PstS groups (Ali *et al*., 2017). This system takes a broader approach to naming races so that individual races are not named, rather they are included into the broad groups and important races within the group are highlighted. Translation between the two systems is ongoing.

4.1.4 Key virulence changes over the years: wheat brown rust

Surveillance of the *Puccinia triticina* (formerly *P. recondita*) population in the UK began a little later than surveys for the other cereal diseases, starting in 1973 with samples collected from 1972. Colleagues at the Welsh Plant Breeding Station (now Institute of Biological, Environmental and Rural Sciences at the University of Aberystwyth) managed the survey of this pathogen until 2006 when the survey was transferred to NIAB. In the early stages of this programme there was very little known or developed in the way of differential sets, and the initial screening of isolates was conducted using a selection of winter and spring wheat varieties from the RL of that year along with some research lines from a Septoria leaf blotch resistance screen. From here, nine varieties were selected that were able to differentiate between the isolates and included current differentials Maris Halberd and Sappo. Like today, wheat brown rust is less important than wheat yellow rust, and at the start of the survey, there were only limited options for resistant varieties, for example Clement, which carried the gene *Lr26* (also referred to as WBR1). Official ratings of resistance to wheat brown rust were not introduced onto the RL until 1977. Dominant races of *P. triticina* tend to match commonly deployed host resistance genes. For example, use of the resistance gene *Lr1* in the variety Glasgow led to the emergence of the Glasgow race in 2005 which carried virulence for this resistance gene (Table 1). Once the acreage of varieties carrying these resistance genes reduces, the frequency of finding these isolates reduces. An example is virulence for *Lr24*. The two varieties carrying this resistance gene (Warrior and Stigg) are no longer widely grown and the population has therefore mirrored this and the frequency of detection continues to decline. In 2014, a change to the population overcame the moderate resistance in the variety Crusoe, however, it is still unclear what resistance gene has broken down. Over recent years pathogen populations have remained relatively stable, however, an unusual outbreak on KWS Firefly in some parts of the country was identified during 2019. In 2021 there were minor changes in virulence frequencies but this was not accompanied by reports of varietal breakdowns.

Table 1: Key wheat brown rust changes in the UK since the start of the survey.

Year	Variety	Key Resistance Gene Combination
1973*	Sappo	*Lr20* (WBR3)
1973*	Maris Halberd	*Lr20* (WBR4)
1974*	Maris Fundin	*Lr17b* (WBR2)
1976	Maris Huntsman	WBR5 (APR)
1977	Clement	*Lr26* (WBR1)
1977	Sterna	*Lr3a* (WBR7)
1978	Maris Ranger	WBR8
1980	Avalon	WBR9
1982	Gamin	WBR6
1991	Slejpner	*Lr26* + APR
1993	Spark	Not specified
1994	Flame	Not specified
1995	Chablis	*Lr3a* + ?
1999	Rialto	*Lr17b, Lr26* + APR
2005	Glasgow	*Lr1*
2005	Claire	*Lr3a, Lr17b, Lr20, Lr26,* APR
2006	Robigus	*Lr28*
2006	Multiple *Lr37* varieties	*Lr1,Lr3a,Lr17b,Lr26,Lr37*
2011	Stigg	*Lr24*
2014	Crusoe	*Unknown*

* Tested for the first time, virulence may have been present in previous years.
APR = Adult plant resistance

4.2 Aims and objectives

The principal aim of the project is to detect new races of economically important pathogens for UK growers to provide an early warning system that will aid effective disease management. To achieve this, the UKCPVS currently monitors the populations of the fungi causing wheat yellow rust and brown rust and wheat and barley powdery mildew. A subset of the isolates collected will be characterised to identify any new races. The reactions of the current RL varieties and candidates will be assessed using some of the newest isolates at both the seedling and adult plant stages to establish future risks of disease outbreaks.

5 Materials and methods

5.1 Wheat yellow rust and wheat brown rust

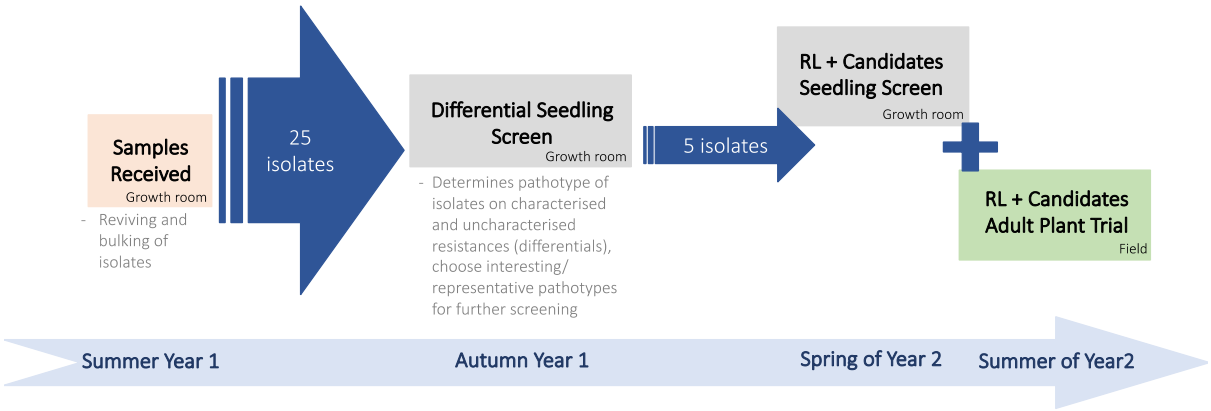

Figure 2: Wheat yellow rust and wheat brown rust sample processing pipeline.

5.1.1 Collection of samples and preparation of isolates

Infected wheat leaves were received from growers, agronomists and operators of RL trials. Spores from the infected samples were transferred on to plants of the universally susceptible variety Victo or Vuka (wheat yellow rust) or Armada (wheat brown rust). Plants were grown under controlled environment conditions on Burkard isolation benches until fresh sporulation was evident. Spores were collected and used to re-infect further pots of the susceptible varieties until enough spores were available to inoculate a differential test.

5.1.2 Characterisation of isolates using differential tests

Seedlings of the differential set were grown in modules (**Figure 3**) and inoculated with spores from the new isolates, using a complete set of differential varieties for each isolate under test (Hubbard *et al.*, 2015). The differentials used and the resistance genes they carry are listed in **Supplementary Table 1** and **Supplementary Table 2**. Approximately 14 days post inoculation the tests were scored using a 0 - 4 scale which was then converted into an average infection type score (AIT). A score of 0 - 2.3 indicates an incompatible (avirulent) reaction, a score of 2.4 - 2.6 represents a borderline reaction and should be treated with caution as it is difficult to be certain whether the reaction is one of virulence or avirulence, and scores of 2.7 – 4.0 indicate a compatible reaction and the isolate is virulent on that differential.

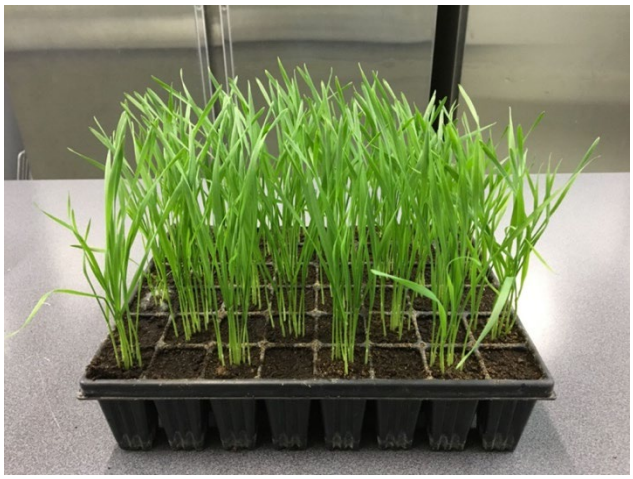

Figure 3: Example of differential seedling test set up.

5.1.3 Characterisation of isolates using variety seedling tests

The isolates under evaluation in the field trials were also used in parallel experiments under controlled environment conditions to assess the seedling reaction of the varieties used in the adult plant tests. These tests were set up and inoculated in the same way as previous differential tests, and assessments were carried out using the same AIT scoring system.

5.1.4 Characterisation of isolates using adult plant trials

Varieties from the current RL, RL candidate varieties and selected control varieties were hand sown in tussock plots for evaluation under field conditions to selected isolates (**Figure 4**). Each of the three isolates were tested in separate trials and each trial consisted of two replicates. As an alternative to foliar fungicide applications to eliminate natural infection, plots were directly inoculated every 7-14 days from approx. GS 23 onwards, with the aim of increasing disease pressure of the target isolate and preventing natural influx which can confound experimental results in high disease pressure seasons. The wheat yellow rust and brown rust trials were individually inoculated eight times. Assessments were made from inflorescence onwards until senescence.

Figure 4: Tussock plots for the evaluation of adult plant resistance under field conditions.

5.1.5 Characterisation of yellow rust isolates using extended daylength growth room trials

In the summer of 2022 extended daylength trials were performed on adult plants in the growth rooms. A subset of thirteen RL varieties and two control varieties were chosen for extended daylength trials. Plants were initially grown under an extended daylength regime with a 22 hour daylength/2 hour dark period and upon reaching GS39 (flag leaf fully unrolled, ligule just visible) they were moved to another controlled environment growth room and placed under standard long day conditions for optimum yellow rust development (16 hours day length/8 hours dark period). The plants were inoculated with two isolates from the 2021 Survey that had already been selected for use in outdoor adult plant field trials, WYR 21/014 and 21/045. After two weeks, percentage infected leaf area was scored on the three different leaf layers, the flag leaf was labelled leaf 1. The scores were an average of two assessments, with the second assessment being a further week later. The mean percentage leaf area infection for each variety was also recorded.

5.2 Wheat and barley powdery mildew

5.2.1 Collection of samples and preparation of isolates

Infected leaves were received from growers, agronomists and trials operators for the RL trials. Individual pustules taken from the infected samples were mounted on agar and when sporulation was seen the pustules were transferred onto fresh detached leaf sections using the universally susceptible varieties Cerco (wheat mildew) and Golden Promise (barley mildew). Subsequent transfers onto new detached leaves were conducted to maintain the isolate.

5.2.2 Characterisation of isolates using differential tests

Seedlings of the differential set were inoculated with spores from the new isolates. The differentials used and the resistance genes they carry are listed in Table 15 and **Table 16.**. Each differential was represented by four detached leaf sections, giving four replicates. This was to ensure the maximum amount of information was obtained using the small amount of spores available. Approximately 14 days post inoculation the detached leaves were scored using a 0 - 4 scale. The score for each of the four detached leaf sections was then averaged to give the final score for each differential. A score of 0 - 2.5 indicates an incompatible (avirulent reaction) and a score of 2.75 - 4 indicates a compatible reaction and the isolate was virulent on that differential.

5.2.3 Characterisation of isolates using adult plant field trials

No adult plant field trials were carried out as part of the UKCPVS mildew survey.

5.3 Wheat yellow rust genotyping

5.3.1 Sample preparation

Infected leaf segments were taken from the sporulating pots of the susceptible variety used to bulk the initial isolate and stored at -80 °C.

5.3.2 DNA extraction and amplification of genes

Genomic DNA (gDNA) was extracted from 48 samples from 2021 using the Qiagen DNeasy Plant Pro kit (Qiagen), following the manufacturer's protocol. The quantity and purity of the gDNA were determined using the NanoDrop (Thermo Fisher Scientific) spectrophotometer and the Qubit 2 Fluorometer (Thermo Fisher Scientific). A total of 242 variable *Pst* genes were amplified from the gDNA samples via multiplex PCR, followed from the MARPLE pipeline described by Radhakrishnan *et al*. (2019). Five pools containing different concentrations of optimised primers were amplified with Q5® Hot Start High-Fidelity 2X Master Mix (New England Biolabs, USA), modified from Radhakrishnan *et al*. (2019). PCR conditions used were 98 °C for 30 s, 40 cycles of 98 °C for 10 s, 63 °C for 30 s and 72 °C for 2 min 30 s, and a final extension of 72 °C for 2 min.

5.3.3 Library preparation and sequencing

Following PCR amplification of the *Pst* genes, an equal mass of purified PCR products from each of the five primer pools were combined prior to library preparation. The amplicon libraries were prepared using Ligation Sequencing Kit (LSK108) with native barcoding (Oxford Nanopore Technologies, UK). Twelve libraries were pooled and were sequenced on the GridION platform on a R9.4.1 flow cell (Oxford Nanopore Technologies, UK) overnight, following the manufacturer's instructions. The flow cell was washed and another 12 pooled 2021 libraries were sequenced on the flow cell, overnight. The other 24 libraries were sequenced on a second flow cell, in the same fashion as the first.

5.3.4 Phylogenetic analysis

A maximum-likelihood approach with RAxML was used for phylogenetic analysis, following Radhakrishnan *et al*. (2019). The phylogenetic tree was visualised with ggplot using R Studio.

6 Results and discussion

6.1 Wheat yellow rust

6.1.1 Samples received

In 2021 the UKCPVS received 155 samples of wheat yellow rust from 19 different counties across the UK (**Figure 5**).

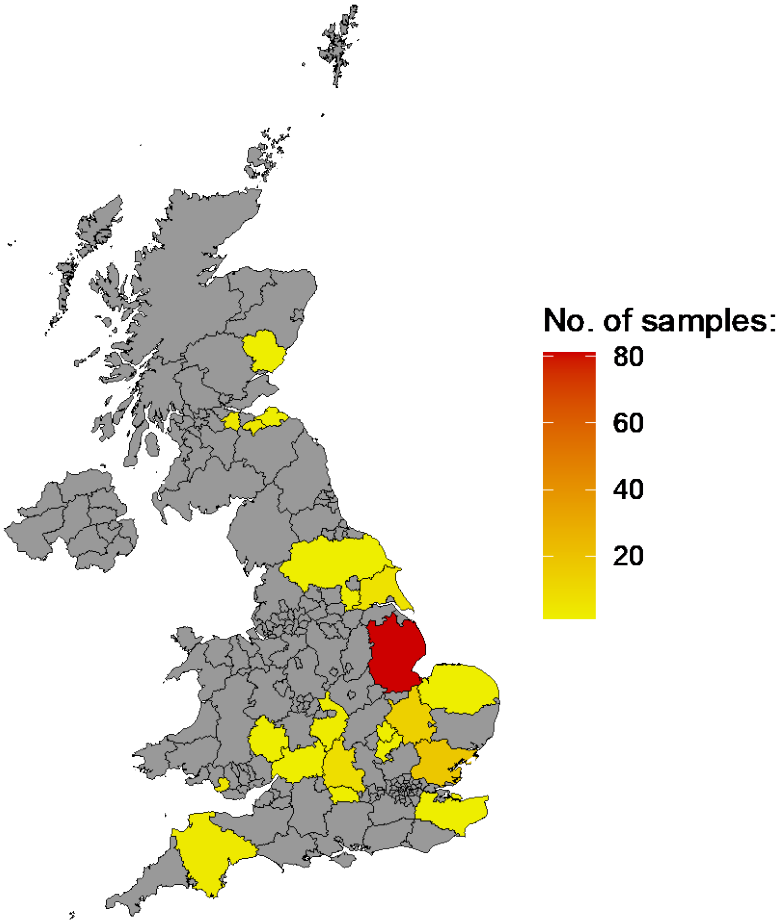

Figure 5: Map of the UK with the number of samples of wheat yellow rust received in 2021 from the different counties.

Disease pressure was lower compared to that experienced in 2020 and this may have been due to the adverse weather experienced by the UK in 2021, April was colder and drier than usual impeding rust development and heavy rainfall was not seen until early May.

The UKCPVS did receive some reports of unusual sightings such as yellow rust in the resistant cultivar KWS Siskin, currently rated a 9 (2022/23) for yellow rust on the Recommended List. Four samples were received from this cultivar in 2021.

In total, samples were received from 54 different varieties consisting of current and past RL varieties, spreader plots and other breeding lines. For the third year running the most sampled variety was KWS Firefly which was closely followed by Skyfall. The full sample register is provided in **Appendix I: Sample Register**. It is important to note that the host varieties in the sample register have not all been confirmed and it is entirely possible that a sample listed as coming from a resistant variety may turn out to be from another more susceptible variety. For

this reason, the sample register is included as an indicator of what was received but should not be used to infer any breakdowns in resistance or changes in rating at this stage.

6.1.2 Pathotyping of isolates

6.1.2.1 Virulence for individual resistance genes and varieties

Forty isolates were selected for further pathotyping (**Supplementary Table 1** and **Table 2**). This number is higher than in recent years due to lower number of wheat brown rust samples received. The isolates were selected based on their county of origin and resistance rating of the host but also took into consideration any notable comments reported by the sampler. Isolates were assessed for their reactions on a differential set and their reactions, expressed as an average infection type (AIT), were recorded. Isolates were classified as virulent if the AIT score was 2.7 or above. Scores between 2.4 and 2.7 were considered borderline. Using these scores, it was possible to combine the scores for reactions to different resistance genes to infer a pathotype for each of the isolates (**Table 2**).

No new virulences to individual resistance genes were detected in the isolates collected in 2021 using the differentials tested at the seedling stage. Changes in frequency of virulence for known individual resistance genes remained relatively minor in comparison to previous years (**Table 3**). A total of 8% of isolates showed virulence for *Yr8*, which was an increase in the percentage of isolates carrying virulence from the previous year. In addition, the virulence for the variety Warrior increased from 43% in 2020 to 73% in 2021. Virulence for Evolution, which has fluctuated widely over the years, decreased from 73% in 2020 to 38% of isolates in 2021. Virulence for Apache, which carries the resistance genes *Yr7 and Yr17*, was seen in all isolates tested. It is unclear at this stage whether these recent changes are significant.

6.1.2.2 Virulence frequencies for pathotype groups

Previously some isolates have been assigned to different genetic groups using tools developed in the Field Pathogenomics project (Diane Saunders, *pers. comm.*, **Table 2**). In the cases where this information was unavailable at the time of writing, the isolates were classed according to the pathotype data only based on results from previous years. There were also a number of isolates which could not be classified into a genetic group due to the expression of seemingly novel pathotypes.

Table 2: Pathotypes of the 2021 wheat yellow rust isolates based on the differential test results in **Supplementary Table 1**. Yellow shading indicates virulence of an isolate for a particular resistance gene or variety; orange shading with parentheses indicates a borderline reaction.

Isolate code	Host	Race Number[1]	Virulence Profile[2]																								
			1	2	3	4	5	6	7	8	9	10	15	17	24	25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	Ev
21/003	LG Skyscraper	Red 34	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca			Ap		Ev
21/005	LG Skyscraper	Red 74	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So			St		Ap		Ev
21/008	LG Skyscraper	Red 83	1	2	3	4		6	7	8	9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/011	Graham	Red 41	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St		Ap		
21/012	KWS Chilham	Red 36	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/014	LG Skyscraper	Red 41	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St		Ap		
21/027	KWS Extase	Red 36	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/029	KWS Extase	Red 43	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca			Ap		
21/034	RGT Saki	Red 3	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So		Ca			Ap		
21/036	Graham	Red 36	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/037	Elation	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
21/045	Skyfall	Red 83	1	2	3	4		6	7	8	9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/046	Graham	Red 41	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St		Ap		
21/054	KWS Siskin	Red 76	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa		St		Ap		Ev
21/055	KWS Siskin	Red 72	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa		St	Kr	Ap		Ev
21/057	KWS Firefly	Red 19	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So			St		Ap		
21/065	Nogal	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
21/066	KWS Kinetic	Red 77	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca		Kr	Ap		Ev
21/081	Claire	Red 28	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So		Ca	St		Ap		Ev
21/082	Stigg	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
21/083	Apache	Red 36	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/089	RGT Illustrious	Red 78	1	2	3			6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	(Cr)	
21/096	KWS Kerrin	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
21/102	KWS Jackal	Red 79	1	2	3	4		6	7	8	9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	Ev
21/105	LG Astronomer	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
21/108	KWS Barrel	Red 80	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So			St	Kr	Ap		Ev
21/110	KWS Extase	Red 41	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St		Ap		
21/111	KWS Siskin	Red 36	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/120	Graham	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
21/126	Skyfall	Red 7	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So		Ca	St		Ap		
21/131	LG Prince	Red 28	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So		Ca	St		Ap		Ev
21/132	RGT Wolverine	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
21/133	KWS Cranium	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
21/135	RGT Wolverine	Red 11	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So		Ca	St		Ap		
21/136	SY Insitor	Red 43	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca			Ap		
21/138	Crusoe	Red 81	1	2	3			6	7		9			17		25	32	Re	Sp	Ro	So		Ca	(St)		Ap		Ev
21/142	Skyfall	Red 25	1	2	3			6	7		9			17		25	32		Sp	Ro	So	(Wa)	Ca			Ap		
21/143	Skyfall	Red 41	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St		Ap		
21/147	RGT Wolverine	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
21/154	KWS Extase	Red 82	1	2				6	7		9			17		25	32		Sp	Ro	So		Ca			Ap		

[1] Race number assigned by the UKCPVS using pathotype data in **Supplementary Table 1**.

[2] Numbers refer to previously designated *Yr* genes, Re = Rendezvous, Sp = Spaldings Prolific, Ro = Robigus, So = Solstice, Wa = Warrior, Ca = Cadenza, St = KWS Sterling, Kr = Kranich, Ap = Apache, Cr = Crusoe, Ev = Evolution.

Table 3: Frequency of detection of isolates carrying virulence to the different yellow rust resistance genes and varieties over the past five years.

Virulence For Resistance Gene or Variety	Percentage of Isolates Identified with Virulence for Gene or Variety				
	2017	2018	2019	2020	2021
Yr1	96	97	94	100	100
Yr2	100	100	100	100	100
Yr3	100	100	94	100	98
Yr4	100	100	97	100	90
Yr5	0	0	0	0	0
Yr6	100	100	100	100	100
Yr7	100	100	100	100	100
Yr8	4	0	16	3	8
Yr9	100	100	94	100	100
Yr10	0	0	0	0	0
Yr15	0	0	0	0	0
Yr17	100	100	100	100	100
Yr24	0	0	0	0	0
Yr25	100	100	100	100	100
Yr32	100	100	100	100	100
Rendezvous	96	67	48	87	73
Spaldings Prolific	96	100	81	100	100
Robigus	100	100	100	100	100
Solstice	100	100	100	100	100
Warrior	46	20	61	47	73
Cadenza	96	93	77	83	88
KWS Sterling	89	17	55	70	80
Kranich	7	0	29	33	43
Apache	96	83	68	93	100
Crusoe	7	0	10	7	3
Evolution	75	40	19	73	38
Total Number of Isolates	**28**	**30**	**31**	**30**	**40**

Table 4: Pathotype group frequencies from the past five years.

Pathotype Group*	Frequency of Isolates Found (%)				
	2017	2018	2019*	2020*	2021*
Pink	0	0	7	3	0
Blue	3	0	0	0	0
Red	93	93	74	97	100
Purple	0	3	0	0	0
Other	4	4	19	0	0
Number of Isolates	**28**	**30**	**31**	**30**	**40**

* Genetic groups have been assigned using genotyping data where available. Novel isolates are currently classified as 'Other' until a genetic group can be assigned. Figures are correct at the time of publication and may be updated in future reports.

6.1.2.3 Commonly detected isolates

In 2021 there were 22 different pathotypes detected (**Table 2**), seven of which were unique to this year. The genotyping results (see **Section 6.1.4**) showed that all 2021 isolates fell into the Red group (**Table 4**).

The three most common groups of isolates in 2021, equally represented by 12.5% of isolates, were Red 36 with the pathotype *Yr1,2,3,4,6,7,9,17,25,32*,Re,Sp,Ro,So,Wa,Ca,St,Kr,Ap; Red 37 which has the pathotype *Yr1,2,3,4,6,7,9,17,25,32,*Re,Sp,Ro,So,Wa,Ca,St,Kr,Ap,Ev and Red 41 pathotype *Yr1,2,3,4,6,7,9,17,25,32*,Sp,Ro,So,Wa,Ca,St,Ap.

No correlation between pathotype and location was found when the data was examined.

No isolates from the Pink, Purple or Blue pathotype groups were found in 2021.

6.1.3 Variety testing of isolates from 2021

Five isolates from the forty isolates tested were selected for further testing on the wider set of RL varieties and candidates (**Table 5**). Each year's isolates are selected to best represent the results of the tested isolates, choosing isolates with the most complex or novel virulence profiles where possible. In 2021, the isolates WYR 21/012, 21/014, 21/045, 21/102 and 21/135 were selected due to their novel and common pathotypes.

Table 5: Virulence profile of the isolates chosen for further characterisation in seedling and adult plant tests.

Isolate code	Host	Race Number[1]	Virulence Profile[2]																								
			1	2	3	4	5	6	7	8	9	10	15	17	24	25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	Ev
21/012	KWS Chilham	Red 36	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/014	LG Skyscraper	Red 41	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St		Ap		
21/045	Skyfall	Red 83	1	2	3	4		6	7	8	9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		
21/102	KWS Jackal	Red 79	1	2	3	4		6	7	8	9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	Ev
21/135	RGT Wolverine	Red 11	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So		Ca	St		Ap		

Re = Rendezvous, Sp = Spaldings Prolific, Ro = Robigus, So = Solstice, Wa = Warrior, Ca = Cadenza, St = KWS Sterling, Kr = Kranich, Ap = Apache, Cr = Crusoe, Ev = Evolution. Yellow shading = compatible reaction (virulence), blank = avirulence, * = missing data.

6.1.3.1 Variety seedling tests

The five selected isolates were tested in seedling tests containing RL and candidate varieties in the controlled environment rooms at NIAB in the spring of 2022. Results are combined with the adult plant test results (**Table 6**) and are sorted by the reaction on the adult plant trials (see **Section 6.1.3.2**). Twenty-six of the RL and RL candidate varieties were resistant to all five isolates at seedling stage.

Virulence for Crusoe, first detected in 2013, continues to be detected in occasional isolates, such as 19/038 and 19/215 in 2019 and 20/293 and 20/304 in 2020. Isolate 21/102 was found to be virulent on Crusoe in initial seedling differential tests but gave a borderline reaction of 2.4 in the subsequent variety seedling tests. At the adult plant stage Crusoe remained resistant to all five isolates tested.

In general, there was good agreement between the control differentials included in this test and the original differential test results (**Table 7**). This data is combined with the seedling test results of the re-isolates sampled directly from the inoculated trials. Some variation was seen in the "supplementary" differentials, these are differentials that are included as they carry currently uncharacterised resistance genes. The reasons for these discrepancies are unclear, although it is possible that despite our best efforts and following subsequent rounds of multiplication one or more of the isolates are more heavily selected for, hence the differences. The re-isolates may show that natural infection contamination could have been present late in the season but this did not seem to adversely affect the trial results.

6.1.3.2 Adult plant tests

Alongside the seedling tests, the five isolates were also evaluated in the UKCPVS adult plant trials at NIAB in the summer of 2022 which contained RL and candidate varieties. Plots were directly inoculated early in the season to help keep natural infection at bay and inoculated every 7-14 days until the flag leaf had fully emerged. The first inoculation was carried out on the 29th March 2022 and the first assessment was made on 20th May when the plants were at GS50. The percentage of plot area infected was assessed and the mean was calculated from four assessments (**Table 6**).

Disease levels were moderate to high in the trials. Long dry periods of hot weather without rainfall during the season may have impacted on disease development but infection levels in the susceptible control varieties were considered good. In combination with results from the control varieties included in the trials, the adult plant results suggested that the trials were generally infected with the correct races. As expected, the susceptible control Robigus produced the highest levels of disease with up to 53.3% mean plot infection in the trial infected with 21/012. KWS Zyatt was the most susceptible current RL variety in trials, followed by Skyfall. Many of the RL and RL candidates under test were resistant to all five isolates (**Table 6**).

During the 2021 field season, the most commonly sampled variety was KWS Firefly. In these adult plant trials KWS Firefly showed low to low/moderate levels of infection and was resistant in the trial inoculated with 21/045 (**Table 6**).

Table 6: Seedling and adult plant reactions to the five isolates selected for further characterisation. Seedling results are shown as average infection types on a scale of 0-4. Adult plant results are given as a percentage leaf area infected averaged over four assessments. Varieties are ordered in level of disease at adult plant stage. Control varieties are highlighted in green text.

Variety	RL Rating 2022/23	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		21/012	21/014	21/045	21/102	21/135	21/012	21/014	21/045	21/102	21/135
CRUSOE	9	0.1	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
KWS BRIUM	9	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
KWS DAWSUM	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KWS GUIUM	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KWS PALLADIUM	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LG TYPHOON	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
THEODORE	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELICIT	8	3.0	2.6	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0
KWS CRANIUM	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KWS JACKAL	8	2.9	1.9	3.0	2.4	3.0	0.0	0.0	0.0	0.0	0.0
LG ASTRONOMER	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LG PRINCE	8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RGT SAKI	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KWS ULTIMATUM	Candidate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KWS ZEALUM	Candidate	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
KWS SISKIN	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
MAYFLOWER	9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
ELATION	8	2.6	0.6	3.0	2.7	0.3	0.1	0.0	0.0	0.0	0.0
KWS EXTASE	8	0.0	0.0	0.0	2.3	0.0	0.0	0.1	0.0	0.0	0.0
RGT RASHID	8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
GRAHAM	7	3.0	3.0	3.0	3.0	3.0	0.1	0.0	0.0	0.0	0.0
OXFORD	Candidate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
MERIT	8	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.0
COSTELLO	9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.6
RENDEZVOUS	-	3.0	0.0	2.9	3.0	3.0	0.1	0.1	0.0	0.0	0.5
STRATOSPHERE	-	3.5	3.0	1.6	3.0	3.0	0.3	0.1	0.1	0.2	0.0
LG SKYSCRAPER	7	3.0	3.0	3.0	3.0	3.0	0.4	0.2	0.0	0.1	0.0
CHAMPION	8	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.0	0.1	0.0
LG REDWALD	Candidate	3.0	2.5	3.0	3.0	3.0	0.2	0.4	0.0	0.0	0.6
RGT WILKINSON	Candidate	3.0	0.0	3.0	3.0	3.0	1.1	0.0	0.0	0.2	0.0
ZOOM	Candidate	3.0	3.0	3.0	3.0	3.0	0.2	0.8	0.0	0.8	0.1
RGT BAIRSTOW	7	0.0	0.1	0.0	0.0	0.0	0.8	0.9	0.0	0.1	0.4
RGT STOKES	7	0.0	0.0	0.0	0.0	0.0	0.9	0.6	0.3	0.2	0.2
COUGAR	-	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.2	0.4	0.8
WARRIOR	-	1.1	1.5	1.4	2.7	0.0	0.1	0.8	0.0	1.3	0.0
LGW110	-	0.0	3.0	0.5	2.6	0.0	0.0	2.4	0.0	0.0	0.0
LG ILLUMINATE	7	0.0	0.0	0.0	0.0	0.0	1.2	0.1	0.0	2.9	0.1
AMBITION	-	0.0	2.7	2.1	2.5	0.0	0.2	2.4	0.0	1.7	0.1
RGT ILLUSTRIOUS	8	3.0	0.0	2.8	3.0	3.0	1.2	2.1	0.0	0.0	1.5
SY COACH	Candidate	3.0	2.9	3.0	3.0	3.0	5.4	0.8	0.0	0.2	0.0
KRANICH	-	2.7	0.0	2.1	3.0	0.6	0.0	5.9	0.0	1.0	0.1
SWALLOW	6	0.0	0.3	0.0	0.0	0.0	1.5	2.5	0.6	0.9	1.9
SY INSITOR	5	3.0	3.0	3.0	3.0	3.0	4.9	0.3	1.9	1.2	0.0
KWS FIREFLY	6	0.0	0.0	0.0	0.0	0.0	7.9	2.2	0.0	2.7	1.1
GLEAM	5	2.5	1.7	3.0	3.0	0.4	6.9	4.2	0.5	3.1	0.8
KWS GATOR	-	0.0	1.9	0.2	3.0	1.3	9.4	1.7	2.6	6.8	0.5
KWS WRENUM	Candidate	3.0	2.1	3.0	3.0	3.0	7.6	9.6	1.4	3.2	3.1
MINDFUL	Candidate	3.0	0.0	0.1	3.0	3.0	8.8	6.9	1.6	2.6	8.1

Variety	RL Rating 2022/23	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		21/012	21/014	21/045	21/102	21/135	21/012	21/014	21/045	21/102	21/135
KWS WEBBUM	Candidate	3.0	3.0	2.7	3.0	3.0	17.4	4.6	0.2	7.0	0.2
KWS BARREL	6	3.0	0.0	3.0	3.0	3.0	7.9	11.1	1.0	4.9	8.9
TORCH	-	3.0	3.0	3.0	2.4	2.0	3.6	10.8	3.7	16.0	2.9
DELPHI	-	1.6	0.9	2.6	3.0	1.6	12.0	4.8	0.0	12.9	12.6
APACHE	-	3.0	2.5	3.0	3.0	3.0	9.5	11.8	7.6	6.1	8.4
GEFION	Candidate	2.4	0.0	2.6	3.0	0.0	20.0	6.0	2.6	12.0	8.3
CADENZA	-	3.0	3.0	3.0	3.0	3.0	14.0	14.6	8.2	7.1	9.9
KWS STERLING	-	3.0	2.2	3.0	3.0	3.0	10.0	26.9	8.6	4.7	12.8
RGT WOLVERINE	4	3.1	3.0	3.0	3.0	3.0	20.4	18.1	9.1	10.2	12.6
HOBBIT	-	3.0	3.0	3.0	3.0	3.0	12.2	18.5	9.3	18.0	13.8
SOLSTICE	-	3.0	3.0	3.0	3.0	3.0	22.6	18.5	7.1	12.2	16.6
CLAIRE	-	3.0	3.0	3.0	3.0	2.7	27.9	11.1	8.0	24.5	12.1
REFLECTION	-	3.0	3.0	3.0	3.0	3.0	33.8	11.5	5.9	28.5	17.9
CORDIALE	-	3.0	3.0	2.1	1.5	3.0	26.0	27.6	14.0	22.3	18.9
RGT ZINZAN	Candidate	3.0	3.0	3.0	3.0	3.0	28.4	20.1	15.5	24.8	23.4
BRITANNIA	-	3.0	3.0	3.0	3.0	2.8	35.0	18.7	28.4	26.4	15.0
SKYFALL	3	3.0	3.0	3.1	3.0	3.0	30.0	27.1	24.5	25.0	20.3
KWS ZYATT	4	3.1	3.0	3.0	3.0	3.0	37.9	39.0	10.3	13.4	29.5
ROBIGUS	-	3.1	3.0	3.0	3.0	3.0	53.3	48.7	26.7	37.3	39.7
Avocet Yr1	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Chinese 166	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Kalyansona	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Vilmorin 23	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Hybrid 46	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Suwon Omar	-	0.4	3.0	0.5	3.0	3.0	*	*	*	*	*
Avocet Yr5	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Avocet Yr6	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Heines Kolben	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Heines Peko	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet Yr7	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Lee	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet Yr8	-	0.0	0.7	3.0	2.4	0.0	*	*	*	*	*
Compair	-	0.0	0.0	3.0	0.0	0.0	*	*	*	*	*
Avocet Yr9	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Clement	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Moro	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Avocet Yr15	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
VPM1	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet Yr17	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet Yr24	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Heines VII	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Strubes Dickkopf	-	3.2	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet Yr32	-	3.1	3.0	3.0	3.0	3.0	*	*	*	*	*
Carstens V	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet Sp	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Spaldings Prolific	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet S	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Vuka	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Evolution	-	1.9	2.6	0.8	3.0	1.8	*	*	*	*	*
Mean		*	*	*	*	*	**7.9**	**6.5**	**3.3**	**5.6**	**5.1**

* = missing data. Yellow shading indicates a compatible reaction; orange shading indicates a borderline reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

Table 7: Comparison between initial differential test results, variety seedling test results and re-isolations from samples taken from variety adult plant trials for the isolates used in the 2021 variety tests and trials. Yellow shading indicates a compatible reaction; orange shading indicates a borderline reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

Differential	21/012			21/014			21/045			21/102			21/135		
	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]
Avocet Yr1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Chinese 166	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kalyansona	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Vilmorin 23	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Hybrid 46	3.0	3.0	3.0	3.0	3.0	2.3	3.0	3.0	3.0	3.0	3.0	2.1	2.0	3.0	3.0
Suwon Omar	3.0	0.4	3.0	3.0	3.0	3.0	2.7	0.5	3.0	2.8	3.0	2.5	3.0	3.0	3.0
Avocet Yr5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avocet Yr6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Heines Kolben	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Heines Peko	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Avocet Yr7	3.2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Lee	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Avocet Yr8	0.0	0.0	0.0	0.0	0.7	0.0	3.0	3.0	3.0	3.0	2.4	0.0	0.0	0.0	0.0
Compair	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Avocet Yr9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Clement	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Moro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avocet Yr15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VPM 1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Avocet Yr17	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Avocet Yr24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heines VII	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Strubes Dickkopf	3.0	3.2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Avocet Yr32	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Carstens V	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Rendezvous	3.0	3.0	1.8	1.5	0.0	1.3	2.8	2.9	2.1	2.8	3.0	2.0	3.0	3.0	2.2
Avocet Sp	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Spaldings Prolific	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.7	3.0	3.0	3.0	3.0	3.0
Robigus	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Solstice	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Warrior	3.0	1.1	3.0	3.0	1.5	3.0	3.0	1.4	3.0	3.0	2.7	3.0	2.1	0.0	3.0
Cadenza	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.7
KWS Sterling	3.0	3.0	3.0	2.7	2.2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.3
Kranich	3.0	2.7	0.0	1.9	0.0	1.4	2.7	2.1	2.7	2.9	3.0	2.6	2.0	0.6	1.1
Apache	3.0	3.0	3.0	3.0	2.5	3.0	3.0	3.0	2.9	3.0	3.0	3.0	3.0	3.0	3.0
Crusoe	0.2	0.1	0.0	0.6	0.0	0.0	0.2	0.0	0.0	3.0	2.4	0.0	1.0	0.0	0.2
Evolution	0.0	1.9	0.5	0.5	2.6	0.0	1.8	0.8	0.0	3.0	3.0	0.3	0.6	1.8	0.0

[1] Diff = Differential test result, [2] Var = Variety seedling test result, [3] Re-Isol = Re-isolation results from adult plant trials.

6.1.4 Genotyping

Forty-eight isolates from 2021 were selected for genotyping based on their location and host cultivar (detailed in **Appendix I: Sample Register**). A phylogenetic tree based on 242 *Pst* genes following the MARPLE pipeline (Radhakrishnan *et al*., 2019) was constructed of the 48 isolates from 2021 (**Figure 6**). The tree also includes 24 isolates selected from the 2020 survey and 24 isolates from the 2019 survey.

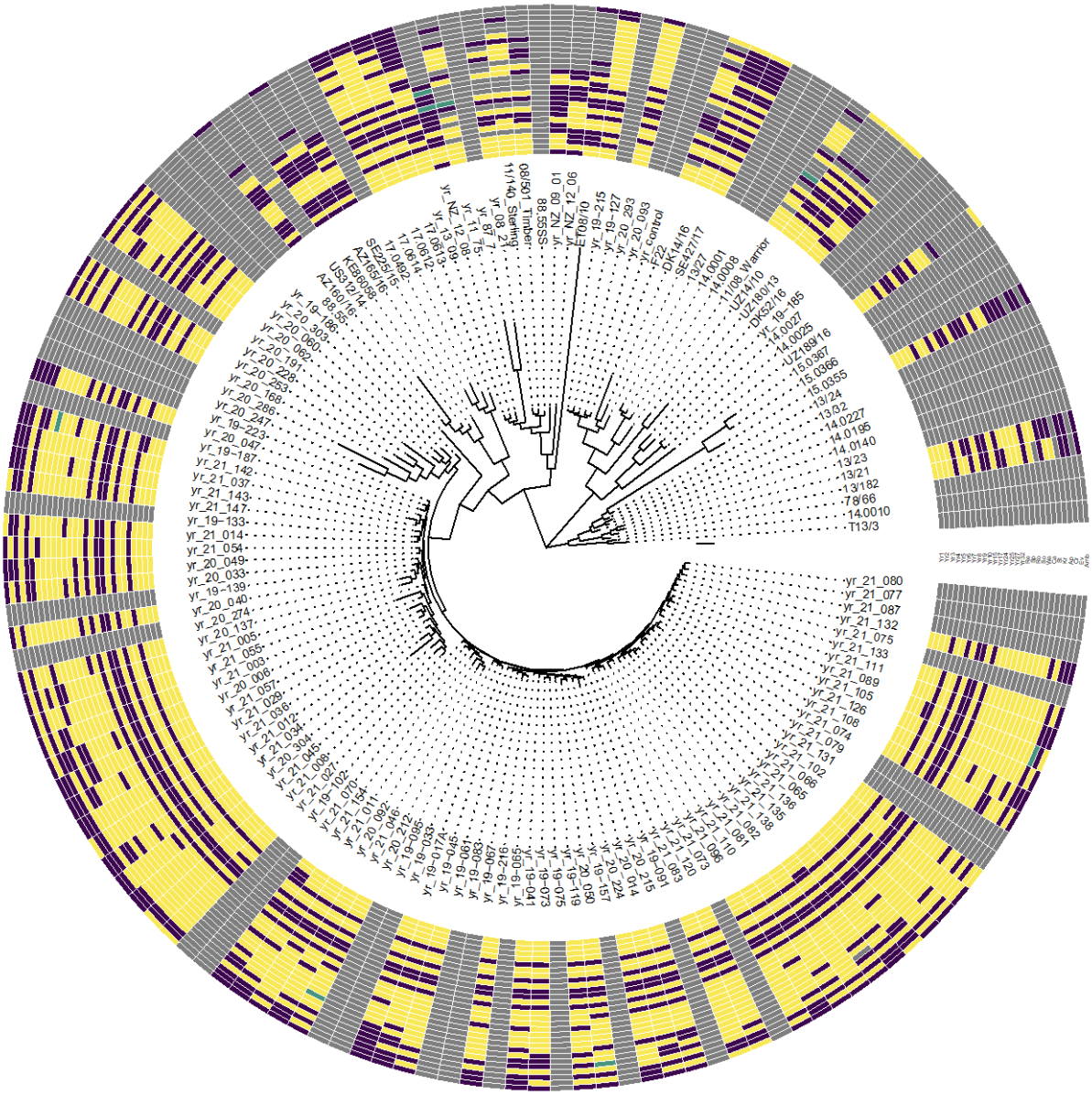

Figure 6: Phylogenetic analysis of 242 *Pst* genes from selected isolates from the UKCPVS programme from the 2019, 2020 and 2021 surveys. The heatmap on the outside of the figure shows the seedling pathotyping data for each isolate; yellow indicates where the isolate was virulent on the differential, purple where the isolate was not able to cause disease on the differential and green where the result was borderline.

The majority of UK genotyped isolates from across all three years belong to the Red Group (red colour, centre of **Figure 6**). In 2019, out of 24 isolates genotyped, two of the isolates grouped with the Pink Group (19/127 and 19/215; pink colour, centre of **Figure 6**) and one to the Purple Group (19/185; purple colour, centre of **Figure 6**). In 2020, out of 24 isolates genotyped, just two grouped with the Pink Group (20/093 and 20/293; pink colour, centre of **Figure 6**). In 2021, all the 48 isolates genotyped grouped with the Red Group.

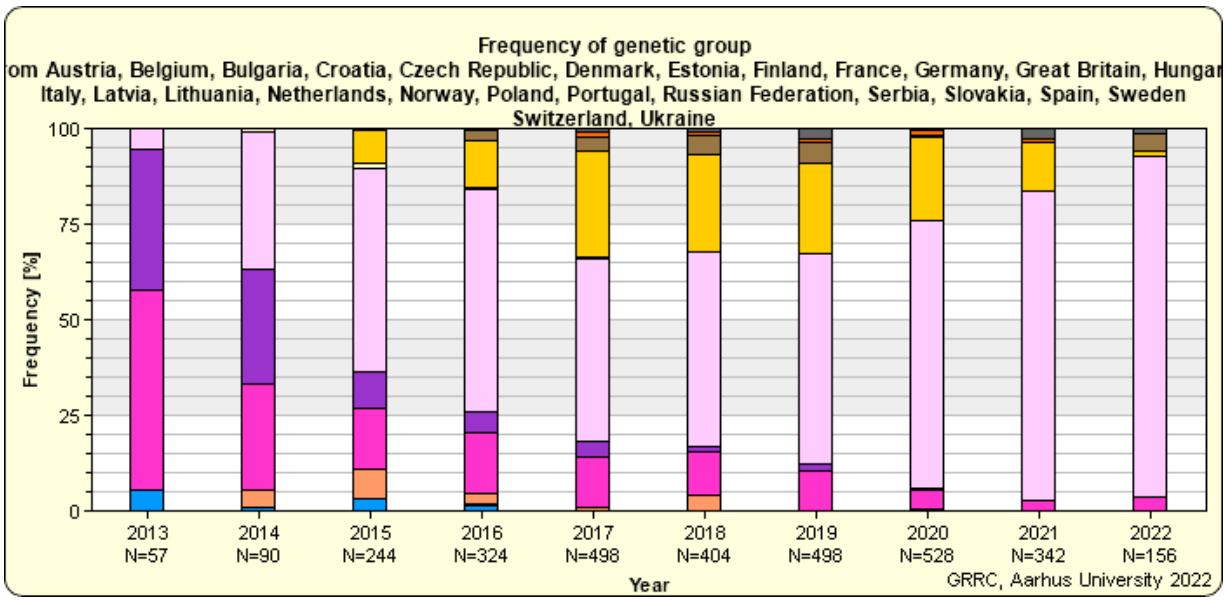

Figure 7: Genetic group frequency across Europe (data from Global Rust Reference Centre, Aarhus University).

Our results mirror findings from across Europe, where the Red Group (PstS10; shown in pink in **Figure 7**) was the most prevalent genetic group within the surveyed areas in Europe (results from the European RustWatch project H2020 No 773311) and has been the case in recent years. Comparison of the European PstS and UK nomenclature for several key groups is shown in **Table 8**.

Table 8: Comparison of European PstS (*Puccinia striiformis* f. sp. *tritici* Stain) and UK colour nomenclature for wheat yellow rust.

UK Colour Code	PstS Genetic Group	Race	Colour in Figure 7
Navy	PstS0		Blue
Pink	PstS7	Warrior	Hot pink
Purple	PstS8	Kranich	Purple
Red	PstS10	Warrior(-) Kalmar Benchmark Amboise	Pale pink

6.1.5 Extended daylength adult plant tests

A subset of thirteen RL varieties and two control varieties were chosen for extended daylength trials. The plants were inoculated at GS39 with WYR 21/014 and 21/045 from the 2021 Survey, that had been selected for use in adult plant field trials (**Table 5**).

Percentage leaf area infected was recorded for three different leaves, Leaf 1 is the flag leaf and the mean percentage leaf area infection for each variety is also given (**Table 9**).

KWS Siskin was the only variety in the tests to remain completely resistant to both isolates and no infection was observed. Theodore was also considered resistant although some stripes were recorded for both isolates.

LG Astronomer performed well, some infection was seen on leaf 1 with both isolates although this was not unexpected considering its disease resistance rating of 8 (2022/23 rating).

KWS Extase was notably more susceptible to isolate 21/014 with an average of 28.9% leaf area infected on the flag leaves. Several other varieties were more susceptible to 21/014 such as LG Skyscraper, Gleam and KWS Zyatt. RGT Wolverine and Skyfall were more susceptible to 21/045.

The control variety Robigus failed in the test inoculated with 21/014 due to stress under the extended daylength regime. Similarly, the control variety Vuka failed to reach GS39 by the time the tests were inoculated so infection levels seen on leaf 1 (flag leaf) were very low.

The performance of the varieties to these two isolates did not always match the adult plant trial results (**Table 6**) but this may be because of the additional stress of the extended daylength conditions or other environmental factors.

Table 9: Results from the extended daylength adult plant growth room trials.

Variety	RL Rating 2022/23	21/014				21/045			
		Percentage leaf area infected				Percentage leaf area infected			
		Leaf 1	Leaf 2	Leaf 3	Mean	Leaf 1	Leaf 2	Leaf 3	Mean
Crusoe	9	11.8	1.7	0.0	**4.5**	2.01	3.2	2.2	**2.5**
KWS Siskin	9	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
Theodore	9	0.5	0.0	0.0	**0.2**	0.0	0.1	0.6	**0.2**
KWS Extase	8	28.9	14.0	15.5	**19.5**	0.0	0.1	2.01	**0.7**
LG Astronomer	8	1.3	0.0	0.0	**0.4**	2.4	0.0	0.0	**0.8**
LG Skyscraper	7	14.1	15.1	6.5	**11.9**	2.8	2.6	2.0	**2.5**
KWS Barrel	6	15.0	30.5	10.5	**18.7**	22.0	22.5	17.0	**20.5**
KWS Firefly	6	14.2	3.9	0.0	**6.0**	16.0	3.7	1.2	**7.0**
Gleam	5	32.5	11.6	2.7	**15.6**	4.0	13.6	10.0	**9.2**
SY Insitor	5	28.5	16.0	12.0	**18.8**	17.0	19.7	15.0	**17.2**
KWS Zyatt	4	43.5	11.8	3.3	**19.5**	20.5	3.9	2.0	**8.8**
RGT Wolverine	4	10.8	6.9	8.5	**8.7**	27.5	22.5	11.5	**20.5**
Skyfall	3	15.4	22.7	2.1	**13.4**	51.5	18.0	1.5	**23.7**
Robigus	-	0.5	0.0	0.0	**0.2**	64.0	58.0	21.0	**47.7**
Vuka	-	0.6	19.0	38.3	**19.3**	4.3	57.5	72.0	**44.6**

6.2 Wheat brown rust

6.2.1 Samples received

In 2021, the UKCPVS received ten samples of wheat brown rust from four different counties across the UK (**Figure 8**).

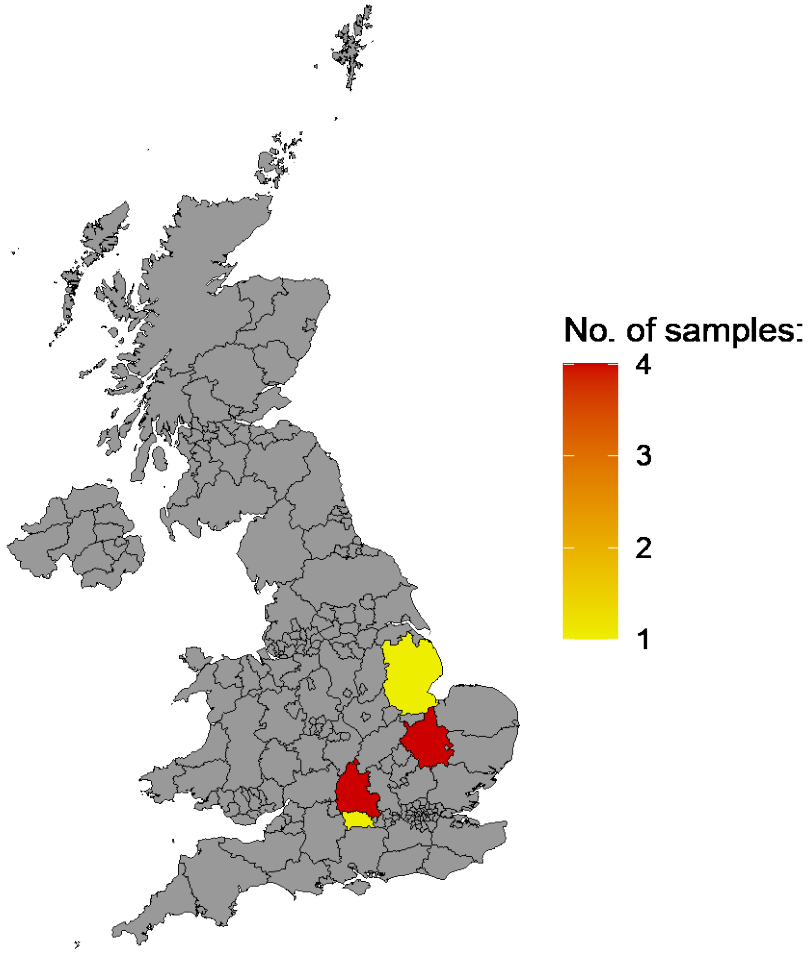

Figure 8: Map of the UK with the number of samples of wheat brown rust received in 2021 from the different counties.

The full sample register is provided in **Appendix I: Sample Register**. Samples were received from seven different varieties. The host varieties in the sample register have not all been confirmed, and it is entirely possible that a sample listed as coming from a resistant variety may turn out to be another more susceptible variety. For this reason, the sample register is included as an indicator of what was received but should not be used to infer any breakdowns in resistance or changes in rating at this stage.

6.2.2 Pathotyping of isolates

6.2.2.1 Virulence for individual resistance genes and varieties

Due to the lower number of samples received in 2021, all isolates cultured from the 10 samples received were selected for further pathotyping (**Supplementary Table 2**). Isolates were assessed for their reactions on a differential set, their reactions are expressed as an average infection type (AIT). As before, isolates were classified as virulent if the AIT score was 2.7 or above. Scores between 2.4 and 2.7 were considered borderline. Using these scores, along with data from other differentials not listed here, it was possible to combine the scores for reactions to different resistance genes to infer a pathotype for each of the isolates (**Table 10**). The UKCPVS employed the use of the differential set which aligns the UKCPVS with other virulence surveys across the world (for

example Kolmer *et al*., 2013). The frequency of detection of virulence for the *Lr* genes monitored is shown in **Table 11**.

Virulence for *Lr1, Lr10, Lr13, Lr14a, Lr15, Lr16, Lr17, Lr17b*, *Lr37* and for the additional cultivar Crusoe was detected in all isolates. Virulence for *Lr20* was detected in 29% of isolates returning to levels last seen in 2019. Virulence for *Lr23* also rose as did virulence for *Lr28*. Robigus is thought to carry *Lr28* and virulence for this cultivar mirrored the rise seen in the Thatcher *Lr28* differential and was detected in 50% of isolates.

Virulence for *Lr3ka* and *Lr26* declined.

No virulence was detected for *Lr2a, Lr2b* and *Lr24* which continues the trend seen in previous years.

There appeared to be no major effects on RL varietal performance relating to these changes.

6.2.2.2 Commonly detected races

In 2021 there were 6 different pathotypes detected in the 10 isolates tested, most of which were pre-existing pathotypes. The most common pathotype identified was *Lr1,10,13,14a,15,16,17,28,37*,Cr and was carried by 40% of the isolates tested. One new pathotype was identified carried by only 10% of isolates *Lr1,3a,3bg,3ka,10,13,14a,15,16,17,23,37,*Cr.

Although it is likely that there will be more than one race present in some of the samples based on the experience of colleagues in France (H. Goyeau, *pers. comm.*), every effort is now made to culture single pustule isolates to solve any issues with mixed isolates.

6.2.3 Variety testing of isolates from 2021

Five isolates from the 10 tested isolates were selected for further testing on the wider set of RL varieties and candidates (**Table 12**), these were selected to best represent the diversity of the isolates tested. The isolates selected were WBR 21/002, 21/003, 21/004, 21/006 and 21/008.

Table 10: Pathotypes of the 2021 *Puccinia triticina* isolates based on the differential test results in **Supplementary Table 2**. Numbers refer to specific *Lr* resistance genes, Cr = Crusoe, Ro = Robigus.

Isolate Number	Host variety	Virulence Profile																				
		1	2a	2b	2c	3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26	28	37	17b	Ro	Cr
21/001	LG Skyscraper	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23		26		37	17b		Cr
21/002	KWS Kerrin	1			2c	3a	3bg	3ka	10	13	14a	15	16	17	20	23		26		37	17b		Cr
21/003	LG Skyscraper	1							10	13	14a	15	16	17					28	37	17b	Ro	Cr
21/004	KWS Basset	1				3a	3bg	3ka	10	13	14a	15	16	17		23		26		37	17b		Cr
21/005	Graham	1				3a	3bg	3ka	10	13	14a	15	16	17		23		26		37	17b		Cr
21/006	KWS Cranium	1							10	13	14a	15	16	17	20				28	37	17b	Ro	Cr
21/007	KWS Cranium	1							10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
21/008	Relay	1				3a	3bg	3ka	10	13	14a	15	16	17		23				37	17b		Cr
21/009	Graham	1							10	13	14a	15	16	17					28	37	17b	Ro	Cr
21/010	Crusoe	1							10	13	14a	15	16	17				26	28	37	17b	Ro	Cr

Table 11: Frequency of detection of isolates carrying virulence to the different brown rust resistance genes and varieties over the past five years. * = missing data.

Virulence for Resistance Gene or Variety	Percentage of Isolates Identified with Virulence for Gene or Variety				
	2017	**2018**	**2019**	**2020**	**2021**
Lr1	68	81	89	100	100
Lr2a	0	0	0	0	0
Lr2b	16	0	0	0	0
Lr2c	48	26	11	12	10
Lr3a	87	48	75	56	50
Lr3bg	81	71	75	56	50
Lr3ka	77	74	93	80	50
Lr10	87	100	100	96	100
Lr13	84	100	100	100	100
Lr14a	87	100	100	100	100
Lr15	84	100	100	100	100
Lr16	58	52	100	100	100
Lr17	87	100	100	100	100
Lr17b	55	100	100	100	100
Lr20	87	77	29	12	30
Lr23	45	39	36	32	50
Lr24	3	0	0	0	0
Lr26	58	100	82	92	60
Lr28	0	6	25	40	50
Lr37	74	100	100	100	100
Robigus	0	6	14	40	50
Crusoe	77	100	100	100	100
Total Number of Isolates	**27**	**31**	**28**	**25**	**10**

Table 12: Virulence profile of the isolates chosen for further characterisation in seedling and adult plant tests. Numbers refer to specific *Lr* resistance genes, Ro = Robigus, Cr = Crusoe. Yellow shading = compatible reaction (virulence), blank = avirulence.

Isolate Number	Host variety	Virulence Profile																				
		1	2a	2b	2c	3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26	28	37	17b	Ro	Cr
21/002	KWS Kerrin	1			2c	3a	3bg	3ka	10	13	14a	15	16	17	20	23		26		37	17b		Cr
21/003	LG Skyscraper	1							10	13	14a	15	16	17					28	37	17b	Ro	Cr
21/004	KWS Basset	1							10	13	14a	15	16	17		23		26		37	17b		Cr
21/006	KWS Cranium	1				3a	3bg	3ka	10	13	14a	15	16	17	20				28	37	17b	Ro	Cr
21/008	Relay	1				3a	3bg	3ka	10	13	14a	15	16	17		23				37	17b		Cr

6.2.3.1 Variety seedling tests

The five selected isolates were tested in seedling tests containing RL and RL candidate varieties in the controlled environment rooms at NIAB in the spring of 2022. Results are combined with the adult plant test results (**Table 13**) and are sorted by the reaction on the adult plant trials (see **Section 4.2.3.2**). Many of the RL varieties and candidates tested were susceptible at the seedling stage to all five of the isolates tested. Theodore was the only RL variety to remain resistant to all isolates tested.

A general agreement was seen when the variety seedling test results were compared with those of the initial differential tests. These results are shown alongside data from the seedling tests conducted on re-isolates sampled from the inoculated trials (**Table 13**). Purification methods have now been used by the UKCPVS to solve the problem of multiple isolates in a sample. Discrepancies seen now are most likely due to environmental isolates.

6.2.3.2 Adult plant tests

Alongside the seedling tests, the five isolates were also evaluated in the UKCPVS adult plant trials at NIAB in the summer of 2022 which contained RL and candidate varieties. As with the yellow rust trials, the plots were directly inoculated early in the season to help keep natural infection at bay and inoculated every 7-14 days until the flag leaf had fully emerged. The first inoculation was carried out on the 13th April 2022 and the first assessment was made on 23rd May when the plants were at GS55. The percentage plot infected was assessed and the mean was calculated from four assessments (**Table 13**). Disease levels were considered good in the trials and final scores were higher than the calculated mean shown here. The susceptible control and current RL variety Crusoe, rated 3, showed the highest levels of disease. KWS Guium, also rated 3, was the second most susceptible RL variety trialled.

Out of the 47 RL varieties and candidates under evaluation, Theodore was the most resistant RL variety tested. Theodore continues to perform consistently well in UKCPVS trials. During the 2022 field season, the UKCPVS did receive a report of higher than expected levels of disease in Theodore but a sample from this report was not received.

RGT Zinzan and RGT Wolverine also performed well in the brown rust trials.

Many of the current RL varieties have moderate brown rust disease resistance ratings of 5 or 6 and this was reflected in the results with many of the varieties showing moderate – high levels of disease. LG Illuminate and RGT Saki with an RL rating of 7 tabled lower than many with a rating of 5 or 6, possibly indicating an erosion of resistance in these varieties.

As mentioned in **Section 6.2.3.1** samples were taken from the trials to confirm that the isolates used to inoculate the trial were present (**Table 14**). Tests on these re-isolates generally agreed with the differential seeding tests, suggesting that the new inoculation techniques are significantly lowering levels of natural infection.

Table 13: Seedling and adult plant reactions to the five isolates selected for further characterisation. Seedling results are shown as average infection types on a scale of 0-4. Adult plant results are given as a percentage leaf area infected averaged over four assessments. Varieties are ordered in level of disease at adult plant stage. Control varieties are highlighted in green text.

Variety	RL Rating 2022/23	Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		21/002	21/003	21/004	21/006	21/008	21/002	21/003	21/004	21/006	21/008
MARIS RANGER	-	1.0	2.0	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.1
THEODORE	8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.1	0.0
WARRIOR	-	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.5	0.1
MARIS HALBERD	-	1.9	3.0	0.9	2.0	1.5	0.5	0.1	0.0	0.3	0.1
RGT ZINZAN	Candidate	3.0	1.3	2.0	3.0	3.0	1.0	0.0	0.2	0.0	0.5
RGT WOLVERINE	8	3.0	3.0	3.0	3.0	3.0	1.3	0.2	0.3	0.4	2.0
SKYFALL	8	3.0	0.7	2.0	2.0	2.0	3.2	0.0	2.9	0.1	0.1
STERNA	-	3.0	0.4	3.0	2.0	3.0	4.9	0.2	3.2	2.0	2.4
KWS DAWSUM	7	3.0	3.0	2.0	3.0	2.0	4.8	2.6	3.8	3.1	3.5
ROBIGUS	-	3.0	2.0	3.0	1.1	1.1	6.5	3.3	3.0	5.9	3.1
KWS WEBBUM	Candidate	3.0	3.0	3.0	3.0	1.7	7.4	3.9	4.7	2.8	3.1
KWS EXTASE	7	3.0	3.0	2.5	3.0	3.0	6.5	5.3	3.6	3.5	3.5
KWS TARGET	-	3.0	3.0	2.5	3.0	3.0	3.2	3.2	3.7	6.9	5.9
GAMIN	-	3.0	3.0	3.0	3.0	3.0	9.3	1.8	8.3	2.3	3.4
GEFION	Candidate	3.0	3.0	3.0	3.0	3.0	7.3	3.5	4.3	6.2	4.6
STIGG	-	0.2	3.0	1.2	1.2	0.4	5.4	6.5	3.9	4.7	5.5
KWS WRENUM	Candidate	3.0	3.0	3.0	3.0	3.0	3.5	5.3	5.8	5.5	6.1
LG PRINCE	7	1.2	2.0	3.0	3.0	2.0	5.9	5.1	4.8	6.3	4.9
LG ASTRONOMER	8	0.3	3.0	2.1	2.0	2.3	5.2	5.6	6.1	7.3	3.4
MAYFLOWER	6	3.0	3.0	3.0	3.0	3.0	9.0	3.4	6.2	3.9	5.3
LG REDWALD	Candidate	3.0	3.0	3.0	3.0	3.0	6.5	5.7	6.0	4.9	5.3
KWS ZYATT	6	3.0	3.0	3.0	3.0	3.0	9.8	6.0	3.4	6.1	3.7
KWS STERLING	-	3.0	1.3	0.1	3.0	1.5	7.0	6.0	6.3	8.0	4.9
ARMADA	-	3.0	3.0	3.0	3.0	3.0	9.8	4.5	6.9	5.6	5.8
MERIT	7	0.6	2.1	3.0	2.2	2.0	4.8	8.0	7.2	8.3	5.3
MINDFUL	Candidate	3.0	3.0	3.0	3.0	2.0	9.1	6.2	7.2	5.6	6.5
SAPPO	-	2.0	3.0	2.1	3.0	2.0	10.5	6.8	5.8	8.2	3.8
RGT STOKES	5	3.0	3.0	3.0	3.0	2.5	7.9	6.2	7.1	6.4	8.1
GLASGOW	-	3.0	3.0	3.0	3.0	3.0	9.5	6.7	6.4	5.6	7.5
KWS ULTIMATUM	Candidate	3.0	3.0	3.0	3.0	3.0	9.1	7.5	6.8	6.5	6.9
RGT ILLUSTRIOUS	6	3.0	3.0	3.0	3.0	2.1	10.6	7.5	6.4	5.5	7.3
KWS FIREFLY	5	0.2	2.9	1.1	3.0	2.5	6.5	6.1	6.4	10.1	8.6
OXFORD	Candidate	1.4	3.0	2.0	3.0	1.2	6.1	9.7	7.8	7.5	7.3
ELICIT	6	3.0	3.0	3.0	3.0	3.0	9.9	6.5	8.3	7.6	6.6
RGT BAIRSTOW	6	1.0	3.0	1.8	1.2	2.5	7.4	7.1	8.8	7.7	8.0
KWS SISKIN	5	3.0	3.0	3.0	3.0	3.0	9.8	8.1	5.5	9.2	7.3
KWS BARREL	5	3.0	3.0	3.0	3.0	2.5	11.6	7.8	8.8	5.7	7.8
SY COACH	Candidate	3.0	3.0	3.0	3.0	2.0	11.3	5.9	7.8	7.6	10.1
LG TYPHOON	6	2.0	2.0	3.0	3.0	1.9	7.3	9.1	7.7	9.3	9.8
KWS PALLADIUM	5	2.0	3.0	2.0	3.0	2.8	12.1	7.9	8.5	7.6	7.6
KWS JACKAL	5	3.0	3.0	1.8	3.0	3.0	10.5	8.1	8.3	12.3	5.3
KWS BRIUM	5	2.0	3.0	3.0	3.0	1.7	10.0	7.7	9.1	9.4	9.3
LG ILLUMINATE	7	1.5	0.1	0.6	3.0	1.0	10.4	8.1	7.1	9.8	10.1
RGT SAKI	7	0.1	3.0	1.5	3.0	2.0	9.5	11.0	7.2	9.9	9.1
ZOOM	Candidate	3.0	3.0	3.0	3.0	3.0	14.3	8.3	7.6	7.4	9.1
KWS ZEALUM	Candidate	3.0	3.0	3.0	3.0	3.0	9.6	8.4	11.3	9.6	9.3

Variety	RL Rating 2022/23	Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		21/002	21/003	21/004	21/006	21/008	21/002	21/003	21/004	21/006	21/008
SY INSITOR	5	3.0	3.0	3.0	3.0	3.0	15.6	3.8	10.3	8.3	10.3
KWS CRANIUM	4	3.0	2.6	2.5	3.0	3.0	11.5	9.9	8.8	9.9	8.4
TUXEDO	-	3.0	3.0	3.0	3.0	2.7	19.8	6.5	7.9	6.3	9.1
SWALLOW	6	1.8	3.0	1.9	3.0	3.0	9.8	9.8	8.3	10.8	11.3
LG SKYSCRAPER	5	3.0	3.0	1.7	3.0	2.0	14.4	8.9	8.2	11.2	8.2
GLEAM	6	2.0	2.9	2.0	3.0	2.5	12.4	10.6	10.9	9.0	10.3
RGT WILKINSON	Candidate	3.0	3.0	3.0	3.0	3.0	10.3	8.4	8.8	15.8	10.2
RGT RASHID	6	3.0	3.0	1.5	3.0	2.5	15.0	10.1	9.8	8.3	12.6
AVALON	-	3.0	3.0	3.0	2.0	3.0	15.6	9.1	13.5	9.5	9.8
ELATION	5	3.0	3.0	3.0	3.0	3.0	11.4	12.1	14.2	11.7	10.9
GRAHAM	5	3.0	3.0	3.0	3.0	3.0	13.0	16.6	10.6	10.6	10.3
COSTELLO	5	2.0	2.8	1.0	3.0	2.0	12.9	12.1	8.2	10.4	19.7
MARIS HUNSTMAN	-	3.0	3.0	3.0	3.0	2.2	18.5	18.0	11.0	14.9	9.0
CHAMPION	5	0.8	3.0	3.0	3.0	2.1	14.3	18.4	10.5	14.1	20.8
REAPER	-	2.0	2.8	2.5	3.0	2.5	21.0	17.5	16.8	21.7	8.4
MASCOT	-	3.0	3.0	3.0	3.0	3.0	21.2	28.8	8.5	18.4	14.6
SOISSONS	-	2.0	3.0	3.0	3.0	3.0	19.4	24.6	19.5	17.1	14.4
CONSORT	-	3.0	3.0	3.0	3.0	3.0	17.0	25.0	25.8	25.9	13.1
KWS GUIUM	3	2.0	3.0	1.6	3.0	3.0	14.8	20.1	21.4	28.9	27.9
MARIS FUNDIN	-	3.0	3.0	3.0	3.0	3.0	25.8	29.9	26.3	24.5	24.0
BUSTER	-	3.0	3.0	3.0	3.0	3.0	36.1	32.5	28.4	27.0	30.8
CRUSOE	3	3.0	3.0	3.0	3.0	3.0	35.1	29.6	27.1	32.4	31.8
Thatcher Lr 1	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Thatcher Lr 2a	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Thatcher Lr 2b	-	0.2	0.0	0.1	0.0	0.2	*	*	*	*	*
Thatcher Lr 2c	-	2.0	0.2	0.2	0.0	2.0	*	*	*	*	*
Thatcher Lr 3a	-	3.0	1.5	3.0	2.0	3.0	*	*	*	*	*
Thatcher Lr 3bg	-	3.0	1.2	3.0	2.0	3.0	*	*	*	*	*
Thatcher Lr 3ka	-	2.0	3.0	3.0	2.0	3.0	*	*	*	*	*
Thatcher Lr 10	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Thatcher Lr 13	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Thatcher Lr 14a	-	2.2	3.0	3.0	3.0	3.0	*	*	*	*	*
Thatcher Lr 15	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Thatcher Lr 16	-	3.0	1.5	3.0	0.3	3.0	*	*	*	*	*
Thatcher Lr 17	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Thatcher Lr 20	-	2.0	2.6	0.6	3.0	3.0	*	*	*	*	*
Thatcher Lr 23	-	1.3	1.0	1.2	0.1	0.5	*	*	*	*	*
Thatcher Lr 24	-	1.0	0.8	1.0	1.6	1.3	*	*	*	*	*
Thatcher Lr 26	-	3.0	3.0	1.8	3.0	3.0	*	*	*	*	*
Thatcher Lr 28	-	2.8	3.0	1.5	3.0	2.0	*	*	*	*	*
Thatcher Lr 37	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Clement	-	3.0	2.0	3.0	2.0	2.5	*	*	*	*	*
Mean	**-**	*	*	*	*	*	**10.5**	**8.9**	**8.4**	**9.0**	**8.4**

Yellow shading indicates a compatible reaction; orange shading indicates a borderline reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

Table 14: Comparison between initial differential test results, variety seedling test results and re-isolations from samples taken from variety adult plant trials for the isolates used in the 2021 variety tests and trials.

Differential	21/002			21/003			21/004			21/006			21/008		
	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]	Diff[1]	Var[2]	Re-Isol[3]
Thatcher Lr 1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Thatcher Lr 2a	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Thatcher Lr 2b	1.0	0.2	0.0	0.0	0.0	0.0	1.0	0.1	1.0	1.0	0.0	0.0	1.0	0.2	0.2
Thatcher Lr 2c	3.0	2.0	1.2	2.0	0.2	0.2	2.0	0.2	2.0	2.0	0.0	0.3	1.0	2.0	1.1
Thatcher Lr 3a	3.0	3.0	3.0	2.0	1.5	2.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0
Thatcher Lr 3bg	3.0	3.0	2.0	2.0	1.2	2.0	3.0	3.0	3.0	2.0	2.0	2.5	3.0	3.0	3.0
Thatcher Lr 3ka	3.0	2.0	2.5	2.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.1	3.0	3.0	3.0
Thatcher Lr 10	3.0	3.0	2.8	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.5	3.0	3.0	3.0
Thatcher Lr 13	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Thatcher Lr 14a	3.0	2.2	2.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0
Thatcher Lr 15	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.1	3.0	3.0	2.1	3.0	3.0	2.0
Thatcher Lr 16	3.0	3.0	2.0	3.0	1.5	2.0	3.0	3.0	2.0	3.0	0.3	2.0	3.0	3.0	2.1
Thatcher Lr 17	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0
Thatcher Lr 20	3.0	2.0	1.1	2.0	2.6	2.0	2.0	0.6	1.0	3.0	3.0	2.0	2.0	3.0	1.0
Thatcher Lr 23	3.0	1.3	2.1	2.0	1.0	1.4	3.0	1.2	2.0	2.0	0.1	1.2	3.0	0.5	2.0
Thatcher Lr 24	0.9	1.0	0.2	0.6	0.8	1.1	1.2	1.0	1.9	0.3	1.6	1.1	0.9	1.3	1.8
Thatcher Lr 26	3.0	3.0	3.0	2.0	3.0	2.2	3.0	1.8	2.0	2.0	3.0	3.0	1.0	3.0	1.3
Thatcher Lr 28	2.0	2.8	2.5	3.0	3.0	2.0	2.0	1.5	2.1	3.0	3.0	2.0	0.3	2.0	3.0
Thatcher Lr 37	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.2	3.0	3.0	3.0	3.0	3.0	3.0
Armada	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Crusoe	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Maris Fundin	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Robigus	2.0	3.0	3.0	3.0	2.0	3.0	2.0	3.0	2.9	3.0	1.1	3.0	0.0	1.1	3.0
Clement	3.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0	3.0	2.0	2.0	3.0	2.0	2.5	2.8
Glasgow	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Maris Halberd	3.0	1.9	1.0	2.0	3.0	3.0	2.0	0.9	2.0	2.0	2.0	2.0	2.0	1.5	1.0
Sappo	3.0	2.0	1.0	2.0	3.0	3.0	2.0	2.1	2.0	3.0	3.0	2.0	1.0	2.0	1.0
Sterna	3.0	3.0	3.0	2.0	0.4	3.0	3.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0	3.0
Stigg	0.6	0.2	0.6	0.8	3.0	0.6	0.6	1.2	1.4	0.2	1.2	1.7	0.3	0.4	0.8
Warrior	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.9	0.0	0.0	1.0
KWS Firefly	2.0	0.2	1.5	3.0	2.9	3.0	2.0	1.1	3.0	3.0	3.0	3.0	0.0	2.5	3.0

[1] Diff = Differential test result, [2] Var = Variety seedling test result, [3]Re-Isol = Re-isolation results from adult plant trials, * = missing data. Yellow shading indicates a compatible reaction; orange shading indicates a borderline reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

6.3 Wheat powdery mildew

6.3.1 Samples received

Levels of wheat powdery mildew were low in 2021 and the UKCPVS received 10 samples (**Appendix I: Sample Register**). The samples came from 7 different counties (**Figure 9**).

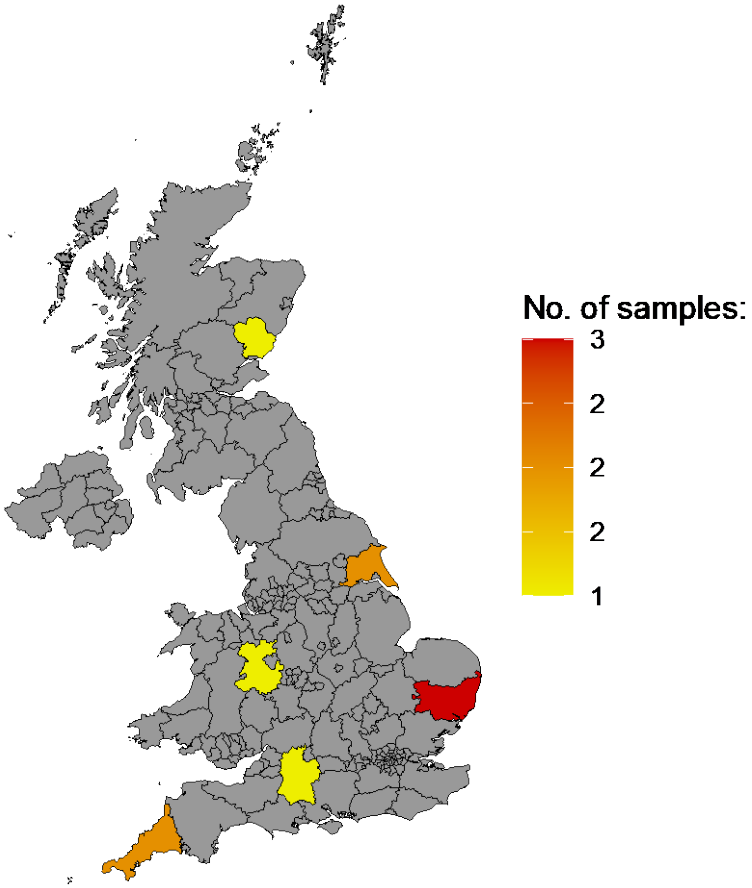

Figure 9: Map of the UK with the number of samples of wheat powdery mildew received in 2021 from the different counties.

6.3.2 Pathotyping of isolates

Two single pustule isolates were tested from four different samples, meaning a total of eight single pustule isolates were seedling virulence tested using detached leaf assays (**Table 15**). It was found that there did appear to be some notable changes in seedling virulence frequencies since the last Survey results conducted in 2018 but these results should be interpreted with caution due to the low number of isolates tested (**Table 16**).

Virulence for *Pm2* dropped to 38% of isolates tested having been seen previously at much higher levels. Virulence for *Pm3b* rose from 15% in 2018 to 100% in 2021 isolates. Unusually, no virulence was seen for *Pm4b*. Virulence for *Pm17* was detected in all 8 isolates tested in 2021 and virulence for MlSh was seen for the first time since 2014, but at a much higher level than usual.

No wheat powdery mildew seedling tests were carried out in 2020 or 2019. Virulence frequencies for 2015 – 2018 and 2021 are listed in **Table 16**.

Table 15: Pathotype results for the wheat powdery mildew detached seedling tests. Average infection types of 2.7 and above (yellow shading) indicate a compatible reaction, values between 2.5 and 2.7 (shaded orange) indicate a borderline reaction and values below 2.5 indicate an incompatible reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Differential varieties are listed along with the known resistance genes carried by these lines.

Isolate Number	Host variety		*Pm2*	*Pm3b*	*Pm4b*	*Pm5*	*Pm6*	*Mld*	*Pm8*	*Pm2,MlTa2*	*Pm5, MlTa2*	*MlTo*	*Pm3d*	*Pm5, MlSi2*	*MlSo*	*MlAx*	*Pm17*	*MlSh*	*MlRo*			
		Cerco	Galahad	Chul	Armada	Flanders	Brimstone	Clement	Maris Dove	Brock	Mercia	Tonic	Broom	Sicco	Wembley	Axona	Amigo	Shamrock	Robigus	Warrior	Stigg	Crusoe
21/02/01	KWS Extase	4.0	1.8	4.0	0.0	3.5	4.0	4.0	4.0	4.0	3.0	4.0	4.0	3.0	4.0	4.0	4.0	3.5	4.0	2.0	4.0	4.0
21/02/02	KWS Extase	4.0	3.0	4.0	0.3	3.5	4.0	2.0	4.0	4.0	4.0	2.5	3.0	2.0	2.0	4.0	4.0	4.0	4.0	1.0	3.5	4.0
21/03/01	Theodore	4.0	1.0	4.0	0.0	1.5	4.0	4.0	4.0	4.0	3.5	4.0	4.0	0.0	0.0	4.0	4.0	1.5	3.5	4.0	4.0	4.0
21/03/02	Theodore	4.0	2.0	4.0	0.0	2.8	4.0	4.0	3.5	4.0	2.5	4.0	4.0	0.0	0.0	4.0	4.0	2.5	3.0	4.0	4.0	3.0
21/05/01	-	4.0	2.5	4.0	0.5	1.5	4.0	3.0	0.0	4.0	4.0	4.0	4.0	0.0	0.0	0.5	4.0	0.0	4.0	2.5	2.8	0.0
21/05/02	-‘	4.0	2.5	4.0	0.0	4.0	4.0	4.0	1.5	4.0	4.0	4.0	4.0	1.0	1.5	0.5	4.0	1.0	4.0	4.0	4.0	2.0
21/06/01	-	4.0	4.0	4.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	4.0	2.8	4.0	4.0
21/06/02	-	4.0	3.0	4.0	0.0	3.0	4.0	4.0	4.0	4.0	4.0	3.5	4.0	1.5	2.3	4.0	3.5	3.5	4.0	0.0	3.0	4.0

Table 16: Virulence frequencies of key wheat powdery mildew resistance genes and varieties over five years of testing. No data available for 2019-2020.

Differential	Known Genes	Virulence Frequency by Year (%)				
		2015	2016	2017	2018	2021
Galahad	*Pm2*	71	88	100	100	38
Chul	*Pm3b*	14	8	20	15	100
Armada	*Pm4b*	64	84	100	96	0
Flanders	*Pm5*	71	76	84	81	75
Brimstone	*Pm6*	64	88	96	93	100
Clement	*Pm8*	50	88	84	93	88
Maris Dove	*Mld*	64	64	68	100	75
Brock	*Pm2,MlTa2*	71	84	96	100	100
Mercia	*Pm5, MlTa2*	79	80	100	93	88
Tonic	*MlTo*	14	28	64	85	88
Broom	*Pm3d*	14	28	60	85	100
Sicco	*Pm5, MlSi2*	0	8	40	11	25
Wembley	*MlSo*	0	4	44	11	25
Axona	*MlAx*	14	32	60	78	75
Amigo	*Pm17*	7	0	8	0	100
Shamrock	*MlSh*	0	0	0	0	50
Robigus	MlRo	64	56	72	85	100
Warrior		0	8	16	74	50
Stigg		0	4	16	74	100
Crusoe		36	72	68	93	75
Total Number of Isolates Tested		**14**	**25**	**25**	**27**	**8**

The wheat powdery mildew isolates are not tested on varieties at the adult plant stage, and so the impact of these population changes can only be assessed through reports from growers, agronomists, and trial managers. No reports were received in 2021.

6.4 Barley powdery mildew

6.4.1 Samples received

Low levels of barley powdery mildew were observed in 2021 and the UKCPVS received 15 samples (**Appendix I: Sample Register**). The majority of the samples came from Lincolnshire, one sample was recorded as location unknown (**Figure 10**).

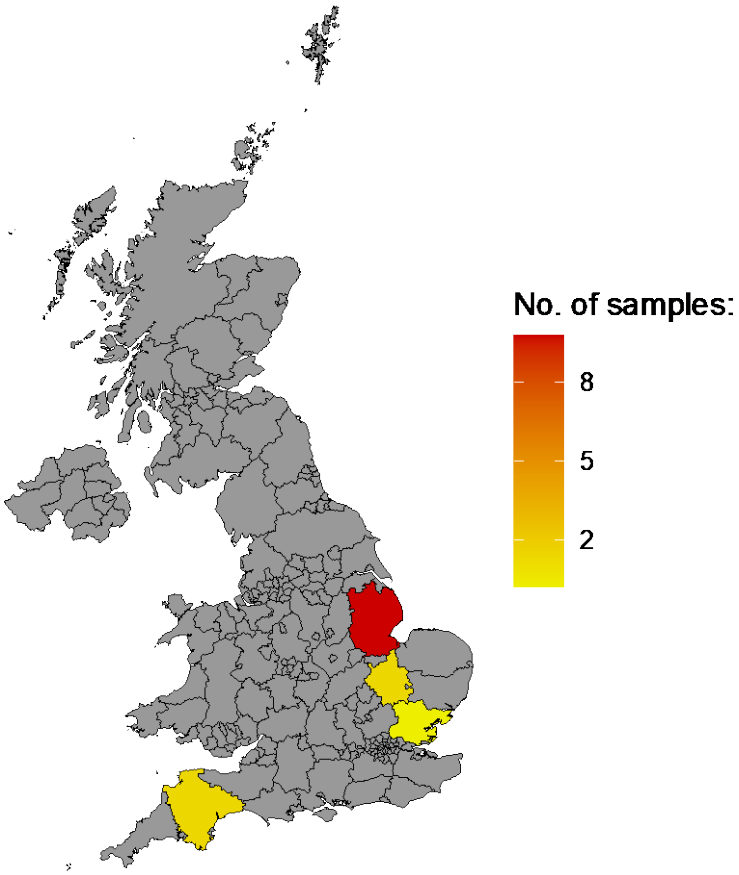

Figure 10: Map of the UK with the number of samples of barley powdery mildew received in 2021 from the different counties.

6.4.2 Pathotyping of isolates

From the 15 samples received, 26 single pustule isolates were obtained, and these were characterised using a differential set (**Table 17**). Virulence for most of the differentials was detected (**Table 18**). Some changes in virulence frequencies were observed. Some minor decreases in virulence were seen for *Mlg, Ml(CP), Mla6*, *MlLa* and for the additional cultivar Vanessa. A more notable decrease was seen for *Mla1* which dropped from 83% in 2020 to 50% in 2021. Virulence for *Mla12* rose from 67% in 2020 to 87% in 2021 bringing it more in line with figures seen in 2017-2018. Virulence for Optic and Propino both rose. No virulence was detected for *Mlo11* carried by Apex and Riviera and, for the second year running, no virulence was seen for *Mla13*.

The UKCPVS received no reports of unexpected outbreaks of barley powdery mildew during 2021 or 2022 so it is possible that this variation in the population did not translate into meaningful differences at the adult plant stage. As with the wheat powdery mildew, no adult plant tests were conducted with these isolates.

Table 17: Pathotype results for the barley powdery mildew detached seedling tests. Average infection types of 2.7 and above (yellow shading) indicate a compatible reaction, values between 2.5 and 2.7 (shaded orange) indicate a borderline reaction and values below 2.5 indicate an incompatible reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Differential varieties are listed along with the known resistance genes carried by these lines.

Isolate Number	Host Variety	0	*Mlh*	*Mlra*	*Mlg*	*Mlg,Ml(CP)*	*Mla6*	*MlLa*	*Mla12*	*Mlk1*	*Mla7*	*MlAb*	*Mla7,MlAb*	*Mla1*	*Mla9*	*Mlo 11*	*Mlo Riv*	*Mla13*	*Mla3*	Vanessa	Optic	Propino
		Golden Promise	W.37/136	W.41/145	Goldfoil	Zephyr	Midas	Lofa	Hassan	H.1063	Porter	Lotta	Triumph	Tyra	Roland	Apex	Riviera	Digger	Ricardo	Vanessa	Optic	Propino
21/1/3	Electrum	3.3	3.8	3.5	3.3	3.5	3.5	2.8	2.3	3.0	3.0	1.3	1.0	3.0	0.0	0.3	0.0	0.0	3.0	0.5	0.0	0.5
21/1/4	Electrum	3.3	4.0	3.5	3.0	3.5	3.0	2.8	3.3	3.0	2.5	1.5	1.8	0.5	3.0	0.5	0.0	0.0	0.3	0.3	2.0	0.3
21/2/1	KWS Tardis	3.5	3.5	2.8	3.0	3.0	3.0	2.0	3.5	1.0	3.0	3.0	2.8	0.0	3.5	1.0	0.0	0.0	2.0	1.3	2.5	3.0
21/2/3	KWS Tardis	3.0	3.5	3.8	3.0	3.0	2.8	2.3	3.5	1.3	3.0	2.3	2.0	3.8	0.0	0.0	0.0	0.0	2.8	0.5	1.3	2.3
21/3/1	KWS Orwell	3.0	3.8	3.8	3.3	2.3	3.0	1.3	3.8	1.8	2.5	2.5	3.0	3.3	0.0	1.0	0.0	0.5	2.3	3.5	1.5	2.8
21/3/3	KWS Orwell	3.0	3.3	3.3	3.0	2.8	3.0	3.0	3.0	2.8	3.0	2.8	2.8	3.0	0.5	0.0	0.0	0.3	3.0	3.3	3.0	2.0
21/3/4	KWS Orwell	3.0	3.8	3.0	3.0	3.0	3.0	1.3	3.5	1.0	3.0	1.0	0.8	0.0	0.0	2.0	0.0	0.0	0.5	3.8	0.5	0.5
21/4/1	KWS Oasis	3.0	4.0	3.5	3.0	3.0	3.0	2.3	3.5	3.0	3.0	3.0	3.0	3.5	1.3	1.3	0.0	0.0	1.8	3.8	1.8	3.0
21/4/3	KWS Oasis	3.0	3.5	3.5	3.0	3.0	3.0	2.3	3.0	2.0	2.8	3.0	3.0	3.0	0.0	0.3	0.3	0.0	2.3	3.8	2.5	3.0
21/5/2	KWS Creswell	3.0	3.8	3.3	3.5	3.3	2.5	3.3	3.3	1.5	3.0	3.0	3.0	3.5	0.0	1.5	0.5	0.0	0.0	3.5	3.0	1.0
21/5/3	KWS Creswell	3.0	4.0	3.3	3.3	3.3	3.0	2.8	3.3	2.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0	2.3	3.3
21/6/1	KWS Cassia	3.3	3.5	3.5	3.0	3.0	2.8	1.5	3.0	3.0	1.5	0.0	0.8	3.8	0.0	0.8	0.0	0.0	2.0	3.0	0.0	0.5
21/6/2	KWS Cassia	3.0	3.5	3.8	3.0	3.0	3.0	2.0	3.3	2.0	3.0	3.0	3.0	3.3	0.0	0.3	0.5	0.0	2.5	4.0	1.8	3.5
21/6/3	KWS Cassia	3.3	3.5	3.0	3.0	3.0	3.0	2.8	2.3	3.0	2.0	1.0	1.5	0.5	0.3	0.0	0.0	0.0	0.5	3.3	0.0	0.3
21/7/1	Surge	3.3	3.5	3.3	3.0	2.8	3.0	1.3	3.8	1.3	1.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.5	1.0
21/7/2	Surge	3.5	3.5	3.8	2.8	3.5	3.0	2.5	4.0	2.0	3.0	2.8	2.5	0.0	0.0	1.0	0.0	0.3	3.0	3.5	2.0	3.0
21/8/1	LG Flynn	3.0	3.3	3.3	2.8	2.5	3.0	2.8	1.8	2.5	1.8	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.3
21/8/2	LG Flynn	3.0	3.5	3.5	3.3	3.0	3.0	2.5	1.0	3.0	3.0	3.0	3.0	0.0	3.0	0.0	0.0	0.0	2.5	3.3	1.5	3.3
21/9/1	Bazooka	3.3	4.0	3.3	3.3	2.8	3.0	3.0	3.3	2.0	3.0	2.8	2.3	3.3	0.0	1.8	0.0	0.0	1.8	3.3	1.3	3.0
21/9/2	Bazooka	3.3	3.5	3.3	3.3	2.5	3.3	2.0	3.8	1.8	2.0	1.5	0.5	0.0	0.0	0.0	1.0	0.3	0.3	0.0	1.5	0.0
21/11/3	-	3.3	3.8	3.5	2.8	2.8	3.5	2.8	3.5	3.0	2.8	3.0	2.0	0.0	0.0	0.0	0.0	0.0	3.0	0.3	2.5	3.3
21/11/4	-	3.3	3.5	3.3	2.3	3.0	3.0	3.3	3.0	2.0	1.8	1.3	1.3	0.3	0.0	0.5	0.0	0.0	1.0	0.3	0.3	0.8
21/12/1	-	3.3	3.5	3.5	3.3	3.3	2.8	1.8	3.3	1.3	2.5	2.0	0.3	2.8	1.8	1.5	0.0	0.0	0.3	1.5	0.8	2.5
21/12/7	-	3.3	3.8	3.3	2.5	2.8	3.0	3.0	3.5	2.0	2.3	0.8	1.0	3.0	0.0	0.0	0.0	0.0	0.8	0.0	0.8	0.0
21/13/1	-	3.5	4.0	3.5	3.0	3.3	3.3	2.5	3.5	3.5	1.8	2.8	1.8	0.0	4.0	0.8	0.0	0.0	0.0	3.0	2.5	0.3
21/13/6	-	2.8	3.3	3.3	3.0	3.0	3.0	3.0	2.8	2.0	2.8	3.0	3.0	3.0	0.0	1.0	0.0	0.0	0.5	3.8	2.8	0.0

Table 18: Virulence frequencies of key barley powdery mildew resistance genes over the past five years of testing.

Differential	Known Genes	Virulence Frequency by Year					
		2016	2017	2018	2019	2020	2021
Golden Promise	0	88	100	100	100	100	100
W.37/136	*Mlh*	100	100	100	100	100	100
W.41/145	*Mlra*	100	100	100	100	100	100
Goldfoil	*Mlg*	100	97	79	100	100	92
Zephyr	*Mlg,Ml(CP)*	100	97	79	100	100	88
Midas	*Mla6*	100	100	100	100	100	96
Lofa	*MlLa*	96	84	38	100	50	46
Hassan	*Mla12*	96	84	83	100	67	85
H.1063	*Mlk1*	31	13	41	25	33	35
Porter	*Mla7*	27	53	31	100	50	58
Lotta	*MlAb*	35	78	59	75	33	50
Triumph	*Mla7,MlAb*	12	22	3	25	17	38
Tyra	*Mla1*	73	56	69	25	83	50
Roland	*Mla9*	15	16	14	0	0	15
Apex	*mlo 11*	15	38	14	0	33	0
Riviera	*mlo 11*	0	6	0	0	0	0
Digger	*Mla13*	23	25	14	75	0	0
Ricardo	*Mla3*	62	75	59	0	17	27
Vanessa	Van	100	97	100	100	67	58
Optic		19	25	7	25	0	12
Propino		77	88	59	0	0	38
Total Number of Isolates		**26**	**32**	**29**	**4**	**6**	**26**

* = Not tested.

7 A brief look at the 2022 season

Whilst at the time of writing the 2022 samples are still being processed, it was noted that the UKCPVS received 190 wheat yellow rust samples, 28 wheat brown rust samples, 10 wheat powdery mildew samples and 29 barley powdery mildew samples from the 2022 season. A selection of these samples is being processed and investigated further.

8 Conclusions

The UK *Pst* population continues to show high levels of diversity since the incursion of the Warrior population in 2011. The current population continues to be dominated by isolates from the Red group, and within that group there are a broad range of virulence profiles which continues to change. Several new combinations of virulence were detected, with one isolate displaying a reaction on *Yr8*. Five isolates displaying previously existing and novel pathotypes were investigated in the adult plant trials. Two of these isolates were screened on a subset of RL and candidates in growth rooms, results were broadly comparable. Genotyping has been established and confirms that Red Group isolates dominate the samples tested.

A new differential set was used for the fifth year to analyse the *P. triticina* population. As seen in previous years, virulence was detected for many of the *Lr* genes tested with notable seedling virulence frequency changes to both *Lr20* and *Lr28*. Seedling variety tests saw an increase in varieties which were resistant to all five races and adult plant trials were successful and only two of the current RL varieties were resistant to all isolates. Many of the current RL varieties have moderate disease resistance ratings to *P. triticina* and this was reflected in the adult plant trial results.

The *Bgt* population did see some major changes but at the time of writing this is not thought to be of concern although further Survey work is needed to monitor the situation in future years.

Small changes in the *Bgh* population were detected, but this should be interpreted with caution due to the very limited number of isolates tested. As in previous years no unusual outbreaks were reported so it is unlikely that these changes have translated into detrimental effects on variety performance.

9 Acknowledgements

We would like to thank Dr Helen Bates and Dr Anne Webb for their excellent work on the yellow rust genotyping, Dr Diane Saunders and team for fruitful discussions and finally Dr Jane Thomas for her continued help and support.

10 Supplementary material

Supplementary Table 1: Average infection type (AIT) scores for the selected isolates against the UKCPVS differential set. Yellow shading indicates a compatible reaction; orange shading indicates a borderline reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Numbers next to the differential variety names indicate the known resistance genes carried by the variety. * = missing data.

Supplementary Table 2: Average infection type (AIT) scores for the selected isolates against the UKCPVS differential set. Yellow shading indicates a compatible reaction; orange shading indicates a borderline reaction. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

11 Appendix I: Sample register

2021 Wheat Yellow Rust Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2021/22	Location	Genotyped
21/083	Apache	June 2021	-	Lincolnshire	Y
21/119	Apache	June 2021	-	Essex	
21/076	Apostle	June 2021	-	Lincolnshire	
21/146	Banquo	June 2021	-	Bridgend County Borough	
21/059	Belipi	April 2021	-	Gloucestershire	
21/077	Brigadier	June 2021	-	Lincolnshire	Y
21/115	Brigadier	June 2021	-	Essex	
21/078	Brimstone	June 2021	-	Lincolnshire	
21/117	Brimstone	June 2021	-	Essex	
21/052	Claire	April 2021	-	Essex	
21/067	Claire	May 2021	-	Lincolnshire	
21/081	Claire	June 2021	-	Lincolnshire	Y
21/075	Cordiale	June 2021	-	Lincolnshire	Y
21/125	Cordiale	June 2021	-	Essex	
21/138	Crusoe	June 2021	9	Oxfordshire	Y
21/037	Elation	April 2021	8	Lincolnshire	Y
21/038	Elation	April 2021	8	Lincolnshire	
21/031	Elicit	March 2021	8	Lincolnshire	
21/129	GK Szzlizard	June 2021	-	East Yorkshire	
21/002	Gleam	November 2020	5	Oxfordshire	
21/022	Gleam	March 2021	5	Cambridgeshire	
21/024	Gleam	March 2021	5	Lincolnshire	
21/030	Gleam	March 2021	5	Lincolnshire	
21/042	Gleam	April 2021	5	Lincolnshire	
21/043	Gleam	April 2021	5	Lincolnshire	
21/044	Gleam	April 2021	5	Lincolnshire	
21/090	Gleam	June 2021	5	Lincolnshire	
21/060	Gleam	April 2021	5	South Yorkshire	
21/113	Gleam	June 2021	5	North Yorkshire	
21/153	Gleam	July 2021	5	Lothians	
21/011	Graham	March 2021	8	Lincolnshire	Y
21/036	Graham	April 2021	8	Lincolnshire	Y
21/039	Graham	April 2021	8	Lincolnshire	
21/046	Graham	April 2021	8	Lincolnshire	Y
21/084	Graham	June 2021	8	Lincolnshire	
21/120	Graham	June 2021	8	Essex	Y
21/108	KWS Barrel	June 2021	7	Lincolnshire	Y
21/006	KWS Basset	November 2020	-	Berkshire	
21/012	KWS Chilham	March 2021	7	Essex	
21/072	KWS Cranium	May 2021	8	Cambridgeshire	
21/097	KWS Cranium	June 2021	8	Lincolnshire	
21/133	KWS Cranium	June 2021	8	Lincolnshire	
21/027	KWS Extase	March 2021	8	Lincolnshire	
21/029	KWS Extase	March 2021	8	Lincolnshire	
21/110	KWS Extase	June 2021	8	Kent	
21/154	KWS Extase	July 2021	8	Norfolk	
21/155	KWS Extase	July 2021	8	Lincolnshire	
21/009	KWS Firefly	March 2021	7	Cambridgeshire	
21/010	KWS Firefly	March 2021	7	Bedfordshire	
21/013	KWS Firefly	March 2021	7	East Yorkshire	
21/015	KWS Firefly	March 2021	7	Lincolnshire	
21/016	KWS Firefly	March 2021	7	Lincolnshire	
21/017	KWS Firefly	March 2021	7	Lincolnshire	
21/018	KWS Firefly	March 2021	7	Essex	

Isolate Number	Host Variety	Date Sampled	RL Rating 2021/22	Location	Genotyped
21/026	KWS Firefly	March 2021	7	Lincolnshire	
21/048	KWS Firefly	April 2021	7	Lincolnshire	
21/050	KWS Firefly	April 2021	7	Lincolnshire	
21/051	KWS Firefly	April 2021	7	Lincolnshire	
21/057	KWS Firefly	April 2021	7	East Yorkshire	Y
21/071	KWS Firefly	May 2021	7	Cambridgeshire	
21/093	KWS Firefly	June 2021	7	Lincolnshire	
21/069	KWS Jackal	May 2021	9	Cambridgeshire	
21/102	KWS Jackal	June 2021	9	Lincolnshire	Y
21/001	KWS Kerrin	November 2020	4	Oxfordshire	
21/096	KWS Kerrin	June 2021	4	Lincolnshire	Y
21/032	KWS Kinetic	March 2021	4	Lincolnshire	
21/066	KWS Kinetic	May 2021	4	Herefordshire	Y
21/104	KWS Kinetic	June 2021	4	Lincolnshire	
21/141	KWS Kinetic	June 2021	4	Midlothian	
21/152	KWS Kinetic	July 2021	4	Lothians	
21/054	KWS Siskin	April 2021	9	Warwick	Y
21/055	KWS Siskin	April 2021	9	Essex	Y
21/111	KWS Siskin	June 2021	9	Lincolnshire	Y
21/123	KWS Siskin	June 2021	9	Essex	
21/007	KWS Zyatt	March 2021	5	Oxfordshire	
21/073	KWS Zyatt	June 2021	5	Cambridgeshire	Y
21/106	KWS Zyatt	June 2021	5	Lincolnshire	
21/128	KWS Zyatt	June 2021	5	Devon	
21/144	KWS Zyatt	July 2021	5	Lincolnshire	
21/151	KWS Zyatt	July 2021	5	Lothians	
21/033	Leeds	March 2021	-	Lincolnshire	
21/047	Leeds	April 2021	-	Lincolnshire	
21/049	Leeds	April 2021	-	Lincolnshire	
21/139	Leeds	June 2021	-	Midlothian	
21/137	Leeds	June 2021	-	Angus	
21/105	LG Astronomer	June 2021	9	Lincolnshire	Y
21/092	LG Illuminate	June 2021	7	Lincolnshire	
21/088	LG Prince	June 2021	8	Lincolnshire	
21/131	LG Prince	June 2021	8	Lincolnshire	Y
21/101	LG Quasar	June 2021	6	Lincolnshire	
21/140	LG Quasar	June 2021	6	Midlothian	
21/003	LG Skyscraper	November 2020	8	Oxfordshire	Y
21/005	LG Skyscraper	November 2020	8	Oxfordshire	Y
21/008	LG Skyscraper	March 2021	8	Essex	Y
21/014	LG Skyscraper	March 2021	8	East Lothian	Y
21/109	LG Skyscraper	June 2021	8	Lincolnshire	
21/023	LG Spotlight	March 2021	6	Lincolnshire	
21/028	LG Spotlight	March 2021	6	Lincolnshire	
21/094	LG Spotlight	June 2021	6	Lincolnshire	
21/127	LG Spotlight	June 2021	6	Devon	
21/041	MV Fredericia	April 2021	-	Warwickshire	
21/064	Nogal	April 2021	-	East Yorkshire	
21/065	Nogal	May 2021	-	East Yorkshire	Y
21/061	Parade	April 2021	-	Lincolnshire	
21/116	Parade	June 2021	-	Essex	
21/019	Reflection	March 2021	-	Cambridgeshire	
21/020	Reflection	March 2021	-	Lincolnshire	
21/086	Relay	June 2021	-	Lincolnshire	
21/122	Relay	June 2021	-	Essex	
21/085	Rendezvous	June 2021	-	Lincolnshire	
21/121	Rendezvous	June 2021	-	Essex	
21/149	RGT Bairstow	June 2021	-	Bridgend County Borough	
21/103	RGT Flintoff	June 2021	-	Lincolnshire	
21/150	RGT Flintoff	July 2021	-	Lothians	

Isolate Number	Host Variety	Date Sampled	RL Rating 2021/22	Location	Genotyped
21/148	RGT Galactus	June 2021	-	Bridgend County Borough	
21/098	RGT Gravity	June 2021	7	Lincolnshire	
21/070	RGT Illustrious	May 2021	8	Cambridgeshire	Y
21/089	RGT Illustrious	June 2021	8	Lincolnshire	Y
21/091	RGT Lantern	June 2021	-	Lincolnshire	
21/145	RGT Lantern	June 2021	-	Bridgend County Borough	
21/034	RGT Saki	March 2021	8	Lincolnshire	Y
21/099	RGT Saki	June 2021	8	Lincolnshire	
21/107	RGT Wolverine	June 2021	5	Lincolnshire	
21/132	RGT Wolverine	June 2021	5	Lincolnshire	Y
21/135	RGT Wolverine	June 2021	5	Cambridgeshire	Y
21/147	RGT Wolverine	June 2021	5	Bridgend County Borough	Y
21/062	Robigus	April 2021	-	Lincolnshire	
21/079	Robigus	June 2021	-	Lincolnshire	Y
21/004	Skyfall	November 2020	3	Oxfordshire	
21/021	Skyfall	March 2021	3	Cambridgeshire	
21/025	Skyfall	March 2021	3	Lincolnshire	
21/035	Skyfall	March 2021	3	Lincolnshire	
21/040	Skyfall	April 2021	3	Lincolnshire	
21/045	Skyfall	April 2021	3	Cambridgeshire	Y
21/056	Skyfall	April 2021	3	Oxfordshire	
21/068	Skyfall	May 2021	3	Lincolnshire	
21/100	Skyfall	June 2021	3	Lincolnshire	
21/126	Skyfall	June 2021	3	Devon	Y
21/134	Skyfall	June 2021	3	Lincolnshire	
21/142	Skyfall	June 2021	3	Midlothian	Y
21/143	Skyfall	July 2021	3	Lincolnshire	Y
21/114	Soissons	June 2021	-	Essex	
21/074	Solstice	June 2021	-	Lincolnshire	Y
21/124	Solstice	June 2021	-	Essex	
21/082	Stigg	June 2021	-	Lincolnshire	Y
21/118	Stigg	June 2021	-	Essex	
21/087	Swallow	June 2021	6	Lincolnshire	Y
21/058	SY Insitor	April 2021	5	Cambridgeshire	
21/095	SY Insitor	June 2021	5	Lincolnshire	
21/136	SY Insitor	June 2021	5	Cambridgeshire	Y
21/112	unknown	June 2021	-	Cambridgeshire	
21/053	Victo	April 2021	-	Essex	
21/063	Victo	April 2021	-	Lincolnshire	
21/080	Victo	June 2021	-	Lincolnshire	Y

2021 Wheat Brown Rust Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2021/22	Location
21/010	Crusoe	July 2021	3	Cambridgeshire
21/005	Graham	November 2020	5	Oxfordshire
21/009	Graham	July 2021	5	Cambridgeshire
21/004	KWS Basset	November 2020	-	Berkshire
21/006	KWS Cranium	June 2021	5	Lincolnshire
21/007	KWS Cranium	June 2021	5	Cambridgeshire
21/002	KWS Kerrin	November 2020	7	Oxfordshire
21/001	LG Skyscraper	November 2020	6	Oxfordshire
21/003	LG Skyscraper	November 2020	6	Oxfordshire
21/008	Relay	July 2021	-	Cambridgeshire

2021 Wheat Powdery Mildew Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2021/22	Location
21/001	KWS Extase	April 2021	7	Shropshire
21/002	KWS Extase	May 2021	7	Cornwall
21/008	LG Quasar	June 2021	6	Angus
21/003	Theodore	May 2021	[7]	Cornwall
21/004	-	May 2021	-	South Yorkshire
21/005	-	May 2021	-	Suffolk
21/006	-	May 2021	-	Wiltshire
21/007	-	June 2021	-	Suffolk
21/009	-	July 2021	-	Suffolk
21/010	-	July 2021	-	East Yorkshire

2021 Barley Powdery Mildew Isolate Register

Isolate number	Host Variety	Date Sampled	RL Rating 2021/22	Location
21/009	Bazooka	May 2021	5	Lincolnshire
21/001	Electrum	May 2021	6	Lincolnshire
21/006	KWS Cassia	May 2021	5	Lincolnshire
21/005	KWS Creswell	May 2021	4	Lincolnshire
21/004	KWS Oasis	May 2021	-	Lincolnshire
21/003	KWS Orwell	May 2021	3	Lincolnshire
21/002	KWS Tardis	May 2021	5	Lincolnshire
21/008	LG Flynn	May 2021	4	Lincolnshire
21/007	Surge	May 2021	5	Lincolnshire
21/010	-	April 2021	-	-
21/011	-	May 2021	-	Devon
21/012	-	May 2021	-	Cambridgeshire
21/013	-	June 2021	-	Essex
21/014		June 2021	-	Devon
21/015	-	June 2021	-	Cambridgeshire

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