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United Kingdom Cereal Pathogen Virulence Survey 2023 Annual Report

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1 Grower summary

Wheat yellow rust

In 2022, disease pressure was slow to build. However, the survey received numerous yellow rust samples by the end of the season. The 2023 season was a stark contrast. A wet spring meant yellow rust failed to take off in many areas, with the lowest number of samples received by UKCPVS for many years.

Although the UK wheat yellow rust population remains diverse, most varieties generally performed in line with their Recommended Lists (RL) disease ratings – no major breakdowns were observed in adult plant trials during 2022. Many recommended and candidate varieties were resistant to all five isolates. KWS Zyatt was the most susceptible variety, followed by Skyfall, which reflects their low yellow rust disease ratings.

The UKCPVS received samples from the resistant cultivars Costello, Mayflower and Theodore. However, all three remained resistant in 2022 seedling virulence tests and 2023 adult plant trials.

Enhanced yellow rust seedling screening results in 2023 identified three varieties classified as resistant at the young plant stage (RL 2023/24) that were susceptible to more than one isolate: KWS Extase, Crusoe and KWS Zealum. Three further varieties, Merit, LG Illuminate and RGT Bairstow, were susceptible to a single isolate. Varieties that are susceptible to a greater number of isolates are more likely to be prone to problems in the field at the young plant stage and should be the priority for monitoring.

Wheat brown rust

Mirroring yellow rust, few brown rust samples were received in the 2023 season. In adult plant trials, many varieties had moderate-to-high levels of disease. This reflects RL data, as many varieties have brown rust disease resistance ratings of 5 or 6. At the adult plant stage, Skyfall was the most resistant RL variety tested, with LG Astronomer also performing well.

The UKCPVS received reports of higher-than-expected levels of disease on Theodore in the South West during 2022 and 2023. Isolates from Theodore were found to carry virulence to *Lr24*, which has not been observed in brown rust samples since 2017. An isolate carrying virulence to *Lr24* (from 2022) was included in the VL/RL 2023 isolate mix to help test the performance of candidate varieties.

Monitoring

Many factors affect disease development, including varieties, location, local weather and global climatic events. Pathogen populations can respond to these changes during the season. It is important to monitor crops closely and report unusual disease levels to the UKCPVS. For monitoring guidance and the latest information, visit: 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 2022 and 2023. Five isolates from 2022 displaying novel and existing pathotypes were investigated in the adult plant trials. The genotyping results confirmed that the majority of isolates tested in 2022 and 2023 belonged to the Red Group, with one isolate in 2022 and 2023 belonging to the Pink Group and one isolate in 2023 belonging to the Purple Group. This mirrors the pattern of the genetic groups observed in Europe over the same time period.

Wheat Brown Rust

As seen in previous years, virulence was detected for many of the *Lr* genes tested. The most notable change was the re-emergence of virulence on *Lr24*, not seen since 2017. Some changes were also observed, for example, virulence for *Lr3a*, *Lr3bg*, *Lr3ka*, *Lr20,* and *Lr28* increased, while virulence for *Lr23* declined. Apart from higher than expected levels of disease in Theodore, no other major changes in varietal performance were reported.

Wheat and Barley Powdery Mildew

No major changes in the *Bgt* or *Bgh* populations were observed in 2022. Reports were received of higher than expected disease levels of *Bgt* in *mlo*-possessing varieties in 2023 RL trials in Scotland. The survey will include several isolates in the 2024 season to investigate this.

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.
Bgh	*Blumeria graminis* f.sp. *hordei*; barley powdery mildew.
Bgt	*Blumeria graminis* f.sp. *tritici*; wheat powdery mildew.
Differential	Varieties/accessions that have known resistance genes. If an isolate (pathogen) is able to 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.
Pst	*Puccinia striiformis* f.sp. *tritici*; wheat yellow rust.
Pt	*Puccinia triticina*; wheat brown rust.
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.
RL	Recommended List.
Seedling	In the case of UKCPVS seedling tests this refers to seedlings infected at the 1st leaf stage. i.e., when the first leaf is fully expanded. Second and 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.
VL	Variety List (formally known as National List).
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 56th 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 recently 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

For the past decade the wheat yellow rust population has remained diverse. 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 *et al*., 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 *et al*., 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 *et al*., 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. In 2022 no isolates were found to carry virulence to *Yr8*, but virulence to Crusoe increased from 3% to 8% of isolates. The most common pathotype identified from the seedling differential test data in 2022 was Red 26.

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 2022 and 2023 there were changes in virulence frequencies, the most notable being the re-emergence of virulence on *Lr24* which was accompanied with reports of higher than expected levels of disease in Theodore.

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

The pipeline for how the wheat rust pathogen were tested in 2022 is depicted in **Figure 2**.

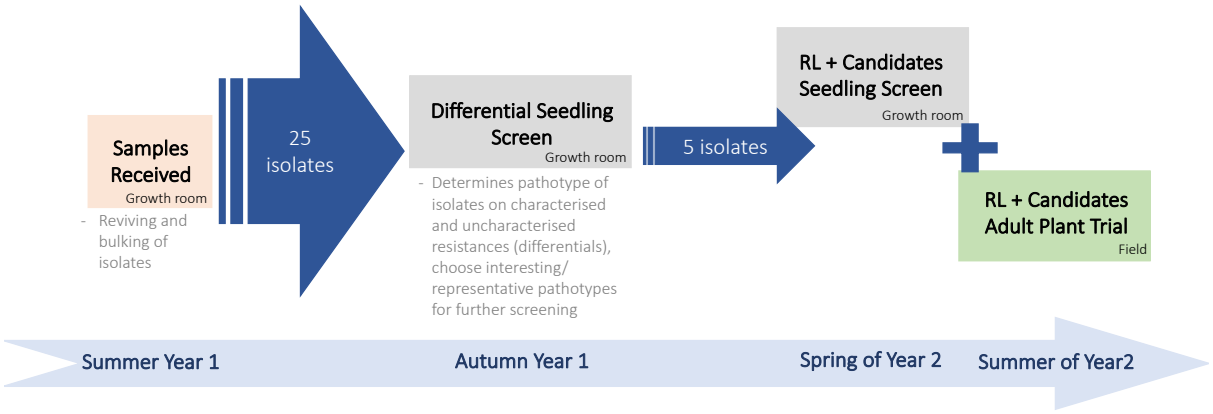

Figure 2: Wheat yellow rust and wheat brown rust sample processing pipeline in 2022 and previously.

In 2023 this pipeline was modified slightly and a sub-set of RL varieties were included in the differential seedling screen to provide earlier data on a wider selection of yellow rust and brown rust isolates.

5.1.1 Collection of samples and preparation of isolates

Infected wheat leaves were received from growers, agronomists and operators of RL trials. Purification methods are used to overcome the problem of multiple isolates in a sample. 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 (seedling is considered to be resistant), 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

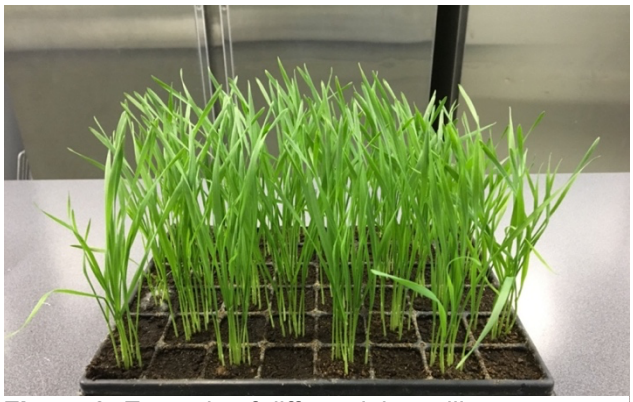

Figure 3: Example of differential seedling test set up.

of 2.7 – 4.0 indicate a compatible reaction and the isolate is virulent on that differential (seedling is considered to be susceptible).

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 five 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 days from approx. GS 31 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 five times. Assessments were made from flag leaf emergence onwards until senescence.

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

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 13** and **Table 15**. 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 24 samples from 2022 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.

The same was repeated for 24 samples from 2023.

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 from 2022 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 2022 libraries were sequenced on the flow cell, overnight.

The same was repeated for 24 samples from 2023.

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 2022 the UKCPVS received 187 samples of wheat yellow rust from 26 different counties across the UK (**Figure 5**).

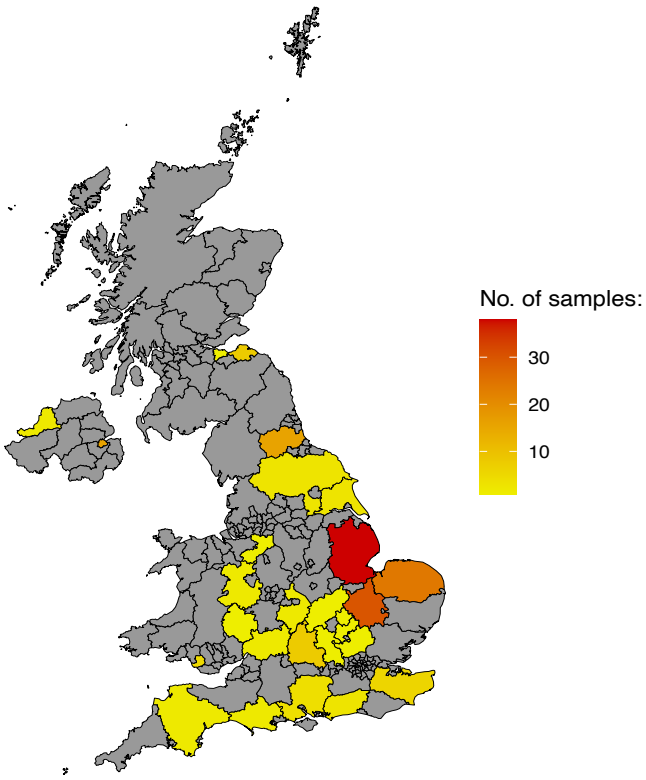

Figure 5: Map of the UK showing the counties where samples of wheat yellow rust were received from in 2022.

Disease pressure was initially impeded by dry weather in April 2022 which was not conducive to rust development. Due to the low numbers of samples received by the end of April the UKCPVS made a call for disease samples and received 187 by the end of June.

The UKCPVS did receive some reports of unusual sightings such as yellow rust in the resistant cultivars KWS Siskin and Costello, both rated a 9 (AHDB 2022/23) for yellow rust on the Recommended List. Four samples were received from KWS Siskin and two samples were received from Costello in 2022. Samples were also received from Mayflower and Theodore (also rated 9).

In total, samples were received from 52 different varieties consisting of current and past RL varieties, spreader plots and other breeding lines. The most sampled variety was KWS Zyatt closely followed by Skyfall.

The full sample register is provided in **Appendix I: 2022 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

Twenty-five isolates were selected for further pathotyping (**Supplementary Table 1** and **Table 2**). 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 2022 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**).

No virulence was detected for *Yr8* which has been seen at low levels in recent years. Virulence for the variety Crusoe increased from 3% in 2021 to 8% in 2022. Virulence for Evolution, which has fluctuated widely over the years, remained at a similar level to that of 2021. Virulence for Apache, which carries the resistance genes *Yr7 and Yr17*, was seen in all but one of the isolates tested.

Table 2: Pathotypes of the 2022 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; blank indicates avirulence.

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
22/001	KWS Zyatt	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/020	Gleam	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/021	Skyfall	Red 43	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca			Ap		
22/032	KWS Extase	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
22/038	Costello	Red 76	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa		St		Ap		Ev
22/047	LG Astronomer	Red 24	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		Ev
22/054	LG Redwald	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
22/055	Gleam	Red 9	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So							
22/060	KWS Zyatt	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/064	RGT Stokes	Red 24	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		Ev
22/084	KWS Firefly	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/097	RGT Rashid	Red 43	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca			Ap		
22/099	SY Insitor	Red 37	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
22/101	LG Spotlight	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/103	KWS Zyatt	Red 43	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca			Ap		
22/113	LG Prince	Red 24	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		Ev
22/143	Mayflower	Red 84	1	2	3			6	7		9			17		25	32		Sp	Ro	So		Ca	St		Ap		
22/145	KWS Barrel	Red 24	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		Ev
22/146	Gefion	Red 85	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca	St	Kr	Ap		Ev
22/154	RGT Wilkinson	Red 24	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		Ev
22/162	KWS Siskin	Pink 18	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	
22/165	RGT Zinzan	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/178	RGT Zinzan	Red 43	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So	Wa	Ca			Ap		
22/180	Theodore	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		Ap		
22/182	KWS Extase	Red 29	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	

[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 wheat 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				
	2018	2019	2020	2021	2022
Yr1	97	94	100	100	100
Yr2	100	100	100	100	100
Yr3	100	94	100	98	100
Yr4	100	97	100	90	96
Yr5	0	0	0	0	0
Yr6	100	100	100	100	100
Yr7	100	100	100	100	100
Yr8	0	16	3	8	0
Yr9	100	94	100	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	67	48	87	73	72
Spaldings Prolific	100	81	100	100	100
Robigus	100	100	100	100	100
Solstice	100	100	100	100	100
Warrior	20	61	47	73	92
Cadenza	93	77	83	88	92
KWS Sterling	17	55	70	80	80
Kranich	0	29	33	43	24
Apache	83	68	93	100	96
Crusoe	0	10	7	3	8
Evolution	40	19	73	38	40
Total Number of Isolates	**30**	**31**	**30**	**40**	**25**

Table 4: Yellow rust pathotype group frequencies from the past five years.

Pathotype Group*	Frequency of Isolates Found (%)				
	2018	2019*	2020*	2021*	2022*
Pink	0	7	3	0	4
Blue	0	0	0	0	0
Red	93	74	97	100	96
Purple	3	4	0	0	0
Other	4	15	0	0	0
Number of Isolates	**30**	**31**	**30**	**40**	**25**

* 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.

6.1.2.2 Commonly detected isolates

In 2022 there were 10 different pathotypes detected (**Table 2**), two of which were unique to this year. The genotyping conducted on 24 of the 25 isolates tested (see **Section 6.1.4**) showed that 23 of the isolates fell into the Red group (**Table 4**).

The most common group of isolates in 2022, represented by 28% of isolates, was Red 26 with the pathotype *Yr1,2,3,4,6,7,9,17,25,32*,Re,Sp,Ro,So,Wa,Ca,St,Ap.

One isolate from the Pink Group was identified, WYR 22/162, carrying the pathotype *Yr1,2,3,4,6,7,9,17,25,32*,Re,Sp,Ro,So,Wa,Ca,St,Kr,Ap,Cr.

No isolates from the Purple or Blue pathotype groups were found in 2022.

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

6.1.3 Variety testing of isolates from 2022

Five isolates from the 25 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 2022, the isolates WYR 22/038, 22/055, 22/143, 22/162 and 22/180 were selected due to their novel and common pathotypes.

Table 5: Virulence profile of the wheat yellow rust isolates chosen for further characterisation in seedling and adult plant tests. Yellow shading indicates virulence of an isolate for a particular resistance gene or variety; blank indicates avirulence.

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
22/038	Costello	Red 76	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa		St		Ap		Ev
22/055	Gleam	Red 9	1	2	3	4		6	7		9			17		25	32		Sp	Ro	So							
22/143	Mayflower	Red 84	1	2	3			6	7		9			17		25	32		Sp	Ro	So		Ca	St		Ap		
22/162	KWS Siskin	Pink 18	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St	Kr	Ap	Cr	
22/180	Theodore	Red 26	1	2	3	4		6	7		9			17		25	32	Re	Sp	Ro	So	Wa	Ca	St		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.

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 2023. Results were 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**). Thirty-two of the 52 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 WYR 19/038 and 19/215 in 2019 and WYR 20/293 and 20/304 in 2020. Isolate WYR 22/162 was found to be virulent on Crusoe in initial seedling differential tests but at the adult plant stage Crusoe remained resistant to all five isolates tested.

KWS Brium, LG Arkle, KWS Extase and the controls Kranich and LGW110 were susceptible to one isolate, WYR 22/162, at seedling stage.

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 2023 which contained RL and candidate varieties. Plots were directly inoculated early in the season to help keep natural infection at bay and inoculated every seven days until the flag leaf had fully emerged. The first inoculation was carried out on the 19th April 2023 and the first assessment was made on 19th May when the plants were at GS39. The percentage of plot area infected was assessed and the mean was calculated from six assessments (**Table 6**).

Disease levels were moderate to high in the trials. Dry periods of 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 variety Robigus produced the highest levels of disease with up to 43.60% mean plot infection in the trial infected with WYR 22/055. 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**).

SY Insitor, Gleam and the control variety Stratosphere showed notably higher levels of disease with isolate WYR 22/055 compared to the other four isolates under test. KWS Zealum (rated 9) was resistant to four of the isolates but saw a mean of 2.80% with isolate WYR 22/055 and for this reason falls lower in the table than some other varieties rated 7 and 8. Swallow, rated 6, showed quite low levels of infection at adult plant stage with a maximum mean of 2.10% with isolate WYR 22/038. KWS Extase showed higher levels of disease with isolate WYR 22/162 with a mean of 7.30% (**Table 6**).

Table 6: Seedling and adult plant reactions to the five wheat yellow rust 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 six assessments. Varieties are ordered in level of disease at adult plant stage. Control varieties are highlighted in green text.

Variety	RL Rating 2023/24	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		22/038	22/055	22/143	22/162	22/180	22/038	22/055	22/143	22/162	22/180
COSTELLO	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS BRIUM	9	1.7	0.7	0.0	3.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS CRANIUM	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS GUIUM	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS PALLADIUM	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS ULTIMATUM	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
LG ASTRONOMER	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
LG TYPHOON	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
MAYFLOWER	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
OXFORD	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
RGT SAKI	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
THEODORE	9	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
CHAMPION	8	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
LG PRINCE	8	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
MERIT	8	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
BLACKSTONE	Candidate	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
BOLINDER	Candidate	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS DRAGUM	Candidate	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
KWS SKATEUM	Candidate	0.3	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
LG ARKLE	Candidate	1.3	0.0	0.0	3.0	2.0	0.00	0.00	0.00	0.00	0.00
LG GRENDEL	Candidate	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
LGWU184	-	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
CRUSOE	9	0.0	0.0	0.0	2.7	0.0	0.00	0.10	0.00	0.00	0.00
KWS DAWSUM	9	0.0	0.0	0.0	0.0	0.0	0.10	0.00	0.00	0.00	0.00
ALMARA	Candidate	0.0	0.0	0.0	0.0	0.0	0.10	0.00	0.00	0.00	0.00
LG REDRUM	Candidate	0.8	0.0	0.0	0.0	0.1	0.10	0.00	0.00	0.00	0.00
SY CHEER	Candidate	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.20	0.00
BAMFORD	Candidate	1.2	0.0	0.0	0.1	0.0	0.30	0.00	0.00	0.00	0.00
LG BEOWULF	Candidate	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.30
GRAHAM	8	3.0	3.0	0.1	3.0	2.0	0.00	0.60	0.00	0.00	0.00
RGT RASHID	8	0.2	0.0	0.0	0.1	0.0	0.00	0.50	0.00	0.20	0.00
LG ILLUMINATE	7	0.0	0.0	0.0	0.0	0.0	0.70	0.00	0.00	0.00	0.00
RENDEZVOUS	-	3.0	0.0	0.3	2.8	2.7	0.50	0.00	0.00	0.50	0.00
LG REDWALD	7	0.8	3.0	0.0	2.4	2.3	0.10	0.10	0.30	0.80	0.50
RGT STOKES	7	0.0	0.0	0.0	0.0	0.0	0.20	0.20	0.70	1.10	0.30
RGT BAIRSTOW	8	0.1	0.0	0.0	0.0	0.0	0.30	0.00	0.00	1.90	0.50
KWS ZEALUM	9	1.4	1.0	0.0	0.1	0.0	0.00	2.80	0.00	0.00	0.00
RGT ILLUSTRIOUS	8	2.4	0.0	0.0	0.3	3.0	0.60	0.60	0.50	0.00	1.20
SWALLOW	6	0.0	0.0	0.0	0.0	0.0	2.10	0.60	0.20	0.10	0.20
COUGAR	-	0.1	0.0	0.0	0.0	0.0	1.30	0.10	0.90	0.50	0.50
RGT WILKINSON	7	3.0	0.0	0.0	3.0	0.3	2.30	0.00	0.00	2.40	0.00
LG SKYSCRAPER	7	3.0	3.0	*	3.0	3.0	0.40	0.00	0.80	3.40	0.50
WARRIOR	-	0.1	3.0	0.7	3.0	3.0	0.50	6.70	0.50	1.60	0.50

Variety	RL Rating 2023/24	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		22/038	22/055	22/143	22/162	22/180	22/038	22/055	22/143	22/162	22/180
KWS EXTASE	8	0.0	0.0	0.0	2.7	0.0	1.10	1.90	0.50	7.30	0.10
KWS WEBBUM	-	3.0	1.9	0.2	0.5	3.0	11.00	0.10	0.20	1.10	0.20
STRATOSPHERE	-	2.6	3.0	0.0	3.0	3.0	0.00	13.00	0.50	0.30	0.10
DELPHI	-	3.0	3.0	3.0	3.0	3.0	15.20	1.50	0.00	0.00	0.00
GEFION	-	3.0	1.7	0.1	0.0	0.3	16.60	0.10	0.00	2.80	0.00
KWS WRENUM	-	2.2	0.0	1.5	1.5	3.0	3.10	1.70	6.70	3.40	10.20
KRANICH	-	0.3	0.0	0.2	3.0	2.0	0.30	0.20	0.10	24.20	0.50
KWS BARREL	-	3.0	0.0	0.0	0.0	1.0	5.30	0.10	6.30	7.80	8.70
LGW110	-	0.1	0.0	0.0	3.0	2.0	4.80	7.80	1.20	14.30	1.10
LG PARTRIDGE	Candidate	0.0	0.0	0.0	3.0	0.5	11.80	6.50	7.50	6.50	0.30
APACHE	-	2.9	2.5	2.7	3.0	3.0	4.10	4.10	5.10	11.50	10.70
KWS STERLING	-	3.0	0.0	3.0	3.0	3.0	8.80	3.90	6.50	5.70	11.10
RW42046	-	3.0	0.2	2.0	1.4	3.0	10.30	2.60	10.50	7.10	12.10
GLEAM	5	3.0	3.1	0.0	0.4	0.0	8.80	26.20	1.20	0.60	6.50
HOBBIT	-	3.0	3.0	3.0	3.0	3.0	6.70	10.50	10.00	4.90	11.70
REFLECTION	-	3.1	3.0	3.0	3.0	3.0	32.30	4.50	2.40	10.40	1.00
CADENZA	-	2.3	2.3	3.0	3.0	3.2	10.00	10.20	12.30	10.10	12.70
RGT WOLVERINE	4	3.0	0.0	3.0	3.0	3.0	13.30	6.70	15.40	4.90	15.80
AMBITION	-	0.7	2.3	0.4	3.0	2.0	6.60	9.90	5.20	31.00	4.40
CORDIALE	-	3.0	3.0	3.0	3.0	3.0	9.70	10.50	12.10	17.30	20.40
SY INSITOR	5	2.5	3.0	0.0	3.0	0.1	4.30	42.70	4.50	11.90	8.10
CLAIRE	-	*	0.0	*	3.0	0.0	30.30	25.70	9.50	12.90	7.90
SKYFALL	3	3.3	3.0	2.8	3.0	3.0	18.60	15.90	15.00	24.90	15.30
TORCH	-	3.0	3.0	3.0	3.0	3.0	11.80	10.30	17.80	49.70	20.90
SOLSTICE	-	3.0	3.2	3.0	3.0	3.0	19.30	28.70	21.60	23.40	28.40
KWS ZYATT	3	3.0	0.0	3.0	3.0	3.0	16.50	22.90	32.20	23.10	29.50
ROBIGUS	-	3.3	3.0	3.0	3.0	3.2	43.30	43.60	33.50	37.70	41.00
Avocet 1	-	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	3.1	3.0	3.0	3.0	*	*	*	*	*
Vilmorin 23	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Hybrid 46	-	2.5	3.0	2.0	3.0	3.0	*	*	*	*	*
Suwon Omar	-	2.7	3.0	1.8	3.1	3.0	*	*	*	*	*
Avocet 6	-	3.2	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 7	-	3.1	3.0	3.0	3.3	3.2	*	*	*	*	*
Lee	-	3.0	3.2	3.0	3.0	3.0	*	*	*	*	*
Avocet 8	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Compair	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Avocet 9	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Clement	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
VPM1	-	3.0	2.3	3.0	3.0	3.2	*	*	*	*	*
Avocet 17	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet 24	-	0.0	0.0	0.0	0.0	0.0	*	*	*	*	*
Heines VII	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Strubes Dickopff	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*

Variety	RL Rating 2023/24	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		22/038	22/055	22/143	22/162	22/038	22/055	22/055	22/143	22/038	22/055
Avocet 27	-	3.2	3.0	3.0	3.0	3.0	*	*	*	*	*
Avocet 32	-	3.2	3.0	3.0	3.0	3.0	*	*	*	*	*
Carstens V	-	3.0	3.0	2.0	3.0	3.0	*	*	*	*	*
Avocet Sp	-	3.1	3.0	3.0	3.0	3.0	*	*	*	*	*
Spaldings Prolific	-	3.0	3.0	3.0	3.0	3.0	*	*	*	*	*
Evolution	-	3.0	0.1	0.0	0.1	0.5	*	*	*	*	*
Mean							**4.8**	**4.6**	**3.5**	**5.3**	**4.0**

* = 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.

6.1.4 Genotyping

Twenty-four isolates from 2022 were selected for genotyping based on their location and host cultivar (detailed in **Appendix I: 2022 Sample Register**). A phylogenetic tree based on 242 *Pst* genes following the MARPLE pipeline (Radhakrishnan *et al.*, 2019) was constructed of the 24 isolates from 2022 (**Figure 6**). The tree also includes 48 isolates selected from the 2021 survey, 24 isolates from the 2020 survey and 24 isolates from the 2019 survey.

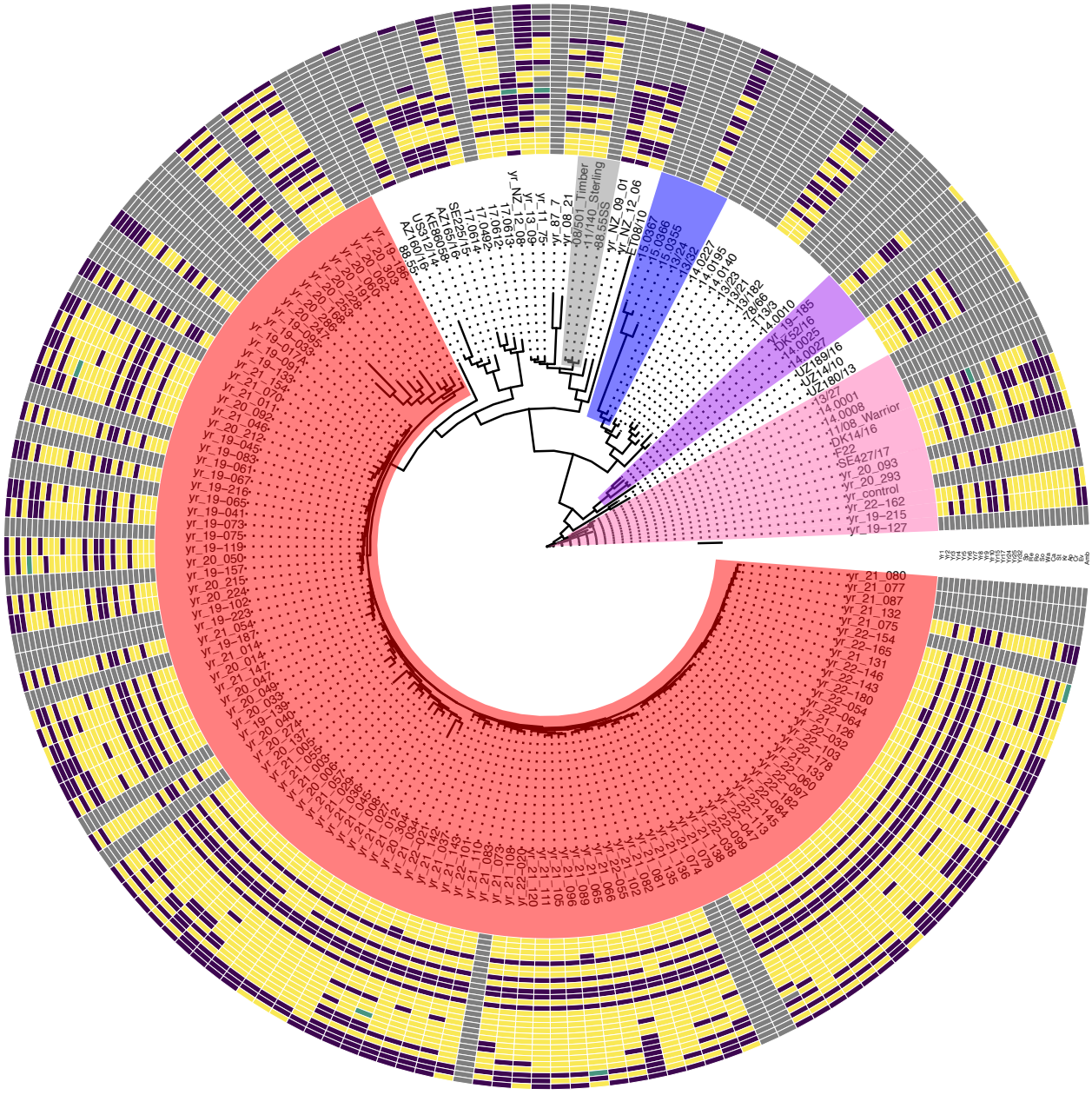

Figure 6: Phylogenetic analysis of 242 wheat yellow rust genes from selected isolates from the UKCPVS programme from the 2019 – 2022 surveys. The heatmap on the outside of the figure shows the seedling pathotyping data for each isolate; yellow indicates where the isolate was virulent on the differential, purple where the isolate was not able to cause disease on the differential and green where the result was borderline. The phylogeny on the inside shows the relationship of the genotyped isolates, with the main genetic groups coloured in red, pink and purple.

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

of **Figure 6**). In 2021, all the 48 isolates genotyped grouped with the Red Group. In 2022, 23 out of 24 isolates genotyped grouped with the Red Group and one isolate WYR 22/162 grouped with the Pink Group.

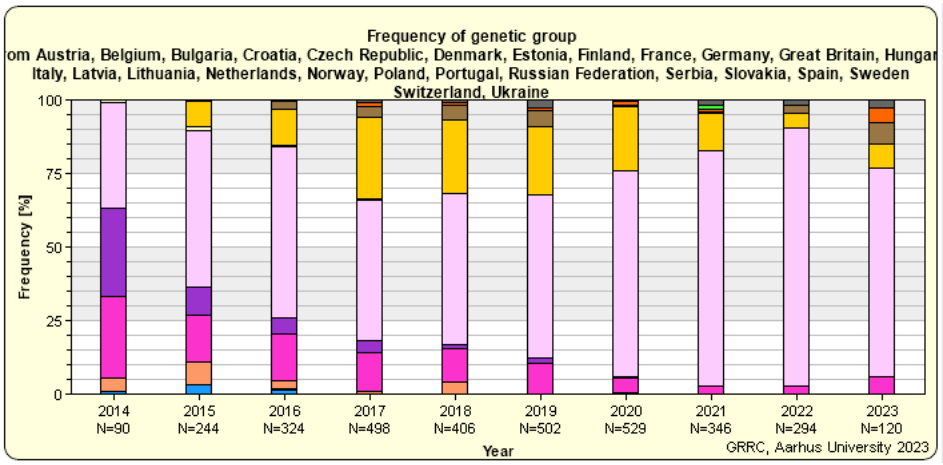

Figure 7: Wheat yellow rust genetic group frequency across Europe (data from Global Rust Reference Centre, Aarhus University).

Our results mirror findings from across Europe, where the Red Group (known as PstS10 in Europe; 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. The Pink Group (PstS7; shown in hot pink in **Figure 7**) was also observed in the UK in 2022 and has been seen at low levels across Europe over the past few years. The European system uses a different genotyping approach, utilising simple sequence repeat markers (SSRs). Comparison of the European PstS and UK nomenclature for several key groups is shown in **Table 7**.

Table 7: 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 6
Navy	PstS0		Blue
Pink	PstS7	Warrior	Hot pink
Purple	PstS8	Kranich	Purple
Red	PstS10	Warrior(-) Kalmar Benchmark Amboise	Pale pink

Within the Red Group, there are a broad range of virulences observed on the differentials, as shown by the pattern of yellow (compatible interaction, the plant was susceptible to that isolate) and purple (incompatible interaction, the plant was resistant to that isolate) boxes (outer heatmap in **Figure 6**).

6.2 Wheat Brown Rust

6.2.1 Samples received

In 2022, the UKCPVS received 28 samples of wheat brown rust from eight different counties across the UK (**Figure 8**).

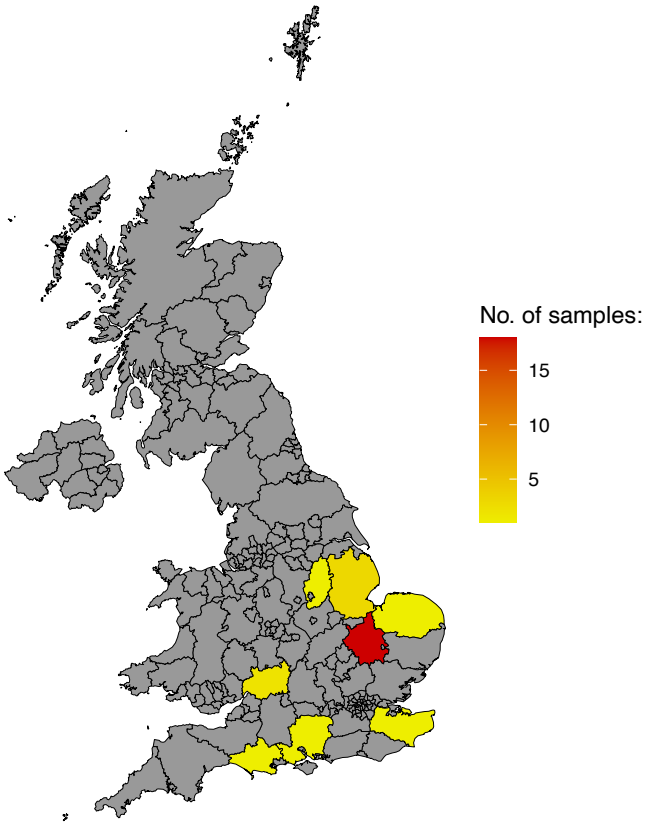

Figure 8: Map of the UK showing the counties where samples of wheat brown rust were received from in 2022.

The full sample register is provided in **Appendix I: 2022 Sample Register**. Samples were received from twenty-four 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

Twenty-five isolates 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 8**). 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 9**.

Table 8: Pathotypes of the 2022 wheat brown rust isolates based on the differential test results in **Supplementary Table 2**. 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
22/001/2	KWS Zealum	1				3a	3bg	3ka	10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/002/1	Crusoe	1				3a	3bg	3ka	10	13	14a	15	16	17				26		37	17b		Cr
22/003/2	RGT Stokes	1				3a	3bg	3ka	10	13	14a	15	16	17				26		37	17b		Cr
22/004	LG Typhoon	1						3ka	10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/005/2	RGT Saki	1							10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/006	KWS Siskin	1			2c	3a	3bg	3ka	10	13	14a	15	16	17	20			26	28	37	17b	Ro	Cr
22/008	KWS Extase	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26		37	17b		Cr
22/009	Soissons	1				3a	3bg	3ka	10	13	14a	15	16	17				26		37	17b		Cr
22/011	Parade	1				3a	3bg	3ka	10	13	14a	15	16	17				26		37	17b	Ro	Cr
22/013	Apache	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23		26		37	17b		Cr
22/014	Crusoe	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23		26	28	37	17b	Ro	Cr
22/015	Rendezvous	1				3a	3bg	3ka	10	13	14a	15	16	17		23		26	28	37	17b	Ro	Cr
22/016	Relay	1				3a	3bg	3ka	10	13	14a	15	16	17		23		26	28	37	17b	Ro	Cr
22/017	KWS Siskin	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23		26	28	37	17b	Ro	Cr
22/018	Oxford	1						3ka	10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/019	KWS Cranium	1				3a		3ka	10	13	14a	15	16	17	20			26	28	37	17b	Ro	Cr
22/020	KWS Extase	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23		26		37	17b		Cr
22/021	KWS Ultimatum	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26		37	17b		Cr
22/022	RGT Saki	1						3ka	10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/023	Champion	1						3ka	10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/024	Theodore	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26		37	17b		Cr
22/025	LG Redwald	1				3a	3bg	3ka	10	13	14a	15	16	17						37	17b		Cr
22/026	Mayflower	1				3a	3bg	3ka	10	13	14a	15	16	17				26		37	17b		Cr
22/027	Mindful	1				3a	3bg	3ka	10	13	14a	15	16	17	20			26	28	37	17b		Cr
22/028	Costello	1							10	13	14a	15	16	17					28	37	17b	Ro	Cr

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 40% of isolates returning to levels last seen in 2019. Virulence for *Lr3a*, *Lr3bg*, *Lr3ka*, *Lr20* increased, 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 half of the isolates. Virulence for *Lr23* declined and no virulence was detected for *Lr2a* and *Lr2b* which continues the trend seen in previous years.

Virulence on *Lr24* was detected for the first time since 2017. One of the isolates was isolated from Theodore (RL rating 8), which had reports over the season of higher than expected levels of disease. Additional cultivars Stigg and Warrior also susceptible to all three isolates, thought to carry the *Lr24* gene.

Table 9: Frequency of detection of isolates carrying virulence to the different brown 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				
	2018	**2019**	**2020**	**2021**	**2022**
Lr1	81	89	100	100	100
Lr2a	0	0	0	0	0
Lr2b	0	0	0	0	0
Lr2c	26	11	12	10	4
Lr3a	48	75	56	50	76
Lr3bg	71	75	56	50	72
Lr3ka	74	93	80	50	92
Lr10	100	100	96	100	100
Lr13	100	100	100	100	100
Lr14a	100	100	100	100	100
Lr15	100	100	100	100	100
Lr16	52	100	100	100	100
Lr17	100	100	100	100	100
Lr17b	100	100	100	100	100
Lr20	77	29	12	30	40
Lr23	39	36	32	50	36
Lr24	0	0	0	0	12
Lr26	100	82	92	60	96
Lr28	6	25	40	50	60
Lr37	100	100	100	100	100
Robigus	6	14	40	50	56
Crusoe	100	100	100	100	100
Total Number of Isolates	**31**	**28**	**25**	**10**	**25**

6.2.2.2 Commonly detected races

In 2022 there were six different pathotypes detected in the 25 isolates tested, two of which were pre-existing pathotypes. The most common pathotype identified was *Lr1*,*3a*,*3bg*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*26,37*,Cr and was carried by 20% of the isolates tested. Four new pathotypes were identified, carried by 28% of isolates *Lr1*,*3a*,*3bg*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*20*,*23*,*24*,*26*,*37*,Cr (12%), *Lr1*,*3a*,*3bg*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*20*,*23*,*26*,*28*,*37*,Cr (8%), *Lr1*,*2c*,*3a*,*3bg*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*20*,*26*,*28*,*37*,Cr (4%) and *Lr1*,*3a*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*20*,*26*,*28*,*37*,Cr (4%).

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 2022

Five isolates from the 25 tested isolates were selected for further testing on the wider set of RL varieties and candidates (**Table 10**), these were selected to best represent the diversity of the isolates tested in 2022. The isolates selected were WBR 22/006, 22/014, 22/018, 22/024 and 22/026.

Since the re-emergence of virulence on *Lr24* was deemed to be interesting and important, isolate WBR 22/024 was selected for inclusion in the VL/RL 2023 isolate mix, ahead of its adult plant trial data.

Table 10: Virulence profile of the wheat brown rust 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
22/006	KWS Siskin	1			2c	3a	3bg	3ka	10	13	14a	15	16	17	20			26	28	37	17b	Ro	Cr
22/014	Crusoe	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23		26	28	37	17b	Ro	Cr
22/018	Oxford	1						3ka	10	13	14a	15	16	17				26	28	37	17b	Ro	Cr
22/024	Theodore	1				3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26		37	17b		Cr
22/026	Mayflower	1				3a	3bg	3ka	10	13	14a	15	16	17				26		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 2023. Results are combined with the adult plant test results (**Table 11**) 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 seedling stage to all five of the isolates tested. Theodore was the only RL variety to be susceptible to just one of the five isolates tested WBR 22/024.

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 2023 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 seven days until the flag leaf had fully emerged. The first inoculation was carried out on the 20th April 2023 and the first assessment was made on 25th May when the plants were at GS43. The percentage plot infected was assessed and the mean was calculated from seven assessments (**Table 13**).

Disease levels were considered good in the trials and final scores were higher than the calculated mean shown here although it was noted that the trial inoculated with WBR 22/006 showed lower levels of infection overall. In the trials the susceptible control variety Buster showed the highest levels of disease followed by the current RL variety Crusoe, rated 3. Theodore was susceptible to the isolate WBR 22/024 with a mean of 27.2% plot infection over seven assessments. Theodore was resistant to the other 4 isolates on trial.

Out of the 52 RL varieties and candidates under evaluation, Skyfall was the most resistant RL variety tested. LG Astronomer 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.

Table 11: Seedling and adult plant reactions to the five wheat brown rust 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 seven assessments. Varieties are ordered in level of disease at adult plant stage. Control varieties are highlighted in green text.

Variety	RL Rating 2023/24	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		22/006	22/014	22/018	22/024	22/026	22/006	22/014	22/018	22/024	22/026
SKYFALL	9	3.0	3.0	0.1	3.0	3.0	0.00	1.00	0.00	1.50	0.00
MARIS RANGER	-	2.1	3.0	3.0	3.0	3.0	0.10	1.10	0.30	1.00	0.10
MARIS HALBERD	-	3.0	3.0	0.2	3.0	0.1	0.10	4.20	0.00	2.60	0.00
LG ASTRONOMER	8	1.0	3.0	3.0	0.1	0.0	0.20	3.60	3.10	0.10	0.40
STERNA	-	3.0	3.0	0.6	3.0	3.0	0.10	1.60	0.00	6.70	3.60
GAMIN	-	3.0	3.0	3.0	3.0	3.0	0.30	1.30	0.40	7.00	5.00
KWS DAWSUM	7	3.0	3.0	3.0	3.0	3.0	0.30	5.00	3.30	4.50	3.40
LG PRINCE	7	1.0	3.0	3.0	0.1	0.0	0.60	6.70	9.30	0.10	0.20
LG ILLUMINATE	6	0.5	3.0	3.0	0.0	0.0	0.90	7.40	9.50	0.10	0.10
GEFION	-	3.0	3.0	3.0	3.0	3.0	0.40	7.70	2.70	3.20	4.70
LG REDWALD	6	2.8	3.0	3.0	3.0	3.0	0.30	5.90	4.20	4.10	4.20
KWS EXTASE	6	3.0	3.0	3.0	3.0	3.0	0.30	4.50	5.70	4.80	4.80
LGWU184	-	3.0	3.0	3.0	3.0	3.0	0.60	4.60	3.20	5.90	6.00
KWS WEBBUM	-	3.0	2.9	3.0	3.0	3.0	1.30	3.50	4.50	1.80	9.50
KWS SKATEUM	Candidate	1.0	3.0	3.0	0.1	0.1	0.70	7.00	12.60	0.80	0.10
ALMARA	Candidate	0.3	3.0	3.0	0.1	0.1	0.30	10.00	11.00	0.00	0.00
OXFORD	6	0.9	3.0	3.0	0.1	0.0	2.40	9.70	9.70	0.30	0.30
SAPPO	-	3.0	3.0	0.0	3.0	0.0	0.80	9.70	1.90	11.10	0.30
STIGG	-	0.2	0.0	0.0	3.0	0.0	1.10	9.00	11.90	2.00	0.30
ROBIGUS	-	0.3	3.0	3.0	0.0	0.0	0.60	12.60	12.70	0.20	0.10
WARRIOR	-	0.0	0.0	0.0	3.0	0.0	0.20	0.00	0.00	24.60	1.70
MERIT	7	1.0	2.8	3.0	0.1	0.0	2.20	10.00	13.70	1.20	0.00
THEODORE	8	0.0	0.0	0.0	3.0	0.0	0.00	0.00	0.10	27.20	0.00
RGT WOLVERINE	7	3.0	3.0	3.0	3.0	3.0	1.30	8.00	4.30	8.40	5.90
MAYFLOWER	6	3.0	3.0	3.0	3.0	3.0	1.30	5.80	3.30	7.70	10.40
SWALLOW	5	1.0	3.0	3.0	0.0	0.0	1.40	14.70	15.70	0.20	0.90
RGT BAIRSTOW	6	0.5	3.0	3.0	0.0	0.0	1.70	16.70	12.00	0.50	2.40
LG TYPHOON	6	1.0	3.0	3.0	0.0	0.0	4.60	12.50	18.30	0.70	0.30
CHAMPION	5	1.0	3.0	3.0	0.0	0.0	5.60	12.10	16.90	0.50	2.50
RGT SAKI	6	0.9	3.0	3.0	0.2	0.0	7.30	9.80	18.30	2.00	0.20
KWS BARREL	-	3.0	3.0	3.0	3.0	3.0	0.70	7.30	9.10	8.50	12.50
RGT ILLUSTRIOUS	6	3.0	3.0	3.0	3.0	3.0	2.40	7.90	9.30	12.90	6.30
LG ARKLE	Candidate	3.0	3.0	3.0	3.0	3.0	3.10	6.90	6.40	10.70	12.10
BOLINDER	Candidate	2.3	3.0	3.0	3.0	3.0	3.20	6.90	14.80	7.30	7.00

Variety	RL Rating 2023/24	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		22/006	22/014	22/018	22/024	22/026	22/006	22/014	22/018	22/024	22/026
KWS BRIUM	5	2.8	3.0	3.0	3.0	3.0	0.50	6.80	14.80	9.30	8.10
ARMADA	-	3.0	3.0	3.0	3.0	3.0	3.80	7.80	6.20	13.80	8.20
BAMFORD	Candidate	3.0	3.0	3.0	3.0	3.0	0.60	6.90	13.90	7.80	11.60
KWS ULTIMATUM	6	2.8	3.0	2.9	3.0	3.0	4.20	11.90	6.10	12.00	7.30
BLACKSTONE	Candidate	3.0	3.0	3.0	3.0	3.0	2.70	9.70	5.20	12.60	11.70
KWS CRANIUM	4	3.0	3.0	3.0	3.0	3.0	2.90	8.10	10.30	10.20	10.40
RGT STOKES	5	3.0	3.0	3.0	3.0	3.0	4.50	7.60	7.80	14.10	8.00
KWS PALLADIUM	5	2.7	3.0	3.0	3.0	3.0	2.40	8.80	7.10	14.80	10.30
RGT RASHID	6	0.3	3.0	3.0	0.1	0.1	5.20	17.90	18.00	2.50	0.80
SY CHEER	Candidate	3.0	3.0	3.0	3.0	3.0	2.90	10.10	5.30	9.90	16.20
LG GRENDEL	Candidate	3.0	3.0	3.0	3.0	3.0	1.60	4.60	4.40	19.00	15.10
MARIS FUNDIN	-	3.0	3.0	3.0	3.0	3.0	2.30	5.90	9.40	14.70	18.20
MARIS HUNSTMAN	-	3.0	1.0	1.0	3.0	3.0	3.10	15.80	10.60	15.30	10.00
LG PARTRIDGE	Candidate	3.0	3.0	3.0	3.0	3.0	4.00	7.30	12.50	16.30	15.60
KWS ZEALUM	5	3.0	3.0	3.0	3.0	3.0	4.70	17.40	9.70	10.90	14.20
COSTELLO	5	3.0	3.0	3.0	3.0	3.0	2.30	19.20	15.00	14.70	7.40
RGT WILKINSON	5	3.0	3.0	3.0	3.0	3.0	3.00	9.70	18.10	17.90	13.10
LG BEOWULF	Candidate	3.0	3.0	3.0	3.0	3.0	5.60	12.60	16.60	15.00	14.70
KWS ZYATT	7	3.0	3.0	3.0	3.0	3.0	3.30	13.90	12.50	18.80	16.20
GRAHAM	5	3.0	3.0	3.0	3.0	3.0	3.70	18.90	22.30	12.00	9.80
LG SKYSCRAPER	5	3.0	3.0	2.7	3.0	3.0	6.90	13.50	9.90	17.20	20.70
SOISSONS	-	2.8	3.0	3.0	3.0	3.0	5.70	17.40	13.40	15.50	17.40
KWS DRAGUM	Candidate	2.5	3.0	3.0	3.0	3.0	6.20	12.90	17.20	14.90	18.40
KWS WRENUM	-	3.0	2.9	3.0	3.0	3.0	3.90	17.40	15.60	21.50	11.20
AVALON	-	3.0	3.0	3.0	3.0	3.0	1.30	12.10	12.80	20.40	23.00
REAPER	-	2.8	3.0	3.0	3.0	3.0	4.90	15.50	17.00	20.40	17.30
GLEAM	6	3.0	3.0	3.0	3.0	3.0	4.90	18.50	24.10	18.60	9.70
LG REDRUM	Candidate	3.0	3.0	3.0	3.0	3.0	5.20	19.60	11.90	20.80	18.50
SY INSITOR	6	3.0	3.0	3.0	3.0	3.0	9.70	15.90	22.80	18.50	11.60
RW42046	-	3.0	3.0	3.0	3.0	3.0	13.20	11.90	18.00	15.10	23.40
MASCOT	-	2.7	3.0	3.0	3.0	3.0	4.50	24.30	13.80	21.70	20.90
KWS GUIUM	3	3.0	3.0	3.0	3.0	3.0	9.60	22.40	20.20	26.00	21.80
CONSORT	-	3.0	3.0	3.0	3.0	3.0	9.20	20.50	19.10	27.40	27.90
GLASGOW	-	3.0	3.0	3.0	3.0	3.0	11.50	18.70	27.20	26.40	22.80
CRUSOE	3	3.0	3.0	3.0	3.0	3.0	9.50	34.90	20.40	25.10	25.20
BUSTER	-	2.9	3.0	3.0	3.0	3.0	15.90	27.50	28.10	29.40	29.20
Thatcher Lr 1	-	3.0	3.0	3.0	3.0	3.0					
Thatcher Lr 2a	-	0.9	0.0	0.0	0.0	0.0					
Thatcher Lr 2b	-	1.5	0.2	0.4	0.5	0.2					

Variety	RL Rating 2023/24	Variety Seedling (Average Infection Type)					Adult Plant (% plot area infected)				
		22/006	22/014	22/018	22/024	22/026	22/006	22/014	22/018	22/024	22/026
Thatcher Lr 2c	-	2.7	0.3	1.1	2.0	1.1					
Thatcher Lr 3a	-	3.0	3.0	1.0	3.0	3.0					
Thatcher Lr 3bg	-	3.0	2.0	0.8	3.0	3.0					
Thatcher Lr 3ka	-	3.0	2.5	2.1	3.0	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	2.9					
Thatcher Lr 14a	-	3.0	3.0	3.0	3.0	3.0					
Thatcher Lr 15	-	3.0	3.0	3.0	3.0	3.0					
Thatcher Lr 16	-	2.3	2.7	3.0	3.0	3.0					
Thatcher Lr 17	-	3.0	3.0	3.0	3.0	3.0					
Thatcher Lr 20	-	3.0	3.0	0.0	3.0	0.6					
Thatcher Lr 23	-	1.3	2.7	2.0	3.0	2.6					
Thatcher Lr 24	-	1.0	3.0	0.9	3.0	0.7					
Thatcher Lr 26	-	2.7	3.0	1.7	3.0	2.7					
Thatcher Lr 28	-	0.3	3.0	3.0	0.1	0.1					
Thatcher Lr 37	-	2.0	3.0	3.0	3.0	3.0					
Clement	-	3.0	3.0	2.6	3.0	3.0					
KWS Firefly	-	0.4	3.0	3.0	0.0	0.0					
Mean							**3.3**	**10.8**	**10.9**	**11**	**9.3**

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 2022 and the UKCPVS received 12 samples (**Appendix I: 2022 Sample Register**). The samples came from six different counties, the majority of the samples were received from Cambridgeshire (**Figure 9**).

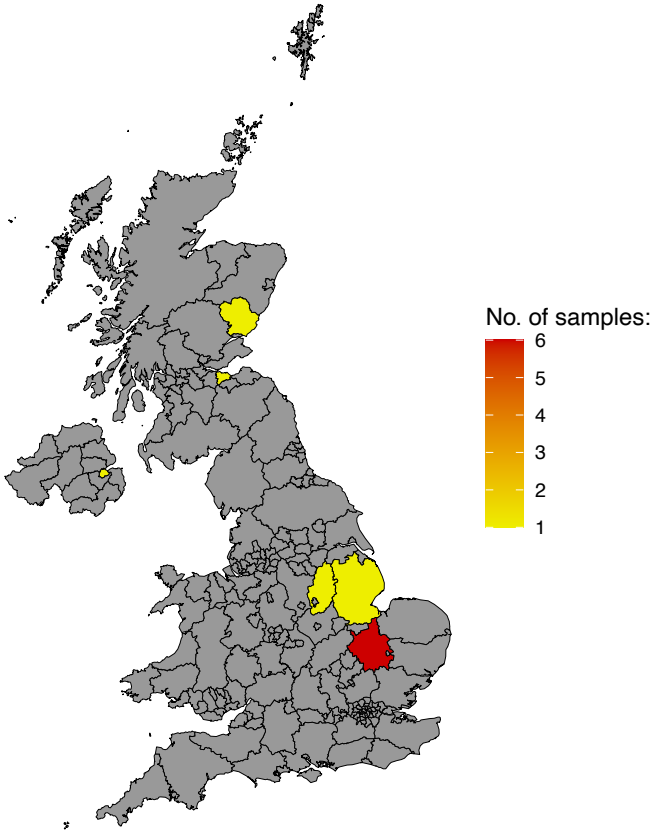

Figure 9: Map of the UK showing the counties where samples of wheat powdery mildew were received from in 2022.

Although sample numbers were considered low the UKCPVS received more samples in 2022 compared to recent years. The 12 samples came from 12 different varieties.

6.3.2 Pathotyping of isolates

From the twelve samples received 19 single pustule isolates were seedling virulence tested using detached leaf assays (**Table 12**). Of the isolates tested, 100% virulence for *Pm4b, Pm6* and for Brock which carries the resistance genes for *Pm2, MlTa2*. Virulence for *Pm17* dropped from 50% in 2021 to 5% in 2022 but it has previously been seen at very low levels (**Table 13**).

No wheat powdery mildew seedling tests were carried out in 2020 or 2019. Virulence frequencies for 2016 – 2018 and 2021 – 2022 are listed in **Table 13**.

Table 12: 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*	*Pm8*	*MId*	*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
22/001/1	LG Spotlight	3.0	3.3	3.3	3.5	3.0	3.5	3.0	0.0	3.3	3.0	3.0	3.0	0.8	1.3	0.3	1.5	0.0	3.0	0.5	1.5	1.0
22/002/1	Treasure	3.3	3.5	2.5	3.5	3.0	3.3	1.5	3.3	3.5	3.0	4.0	3.3	3.5	4.0	3.5	1.8	1.0	3.0	0.0	1.3	3.3
22/002/3	Treasure	3.0	3.3	1.5	3.3	3.0	3.0	3.0	3.0	3.0	3.0	3.3	3.3	4.0	3.3	3.0	0.0	1.3	3.0	0.8	2.8	3.0
22/002/4	Treasure	3.0	3.0	3.3	3.3	3.0	3.5	1.5	3.0	3.3	3.0	2.0	2.5	0.0	0.0	1.0	1.3	3.0	3.0	0.0	2.8	3.0
22/003/1	RGT Rashid	3.0	3.3	3.0	3.8	3.0	3.3	3.0	3.3	3.5	3.0	4.0	3.3	0.0	0.0	3.3	0.5	1.3	3.5	1.3	1.0	3.3
22/003/2	RGT Rashid	3.0	3.5	2.3	3.3	3.0	3.0	3.0	3.0	3.3	3.0	3.3	3.0	3.0	3.8	3.5	1.3	2.5	3.0	0.5	1.5	3.0
22/004/8	KWS Zyatt	3.3	3.0	0.0	3.0	3.0	3.0	2.5	3.5	3.5	3.8	3.0	3.3	0.0	0.0	3.5	2.0	2.0	0.3	0.0	0.0	3.0
22/004/10	KWS Zyatt	3.0	3.3	0.0	3.0	3.0	3.5	3.0	3.0	3.3	3.0	3.3	3.0	0.0	1.0	3.5	3.5	1.0	3.0	1.0	1.5	3.3
22/005/8	KWS Zealum	3.0	3.3	3.3	3.8	3.3	3.0	3.3	3.3	3.5	3.3	3.8	3.8	1.0	1.0	3.3	1.5	2.0	3.3	3.8	3.8	3.0
22/005/9	KWS Zealum	3.0	2.5	3.5	3.5	3.0	3.3	3.0	3.0	3.5	3.0	3.3	3.3	3.3	3.5	3.0	3.0	1.8	3.3	3.3	3.3	3.3
22/008/1	Merit	3.0	3.0	3.0	3.3	3.0	3.5	3.3	3.3	3.5	3.0	2.8	3.3	3.3	3.8	3.3	1.0	1.5	3.0	4.0	3.5	3.3
22/008/2	Merit	3.0	3.3	0.5	3.3	3.0	3.0	3.0	2.8	3.3	3.0	3.8	3.0	3.3	3.8	3.0	0.3	1.8	3.0	3.8	4.0	3.3
22/009/2	RGT Zinzan	3.0	3.5	0.8	3.8	2.8	3.0	3.0	3.0	2.8	3.0	0.0	0.5	0.8	0.0	0.0	2.5	1.5	3.0	0.0	1.8	3.0
22/010/1	Crusoe	3.3	3.3	3.0	3.3	3.0	3.3	3.0	3.3	3.0	3.0	2.8	3.0	0.0	0.0	3.5	2.3	0.8	0.5	0.5	0.3	3.0
22/010/2	Crusoe	3.0	3.8	1.5	3.8	2.3	3.8	3.5	3.5	4.0	1.8	3.3	2.8	0.0	0.0	3.5	0.5	1.5	0.0	0.0	0.0	3.3
22/011/1	LG Astronomer	3.3	2.8	1.3	3.8	1.8	3.5	3.5	1.3	3.3	3.3	0.0	0.0	3.0	3.3	0.0	0.8	0.8	3.0	0.3	0.8	0.5
22/011/3	LG Astronomer	3.0	3.0	2.3	3.0	3.5	3.0	3.0	2.3	3.0	3.0	0.0	1.3	3.0	3.5	0.0	3.8	0.5	3.0	0.3	1.0	2.0
22/012/3	KWS Barrel	3.0	3.3	2.0	3.5	3.0	3.3	2.5	3.0	3.3	3.5	3.8	3.0	0.0	0.0	2.3	0.8	0.8	3.8	0.0	1.5	0.8
22/012/11	KWS Barrel	3.0	2.3	3.3	3.3	3.0	3.0	3.0	3.0	3.0	2.8	4.0	3.0	2.8	4.0	1.8	3.5	1.8	3.0	1.0	2.5	1.8

Table 13: 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 (%)				
		2016	2017	2018	2021	2022
Galahad	*Pm2*	88	100	100	38	89
Chul	*Pm3b*	8	20	15	100	42
Armada	*Pm4b*	84	100	96	0	100
Flanders	*Pm5*	76	84	81	75	89
Brimstone	*Pm6*	88	96	93	100	100
Clement	*Pm8*	88	84	93	88	79
Maris Dove	*Mld*	64	68	100	75	84
Brock	*Pm2,MlTa2*	84	96	100	100	100
Mercia	*Pm5, MlTa2*	80	100	93	88	95
Tonic	*MlTo*	28	64	85	88	79
Broom	*Pm3d*	28	60	85	100	79
Sicco	*Pm5, MlSi2*	8	40	11	25	47
Wembley	*MlSo*	4	44	11	25	47
Axona	*MlAx*	32	60	78	75	63
Amigo	*Pm17*	0	8	0	100	21
Shamrock	*MlSh*	0	0	0	50	5
Robigus	MlRo	56	72	85	100	84
Warrior		8	16	74	50	21
Stigg		4	16	74	100	32
Crusoe		72	68	93	75	74
Total Number of Isolates Tested		**25**	**25**	**27**	**8**	**19**

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 by the UKCPVS in 2022.

6.4 Barley Powdery Mildew

6.4.1 Samples received

The UKCPVS received 29 samples of barley powdery mildew in 2022 (**Appendix I: 2022 Sample Register**). The majority of the samples came from Northern Ireland (**Figure 10**).

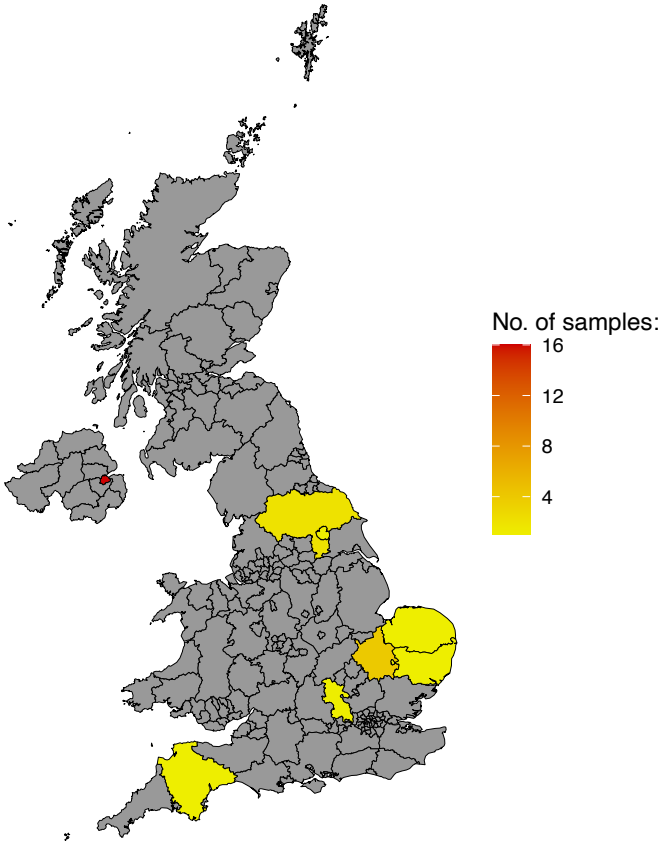

Figure 10: Map of the UK showing the counties where samples of barley powdery mildew were received from in 2022.

Nineteen varieties were represented in the samples received; the most sampled variety was KWS Orwell.

6.4.2 Pathotyping of isolates

From the 29 samples received, 29 single pustule isolates were obtained, and these were characterised using a differential set (**Table 14**). Virulence frequencies were found to be similar to that of 2021(**Table 15**). Of the isolates tested, 90% or more of the isolates carried virulence for *Mlh, Mlra, Mlg, Mla6* and *Mla12.* Virulence for *Mla13* rose to 34% having previously been undetected in 2020 and 2021. No virulence was detected for *mlo11* carried by Riviera for the 5th year in a row. No virulence was detected for the additional cultivar Optic. The barley mildew population seems stable despite the low number of isolates tested in 2019, 2020 and 2021.

The UKCPVS received no reports of unexpected outbreaks of barley powdery mildew during 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 14: 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		*Mlh*	*Mlra*	*Mlg*	*Mlg,Ml(CP)*	*Mla6*	*MlLa*	*Mla12*	*Mlk1*	*Mla7*	*MlAb*	*Mla7,MlAb*	*Mla1*	*Mla9*	*mlo11*	*mlo11*	*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
22/001/2	KWS Faro	3.5	3.8	3.5	3.3	3.0	3.5	3.0	3.0	2.0	2.3	3.0	1.5	1.5	0.5	0.0	0.0	1.0	1.0	3.5	1.0	2.5
22/001/4	KWS Faro	3.0	3.5	3.0	3.0	2.3	3.0	2.8	3.0	2.8	2.0	2.8	0.3	0.0	3.0	0.0	0.3	1.5	2.0	3.0	0.8	3.0
22/002/1	KWS Orwell	3.5	3.8	3.3	3.3	3.3	3.3	2.8	1.5	3.0	1.8	2.0	0.8	3.3	0.0	0.5	0.3	2.3	0.5	3.3	0.3	0.0
22/002/3	KWS Orwell	3.3	3.0	3.0	2.8	2.5	3.0	2.8	3.0	1.8	2.0	0.8	0.3	2.3	0.0	0.0	0.0	3.0	1.8	3.0	0.0	1.5
22/003/1	Craft	3.0	3.0	2.8	3.0	2.5	2.8	2.0	2.8	2.0	1.5	1.0	0.0	1.5	0.5	0.0	0.0	0.0	0.5	2.3	0.0	1.0
22/003/2	Craft	3.5	4.0	2.8	3.0	3.0	3.0	1.5	3.0	1.8	1.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.5	2.3	0.0	0.0
22/004/1	KWS Orwell	3.3	3.8	3.3	3.5	3.0	3.3	2.0	3.5	2.5	2.8	2.8	2.5	3.0	2.0	0.5	0.0	3.0	2.5	3.5	1.3	3.0
22/004/2	KWS Orwell	3.5	3.5	3.0	3.3	3.0	3.5	3.0	3.5	2.8	2.5	2.8	1.0	3.3	2.3	0.0	0.0	3.0	2.0	3.3	1.5	2.8
22/005/3	KWS Orwell	3.5	4.0	3.8	3.8	2.8	3.8	2.8	4.0	1.8	3.3	3.3	2.0	3.0	1.0	0.0	0.0	0.0	3.0	2.5	2.3	3.0
22/005/4	KWS Orwell	3.0	3.0	3.0	3.0	2.8	3.0	2.0	3.0	1.8	2.5	2.0	1.8	2.8	2.5	0.0	0.0	3.0	1.8	3.0	0.5	1.8
22/006/1	KWS Orwell	4.0	4.0	3.8	3.5	3.3	3.5	2.3	3.5	2.0	3.0	1.3	0.3	3.0	2.8	0.3	0.0	0.0	1.0	2.3	0.3	0.0
22/006/2	KWS Orwell	3.0	3.8	3.8	3.3	3.3	3.5	2.0	3.5	3.0	2.3	2.0	1.0	2.5	1.8	0.0	0.0	0.0	0.8	1.0	0.5	2.5
22/007/1	KWS Hawking	3.3	3.5	3.3	3.0	3.0	3.0	2.0	3.0	2.0	2.8	0.3	0.0	3.0	0.0	0.0	0.0	3.0	1.3	3.0	0.0	2.0
22/007/3	KWS Hawking	3.5	3.8	3.5	3.5	3.0	3.0	2.8	2.5	1.8	2.5	0.5	1.0	3.0	0.0	0.8	0.6	3.0	0.8	2.8	0.0	1.8
22/008/4	-	3.3	4.0	3.8	3.5	3.0	3.5	2.8	3.8	1.5	2.8	2.5	1.5	3.0	1.0	0.0	0.0	0.0	3.0	3.3	1.5	3.0
22/008/5	-	3.3	4.0	3.5	3.3	3.0	3.3	2.8	4.0	2.8	2.8	3.0	1.5	3.0	3.0	1.0	0.0	0.5	3.0	3.5	2.3	3.0
22/009/4	-	3.8	4.0	3.3	4.0	3.8	3.3	2.8	4.0	2.0	3.0	3.5	3.0	3.0	3.0	1.0	0.0	0.0	3.0	3.8	1.0	3.3
22/009/5	-	3.0	3.8	3.5	3.5	2.3	3.3	2.3	3.0	2.0	1.8	1.8	0.5	3.0	0.5	0.5	0.3	0.0	1.8	2.8	0.5	2.8
22/011/1	Surge	3.0	3.3	3.0	3.0	3.0	3.0	3.0	3.0	1.3	3.3	3.0	3.0	3.5	0.0	3.0	2.3	0.0	3.5	1.8	2.3	4.0
22/012/1	Funky	3.0	3.8	3.3	3.3	3.3	3.0	3.3	3.0	3.0	3.0	3.0	3.0	3.3	0.0	2.0	0.3	3.5	1.0	3.8	2.5	1.0
22/014/1	KWS Hawking	3.3	4.0	3.5	2.0	0.8	3.0	3.0	3.0	0.5	2.0	2.5	0.5	2.5	0.0	0.0	0.5	0.0	0.8	3.8	0.5	3.3
22/015/1	KWS Tardis	3.0	3.3	3.0	3.0	3.3	2.8	3.5	3.0	1.5	3.0	1.8	2.3	0.0	0.0	2.0	0.0	0.0	2.8	3.5	1.0	1.3
22/016/2	LG Campus	3.0	3.5	3.0	3.0	3.0	3.0	3.0	3.0	1.5	3.0	2.5	1.8	3.0	3.0	1.5	0.0	0.0	0.8	3.8	1.0	1.0
22/019/1	SY Kingston	3.0	3.5	3.3	3.0	3.3	3.0	3.0	3.0	3.3	3.0	3.3	3.0	3.5	0.0	1.5	0.8	3.0	2.8	3.0	1.5	3.8
22/020/1	Belmont	3.3	4.0	3.8	3.3	3.5	3.3	3.5	3.3	1.8	3.0	3.3	3.0	0.0	0.0	2.8	1.3	0.3	3.5	3.0	1.3	3.8
22/021/1	SY Javelin	3.3	3.8	3.5	3.3	3.0	3.0	3.0	3.3	1.8	2.5	2.0	0.8	0.3	0.0	0.0	0.0	3.0	3.3	0.0	0.5	1.3
22/023	KWS Cassia	3.3	3.8	3.5	3.0	3.3	3.3	3.8	3.5	1.5	1.8	1.5	1.3	0.0	0.0	0.8	2.0	3.0	2.5	0.0	0.0	1.5
22/024/1	California	3.5	3.8	3.8	3.0	2.5	3.0	2.8	3.3	3.0	3.0	1.3	0.5	3.5	0.0	0.3	0.5	0.0	2.0	2.8	0.3	0.0
22/025/1	KWS Orwell	3.3	3.8	3.5	3.5	3.0	3.3	3.0	3.3	1.5	3.0	3.0	2.8	3.0	0.3	2.0	1.3	0.0	3.8	2.0	2.0	3.0

Table 15: Virulence frequencies of key barley powdery mildew resistance genes over the past five years of testing.

Differential	Known Genes	Virulence Frequency by Year				
		2018	2019	2020	2021	2022
Golden Promise	0	100	100	100	100	100
W.37/136	*Mlh*	100	100	100	100	100
W.41/145	*Mlra*	100	100	100	100	100
Goldfoil	*Mlg*	79	100	100	92	97
Zephyr	*Mlg,Ml(CP)*	79	100	100	88	79
Midas	*Mla6*	100	100	100	96	100
Lofa	*MlLa*	38	100	50	46	72
Hassan	*Mla12*	83	100	67	85	93
H.1063	*Mlk1*	41	25	33	35	28
Porter	*Mla7*	31	100	50	58	52
Lotta	*MlAb*	59	75	33	50	41
Triumph	*Mla7,MlAb*	3	25	17	38	21
Tyra	*Mla1*	69	25	83	50	62
Roland	*Mla9*	14	0	0	15	17
Apex	*mlo11*	14	0	33	0	7
Riviera	*mlo11*	0	0	0	0	0
Digger	*Mla13*	14	75	0	0	34
Ricardo	*Mla3*	59	0	17	27	34
Vanessa	Van	100	100	67	58	69
Optic		7	25	0	12	0
Propino		59	0	0	38	45
Total Number of Isolates		**29**	**4**	**6**	**26**	**29**

7 Results to date from the 2023 season

7.1 Wheat Yellow Rust

7.1.1 Samples received

During the 2023 season the UKCPVS received 92 wheat yellow rust samples from 21 counties, from 37 varieties as well as one unknown. The most sampled variety was KWS Extase (RL 23/24 rating 8). A largely wet spring hampered rust development in many parts of the UK resulting in the number of samples received was considerably lower than previous years.

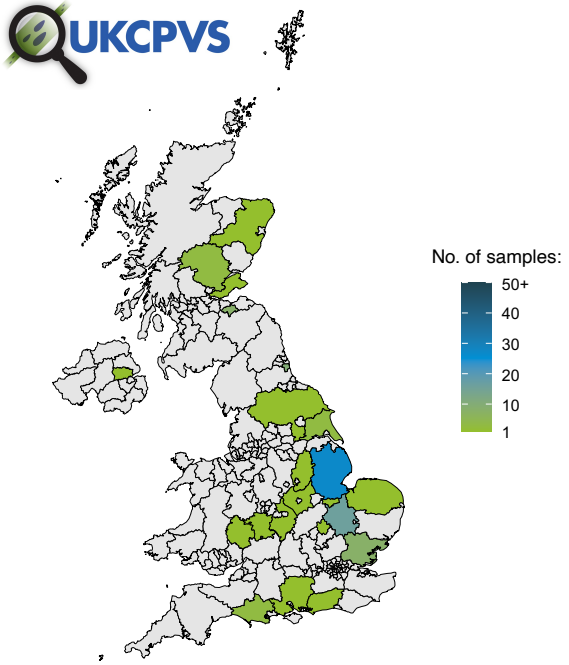

Figure 11: Map of the UK showing the counties where samples of wheat yellow rust were received from in 2023.

The full sample register is provided in **Appendix II: 2023 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.

7.1.2 Pathotyping of isolates

Whilst at the time of writing the 2023 samples are still being processed, seedling differential tests have been completed for 36 wheat yellow rust isolates (increased from 25 due to the low numbers of brown rust isolates received).

This year, to add value to the results, the seedling test differential set was reduced to allow for more RL varieties to be included in the initial round of testing. The RL varieties were chosen based on their young plant status, their adult plant resistance rating and the UK area grown.

The most common pathotype was *Yr1*,*2*,*3*,*6*,*7*,*9,17*,*32*,Sp. This does not necessarily indicate a change in the population, rather this reflects the reduction in virulence genes and additional cultivars included in the tests which were previously used to determine the pathotype. Other common pathotypes identified were *Yr1,2,3,4,6,7,9,17,32*,Sp,Wa and *Yr1*,*2*,*3*,*4*,*6*,*7*,*9*,*17*, *32*,Re,Sp,Wa,St,Kr,Ap,Cr.

One isolate was identified with virulence for *Yr8*. Virulence for *Yr8* was not seen in the 2022 survey but has been detected in previous years at low levels in the population.

Of the RL varieties included, it was found that 67% or more of the isolates infected Graham, LG Redwald, Gleam and SY Insitor. Of the isolates tested, 33% infected RGT Illustrious and 22% of the isolates infected KWS Extase and Crusoe. A smaller percentage, 8%, of the isolates infected KWS Zealum and 3% (one isolate) infected Merit, RGT Bairstow and LG Illuminate.

Table 16: Seedling screen of a sub-set of RL varieties with 36 2023 wheat yellow rust isolates based on the test results in **Supplementary Table 3**. Yellow shading indicates virulence of an isolate on the variety.

2023 Isolate / Variety / RL Rating	Costello	Crusoe	KWs Cranium	KWS Dawsum	KWS Palladium	KWS Siskin	KWS Zealum	LG Astronomer	LG Typhoon	Mayflower	Oxford	RGT Saki	Champion	Graham	KWS Extase	Merit	RGT Bairstow	RGT Illustrious	LG Illuminate	LG Redwald	Swallow	Gleam	SY Insitor
RL Rating	9	9	9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8	7	7	6	5	5
23/001	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	R	S
23/005	R	S	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	R	R	S	R	S	S
23/007	R	S	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S
23/008	R	S	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	R	R	S	R	R	S
23/011	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	S	R
23/015	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/021	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
23/022	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	S
23/023	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
23/026	R	S	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	S	R	R	R	R	R
23/027	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/030	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	S	R	S	R	R	R	R
23/031	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	S
23/034	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	S
23/035	R	S	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	S	R	S	R	R	S
23/037	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	S	S
23/038	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/039	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/041	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/042	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/045	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/051	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	S	S
23/063	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	R	S
23/064	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/066	R	S	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	S	R	S	R	R	S
23/067	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	S	S
23/069	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	S	R	S	R	S	S
23/070	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	S
23/071	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/072	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/075	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	R
23/076	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
23/077	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	R	S	S
23/086	R	S	R	R	R	R	S	R	R	R	R	R	R	S	S	R	R	S	R	S	R	S	S
23/089	R	S	R	R	R	R	S	R	R	R	R	R	R	R	S	R	R	R	R	R	R	S	R
23/092	R	S	R	R	R	R	S	R	R	R	R	R	R	S	R	R	R	S	R	S	R	S	S

7.1.3 Genotyping

Twenty-four isolates from 2023 were selected for genotyping based on their location and host cultivar (detailed in **Appendix II: 2023 Sample Register**). One isolate (WYR 23/071) failed to produce enough data and was removed. A phylogenetic tree based on 242 *Pst* genes following the MARPLE pipeline (Radhakrishnan *et al*., 2019) was constructed of the 23 isolates from 2023 (**Figure 12**). The tree also includes isolates from the previous four years of testing (2019-2022).

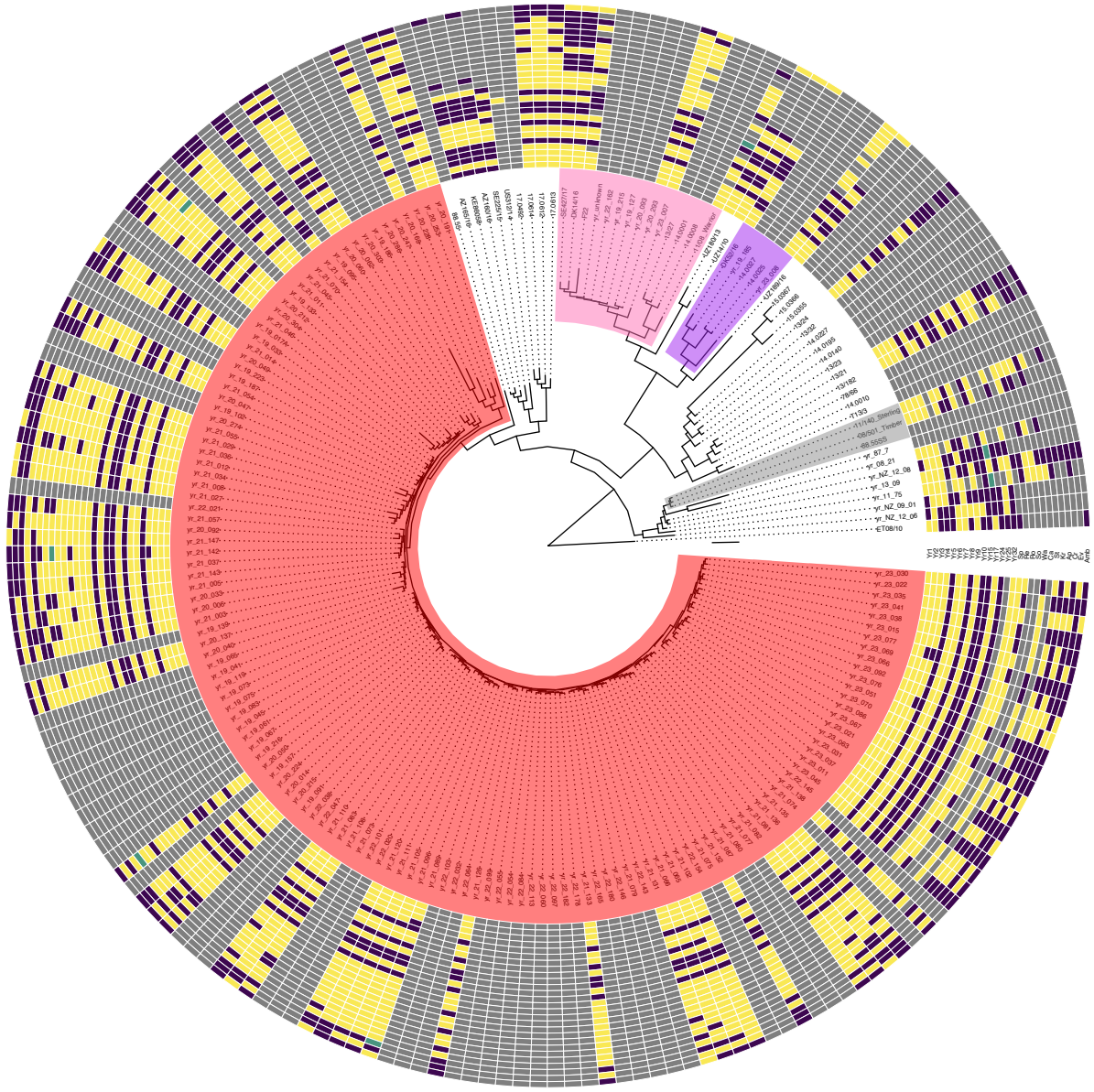

Figure 12: Phylogenetic analysis of 242 wheat yellow rust genes from selected isolates from the UKCPVS programme from the 2019 – 2023 surveys. The heatmap on the outside of the figure shows the seedling pathotyping data for each isolate; yellow indicates where the isolate was virulent on the differential, purple where the isolate was not able to cause disease on the differential and green where the result was borderline. The phylogeny on the inside shows the relationship of the genotyped isolates, which the main genetic groups coloured in red, pink and purple.

As seen in previous years, the Red Group dominated in 2023, with 21 out of 23 isolates grouping with Red Group isolates (**Figure 12**). One isolated grouped with the Pink Group

(WYR 23/007) and one isolate grouped with the Purple Group (WYR 23/008; **Figure 12**). The 2023 results further support the observations seen across Europe (**Figure 7**).

Table 17: Wheat yellow rust pathotype group frequencies from the past five years.

Pathotype Group*	Frequency of Isolates Found (%)				
	2019*	**2020***	**2021***	**2022***	**2023***
Pink	7	3	0	4	4
Blue	0	0	0	0	0
Red	74	97	100	96	92
Purple	4	0	0	0	4
Other	15	0	0	0	0
Number of Isolates	**31**	**30**	**40**	**25**	**23#**

* 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.
# 2023 pathotyping data not used in this figure.

7.2 Wheat Brown Rust

7.2.1 Samples received

During the 2023 season the UKCPVS received 15 wheat brown rust samples from seven counties, from ten varieties. The most sampled variety was Crusoe (RL 23/24 rating 3). The survey received three samples from Theodore, with high infection levels observed on this variety in the South West for a second consecutive year.

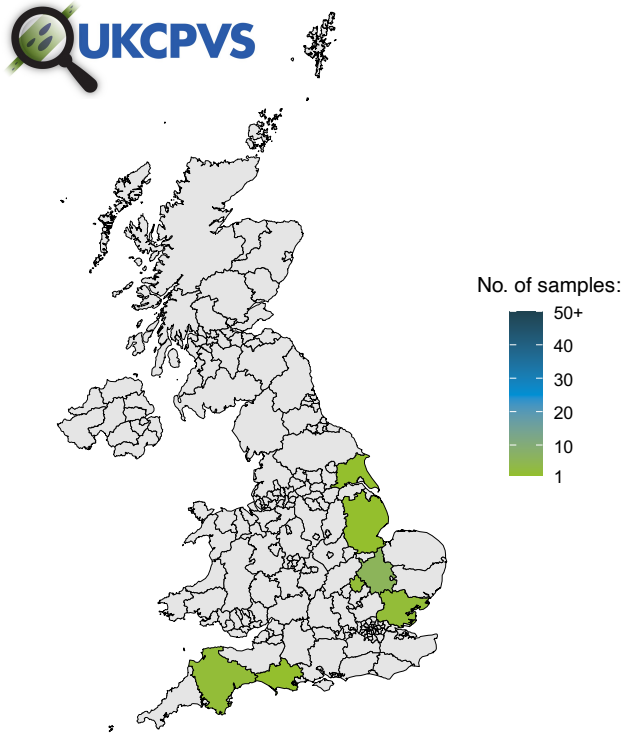

Figure 13: Map of the UK showing the counties where samples of wheat brown rust were received from in 2023.

The full sample register is provided in **Appendix II: 2023 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.

7.2.2 Pathotyping of isolates

At the time of writing, eight isolates have been pathotyped, with seven different pathotypes observed. Four isolates carry virulence to resistance gene *Lr24*. Two of the isolates have the novel pathotype with *Lr24* observed for the first time in 2022; *Lr1*,*3a*,*3bg*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*20*,*23*,*24*,*26*,*37*,Cr. *Lr24* was also detected in two other pathotypes; *Lr1*,*3ka*,*10*,*13*,*14a*,*15*,*16*,*17*,*24*,*26*,*28*,*37*,Cr and *Lr1*,*10*,*13*,*14a*,*15*,*16*,*17*,*24*,*26*,*37*,Cr. Three of these isolates infected Theodore and Warrior in the seedling tests. Three isolates carry virulence to resistance gene *Lr28*.

Table 18: Seedling screen of a sub-set of RL varieties with eight 2023 wheat brown rust isolates based on the test results in **Supplementary Table 4**. Yellow shading indicates virulence of an isolate on the variety.

Variety	Theodore	Skyfall	Champion	LG Astronomer	KWS Dawsum	LG Prince	Merit	Gleam	LG Illuminate	LG Typhoon	RGT Bairstow	RGT Saki	Costello	KWS Brium	KWS Palladium	Swallow	KWS Guium
2023 RL Rating / Isolate		9	8	8	7	7	7	6	6	6	6	6	5	5	5	5	3
23/001	R	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
23/002	R	R	R	R	S	R	R	S	R	R	R	R	S	S	S	R	S
23/003	S	S	R	R	S	R	R	S	R	R	R	R	S	S	S	R	S
23/004	R	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
23/006	R	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
23/008	R	S	S	R	S	R	R	S	R	R	R	R	S	S	S	R	S
23/009	S	R	R	R	S	R	R	S	R	R	R	R	S	S	S	R	S
23/011	S	S	S	R	S	R	R	S	R	R	R	R	S	S	S	S	S

7.3 Wheat and Barley Powdery Mildew

The wheat and barley powdery mildew survey was not conducted in 2023.

Reports were received of higher than expected disease levels of wheat powdery mildew in *mlo*-possessing varieties in RL trials in Scotland. The survey will include several isolates in the 2024 season to investigate this.

8 Conclusions

The UK yellow rust population continues to show high levels of diversity. 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. No new virulences to individual resistance genes were detected in the isolates collected in 2022 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. Five isolates displaying previously existing and novel pathotypes were investigated in the adult plant trials. Routine genotyping confirmed that Red Group isolates dominate the samples tested in 2022 and 2023.

As seen in previous years for brown rust, virulence was detected for many of the *Lr* genes tested with notable seedling virulence frequency changes to *Lr24*, which saw a re-emergence since 2017. Many of the current RL varieties have moderate disease resistance ratings to brown rust and this was reflected in the adult plant trial results.

No major changes in the wheat powdery mildew or barley powdery mildew populations were observed in 2022. Reports were received of higher than expected disease levels of barley powdery mildew in *mlo*-possessing varieties in 2023 RL trials in Scotland. The survey will include several isolates in the 2024 season to investigate this.

9 Acknowledgements

We would like to thank Dr Helen Bates and Dr Anne Webb for their excellent work on the yellow rust genotyping.

10 Supplementary Material

Supplementary Table 1: Average infection type (AIT) scores for the selected yellow rust 2022 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.

Supplementary Table 2: Average infection type (AIT) scores for the selected brown rust 2022 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.

Supplementary Table 3: Average infection type (AIT) scores for the selected yellow rust 2023 isolates against the sub-set of RL varieties. 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.

Supplementary Table 4: Average infection type (AIT) scores for the selected brown rust 2023 isolates against the sub-set of RL varieties. 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: 2022 Sample Register

2022 Wheat Yellow Rust Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2022/23	Location	Genotyped
22/138	Apache	May 2022	-	Cambridgeshire	
22/012	Brimstone	April 2022	-	Cambridgeshire	
22/134	Brimstone	May 2022	-	Cambridgeshire	
22/024	Champion	May 2022	8	Cambridgeshire	
22/061	Champion	May 2022	8	Tyne and Wear	
22/171	Champion	June 2022	8	Northamptonshire	
22/015	Claire	April 2022	-	Cambridgeshire	
22/137	Claire	May 2022	-	Cambridgeshire	
22/140	Cordiale	May 2022	-	Cambridgeshire	
22/038	Costello	May 2022	9	Norfolk	Y
22/077	Costello	May 2022	9	Cambridgeshire	
22/028	Elicit	May 2022	8	Buckinghamshire	
22/106	Elicit	May 2022	8	County Down	
22/132	Evolution	May 2022	-	Cambridgeshire	
22/066	Gefion	May 2022	4 Candidate	Tyne and Wear	
22/088	Gefion	May 2022	4 Candidate	Lincolnshire	
22/093	Gefion	May 2022	4 Candidate	Norfolk	
22/119	Gefion	May 2022	4 Candidate	County Down	
22/146	Gefion	May 2022	4 Candidate	Shropshire	Y
22/152	Gefion	June 2022	4 Candidate	East Lothian	
22/020	Gleam	April 2022	5	Lincolnshire	Y
22/055	Gleam	May 2022	5	Devon	Y
22/075	Gleam	May 2022	5	Tyne and Wear	
22/078	Gleam	May 2022	5	Herefordshire	
22/107	Gleam	May 2022	5	County Down	
22/124	Gleam	May 2022	5	Lincolnshire	
22/153	Gleam	June 2022	5	East Lothian	
22/167	Gleam	June 2022	5	Bridgend County Borough	
22/179	Gleam	June 2022	5	North Yorkshire	
22/043	Graham	May 2022	7	Norfolk	
22/105	Graham	May 2022	7	County Down	
22/081	KWS Barrel	May 2022	6	Lincolnshire	
22/145	KWS Barrel	May 2022	6	Herefordshire	Y
22/155	KWS Barrel	June 2022	6	East Lothian	
22/059	KWS Basset	May 2022	-	Kent	
22/025	KWS Cochise	May 2022	4	Lincolnshire	
22/023	KWS Colosseum	May 2022	-	Cambridgeshire	
22/022	KWS Extase	May 2022	8	Hertfordshire	
22/032	KWS Extase	May 2022	8	Lincolnshire	Y
22/051	KWS Extase	May 2022	8	Oxfordshire	
22/159	KWS Extase	June 2022	8	Cambridgeshire	
22/172	KWS Extase	June 2022	8	Northamptonshire	
22/175	KWS Extase	June 2022	8	Lincolnshire	
22/182	KWS Extase	June 2022	8	Lincolnshire	Y
22/067	KWS Firefly	May 2022	6	Tyne and Wear	
22/084	KWS Firefly	May 2022	6	Lincolnshire	Y
22/110	KWS Firefly	May 2022	6	County Down	
22/108	KWS Jackal	May 2022	8	County Down	
22/035	KWS Kerrin	May 2022	4	Devon	
22/046	KWS Siskin	May 2022	9	Norfolk	
22/123	KWS Siskin	May 2022	9	Lincolnshire	
22/160	KWS Siskin	June 2022	9	Cambridgeshire	
22/162	KWS Siskin	June 2022	9	Lincolnshire	Y
22/065	KWS Webbum	May 2022	5 Candidate	Tyne and Wear	
22/094	KWS Webbum	May 2022	5 Candidate	Norfolk	
22/117	KWS Webbum	May 2022	5 Candidate	County Down	
22/127	KWS Webbum	May 2022	5 Candidate	Lincolnshire	
22/148	KWS Webbum	June 2022	5 Candidate	East Lothian	
22/183	KWS Webbum	June 2022	5 Candidate	Lincolnshire	
22/018	KWS Wrenum	April 2022	6 Candidate	Cambridgeshire	
22/036	KWS Wrenum	May 2022	6 Candidate	Norfolk	
22/071	KWS Wrenum	May 2022	6 Candidate	Tyne and Wear	

Isolate Number	Host Variety	Date Sampled	RL Rating 2022/23	Location	Genotyped
22/085	KWS Wrenum	May 2022	6 Candidate	Lincolnshire	
22/118	KWS Wrenum	May 2022	6 Candidate	County Down	
22/186	KWS Wrenum	June 2022	6 Candidate	Lincolnshire	
22/001	KWS Zyatt	January 2022	4	Kent	
22/002	KWS Zyatt	January 2022	4	Kent	
22/007	KWS Zyatt	April 2022	4	Cambridgeshire	
22/019	KWS Zyatt	April 2022	4	West Sussex	
22/027	KWS Zyatt	May 2022	4	East Yorkshire	
22/029	KWS Zyatt	May 2022	4	Warwickshire	
22/033	KWS Zyatt	May 2022	4	Kent	
22/056	KWS Zyatt	May 2022	4	Hampshire	
22/060	KWS Zyatt	May 2022	4	Kent	Y
22/062	KWS Zyatt	May 2022	4	Tyne and Wear	
22/095	KWS Zyatt	May 2022	4	Norfolk	
22/103	KWS Zyatt	May 2022	4	Gloucestershire	Y
22/104	KWS Zyatt	May 2022	4	West Sussex	
22/122	KWS Zyatt	May 2022	4	Lincolnshire	
22/149	KWS Zyatt	June 2022	4	East Lothian	
22/168	KWS Zyatt	June 2022	4	Bridgend County Borough	
22/047	LG Astronomer	May 2022	8	Norfolk	Y
22/045	LG Illuminate	May 2022	7	Norfolk	
22/063	LG Illuminate	May 2022	7	Tyne and Wear	
22/082	LG Illuminate	May 2022	7	Lincolnshire	
22/113	LG Prince	May 2022	8	County Down	Y
22/049	LG Redwald	May 2022	7 Candidate	Norfolk	
22/054	LG Redwald	May 2022	7 Candidate	Norfolk	Y
22/073	LG Redwald	May 2022	7 Candidate	Tyne and Wear	
22/120	LG Redwald	May 2022	7 Candidate	County Down	
22/181	LG Redwald	June 2022	7 Candidate	Hampshire	
22/185	LG Redwald	June 2022	7 Candidate	Lincolnshire	
22/042	LG Skyscraper	May 2022	7	Norfolk	
22/052	LG Skyscraper	May 2022	7	Oxfordshire	
22/072	LG Skyscraper	May 2022	7	Tyne and Wear	
22/109	LG Skyscraper	May 2022	7	County Down	
22/004	LG Spotlight	March 2022	5	Cambridgeshire	
22/011	LG Spotlight	April 2022	5	Cambridgeshire	
22/031	LG Spotlight	May 2022	5	Scotland	
22/101	LG Spotlight	May 2022	5	Northamptonshire	Y
22/143	Mayflower	May 2022	9	Norfolk	Y
22/173	Mayflower	June 2022	9	Northamptonshire	
22/037	Mindful	May 2022	6 Candidate	Norfolk	
22/070	Mindful	May 2022	6 Candidate	Tyne and Wear	
22/091	Mindful	May 2022	6 Candidate	Lincolnshire	
22/187	Mindful	June 2022	6 Candidate	Lincolnshire	
22/126	Oxford	May 2022	8 Candidate	Lincolnshire	
22/170	Oxford	June 2022	8 Candidate	Norwich	
22/139	Relay	May 2022	-	Cambridgeshire	
22/041	RGT Bairstow	May 2022	7	Norfolk	
22/128	RGT Bairstow	May 2022	7	Lincolnshire	
22/131	RGT Gravity	May 2022	6	Herefordshire	
22/089	RGT Illustrious	May 2022	8	Lincolnshire	
22/097	RGT Rashid	May 2022	8	Norfolk	Y
22/040	RGT Saki	May 2022	8	Norfolk	
22/129	RGT Saki	May 2022	8	Cambridgeshire	
22/163	RGT Saki	June 2022	8	Lincolnshire	
22/064	RGT Stokes	May 2022	7	Tyne and Wear	Y
22/080	RGT Stokes	May 2022	7	Lincolnshire	
22/044	RGT Wilkinson	May 2022	7 Candidate	Norfolk	
22/053	RGT Wilkinson	May 2022	7 Candidate	Norfolk	
22/074	RGT Wilkinson	May 2022	7 Candidate	Tyne and Wear	
22/087	RGT Wilkinson	May 2022	7 Candidate	Lincolnshire	
22/116	RGT Wilkinson	May 2022	7 Candidate	County Down	
22/154	RGT Wilkinson	June 2022	7 Candidate	East Lothian	Y
22/050	RGT Wolverine	May 2022	4	Oxfordshire	
22/069	RGT Wolverine	May 2022	4	Tyne and Wear	
22/083	RGT Wolverine	May 2022	4	Lincolnshire	
22/114	RGT Wolverine	May 2022	4	County Down	
22/176	RGT Wolverine	June 2022	4	Lincolnshire	
22/008	RGT Zinzan	April 2022	5 Candidate	Cambridgeshire	

Isolate Number	Host Variety	Date Sampled	RL Rating 2022/23	Location	Genotyped
22/058	RGT Zinzan	May 2022	5 Candidate	Hampshire	
22/090	RGT Zinzan	May 2022	5 Candidate	Lincolnshire	
22/098	RGT Zinzan	May 2022	5 Candidate	East Yorkshire	
22/147	RGT Zinzan	May 2022	5 Candidate	Shropshire	
22/151	RGT Zinzan	June 2022	5 Candidate	East Lothian	
22/165	RGT Zinzan	June 2022	5 Candidate	Bridgend County Borough	Y
22/178	RGT Zinzan	June 2022	5 Candidate	County Londonderry	Y
22/005	Robigus	March 2022	-	Cambridgeshire	
22/006	Robigus	March 2022	-	Cambridgeshire	
22/013	Robigus	April 2022	-	Cambridgeshire	
22/135	Robigus	May 2022	-	Cambridgeshire	
22/142	Robigus	May 2022	-	Lincolnshire	
22/003	Skyfall	January 2022	3	Kent	
22/021	Skyfall	May 2022	3	West Sussex	Y
22/030	Skyfall	May 2022	3	Warwickshire	
22/034	Skyfall	May 2022	3	Dorset	
22/057	Skyfall	May 2022	3	Hampshire	
22/079	Skyfall	May 2022	3	Lincolnshire	
22/102	Skyfall	May 2022	3	Gloucestershire	
22/121	Skyfall	May 2022	3	Herefordshire	
22/144	Skyfall	May 2022	3	Oxfordshire	
22/150	Skyfall	June 2022	3	East Lothian	
22/161	Skyfall	June 2022	3	Lincolnshire	
22/166	Skyfall	June 2022	3	Bridgend County Borough	
22/169	Skyfall	June 2022	3	Cheshire	
22/177	Skyfall	June 2022	3	County Londonderry	
22/009	Skyfall	April 2022	3	Oxfordshire	
22/133	Soissons	May 2022	-	Cambridgeshire	
22/016	Solstice	April 2022	-	Cambridgeshire	
22/092	Swallow	May 2022	6	Norfolk	
22/112	Swallow	May 2022	6	County Down	
22/125	Swallow	May 2022	6	Lincolnshire	
22/174	Swallow	June 2022	6	Lincolnshire	
22/039	SY Coach	May 2022	7 Candidate	Norfolk	
22/130	SY Coach	May 2022	7 Candidate	Cambridgeshire	
22/026	SY Insitor	May 2022	5	Dorset	
22/068	SY Insitor	May 2022	5	Tyne and Wear	
22/086	SY Insitor	May 2022	5	Lincolnshire	
22/096	SY Insitor	May 2022	5	Norfolk	
22/099	SY Insitor	May 2022	5	East Yorkshire	Y
22/111	SY Insitor	May 2022	5	County Down	
22/156	SY Insitor	June 2022	5	Lincolnshire	
22/164	SY Insitor	June 2022	5	Bridgend County Borough	
22/180	Theodore	June 2022	9	Cambridgeshire	Y
22/010	unknown	April 2022	-	Bedfordshire	
22/100	unknown	May 2022	-	Herefordshire	
22/157	unknown	June 2022		North Yorkshire	
22/158	unknown	June 2022		North Yorkshire	
22/014	Victo	April 2022	-	Cambridgeshire	
22/136	Victo	May 2022	-	Cambridgeshire	
22/141	Victo	May 2022	-	Lincolnshire	
22/017	Zoom	April 2022	7 Candidate	Cambridgeshire	
22/048	Zoom	May 2022	7 Candidate	Norfolk	
22/076	Zoom	May 2022	7 Candidate	Tyne and Wear	
22/115	Zoom	May 2022	7 Candidate	County Down	
22/184	Zoom	June 2022	7 Candidate	Lincolnshire	

2022 Wheat Brown Rust Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2022/23	Location
22/013	Apache	June 2022	-	Cambridgeshire
22/010	Apostle	June 2022	-	Cambridgeshire
22/012	Brimstone	June 2022	-	Cambridgeshire
22/023	Champion	June 2022	5	Lincolnshire
22/028	Costello	June 2022	5	Lincolnshire
22/002	Crusoe	April 2022	3	Cambridgeshire
22/014	Crusoe	June 2022	3	Cambridgeshire
22/007	Dickens	June 2022	-	Cambridgeshire
22/019	KWS Cranium	June 2022	4	Gloucestershire
22/008	KWS Extase	June 2022	7	Cambridgeshire
22/020	KWS Extase	June 2022	7	Gloucestershire
22/006	KWS Siskin	June 2022	5	Cambridgeshire
22/017	KWS Siskin	June 2022	5	Cambridgeshire
22/021	KWS Ultimatum	June 2022	6 Candidate	Cambridgeshire
22/001	KWS Zealum	April 2022	5 Candidate	Cambridgeshire
22/025	LG Redwald	June 2022	7 Candidate	Hampshire
22/004	LG Typhoon	May 2022	6	Cambridgeshire
22/026	Mayflower	June 2022	6	Northamptonshire
22/027	Mindful	June 2022	5 Candidate	Lincolnshire
22/018	Oxford	June 2022	5 Candidate	Norwich
22/011	Parade	June 2022	-	Cambridgeshire
22/016	Relay	June 2022	-	Cambridgeshire
22/015	Rendezvous	June 2022	-	Cambridgeshire
22/005	RGT Saki	May 2022	7	Cambridgeshire
22/022	RGT Saki	June 2022	7	Cambridgeshire
22/003	RGT Stokes	May 2022	5	Kent
22/009	Soissons	June 2022	-	Cambridgeshire
22/024	Theodore	June 2022	8	Dorset

2022 Wheat Powdery Mildew Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2022/23	Location
22/010	Crusoe	June 2022	7	Cambridgeshire
22/012	KWS Barrel	June 2022	6	Angus
22/006	KWS Cranium	May 2022	6	County Down
22/005	KWS Zealum	April 2022	7 Candidate	Cambridgeshire
22/004	KWS Zyatt	April 2022	7	Cambridgeshire
22/011	LG Astronomer	May 2022	4	unknown
22/001	LG Spotlight	March 2022	6	Cambridgeshire
22/008	Merit	June 2022	4	Nottinghamshire
22/003	RGT Rashid	March 2022	4	Cambridgeshire
22/009	RGT Zinzan	June 2022	7 Candidate	Midlothian
22/007	Theodore	June 2022	7	Lincolnshire
22/002	Treasure	March 2022	-	Cambridgeshire

2022 Barley Powdery Mildew Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2022/23	Location
22/017	Bazooka	May 2022	5	County Down
22/018	Belfry	May 2022	6	County Down
22/020	Belmont	May 2022	5	County Down
22/024	California	May 2022	6	County Down
22/003	Craft	November 2022	6	Cambridgeshire
22/010	Craft	May 2022	6	County Down
22/012	Funky	May 2022	5	County Down
22/023	KWS Cassia	May 2022	5	County Down
22/001	KWS Faro	November 2022	-	Cambridgeshire
22/007	KWS Hawking	November 2022	5	North Yorkshire
22/014	KWS Hawking	May 2022	5	County Down
22/002	KWS Orwell	November 2022	3	Norfolk
22/004	KWS Orwell	November 2022	3	Suffolk
22/005	KWS Orwell	November 2022	3	Cambridgeshire
22/006	KWS Orwell	November 2022	3	Devon
22/025	KWS Orwell	May 2022	3	County Down
22/015	KWS Tardis	May 2022	5	County Down
22/016	LG Campus	May 2022	4 Candidate	County Down
22/029	LG Flamenco	June 2022	-	North Yorkshire
22/013	LG Mountain	May 2022	5	County Down
22/028	Propino	June 2022	-	North Yorkshire
22/011	Surge	May 2022	6	County Down
22/021	SY Javelin	May 2022	-	County Down
22/019	SY Kingston	May 2022	7	County Down
22/022	SY Nephin	May 2022	6 Candidate	County Down
22/008	unknown	November 2022	-	Cambridgeshire
22/009	unknown	November 2022	-	Buckinghamshire
22/026	unknown	June 2022	-	North Yorkshire
22/027	unknown	June 2022	-	North Yorkshire

12 Appendix II: 2023 Sample Register

2023 Wheat Yellow Rust Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2023/24	Location	Genotyped
23/009	Avalon	May 2023	-	Cambridgeshire	
23/055	Bamford	June 2023	8 Candidate	Lincolnshire	
23/073	Bamford	June 2023	8 Candidate	Perthshire	
23/011	Bamford	May 2023	8 Candidate	Tyne and Wear	Y
23/084	Creativ	June 2023	-	Essex	
23/026	Crusoe	May 2023	9	Cambridgeshire	
23/035	Crusoe	May 2023	9	Lincolnshire	Y
23/088	Crusoe	July 2023	9	Midlothian	
23/079	DFW SEL 0101	June 2023	-	Essex	
23/082	DFW SEL 0389	June 2023	-	Essex	
23/080	DHF-300	June 2023	-	Essex	
23/081	DHFI 193	June 2023	-	Essex	
23/016	Gefion	May 2023	-	Tyne and Wear	
23/053	Gefion	June 2023	-	Lincolnshire	
23/041	Gleam	May 2023	5	Dorset	Y
23/050	Gleam	June 2023	5	Lincolnshire	
23/071	Gleam	June 2023	5	Perthshire	Y
23/015	Graham	May 2023	8	Tyne and Wear	Y
23/038	Graham	May 2023	8	Norfolk	Y
23/039	Graham	May 2023	8	Cambridgeshire	
23/042	Graham	May 2023	8	Dorset	
23/043	Graham	June 2023	8	County Antrim	
23/046	Graham	June 2023	8	Lincolnshire	
23/072	Graham	June 2023	8	Perthshire	
23/057	KWS Barrel	June 2023	-	Lincolnshire	
23/086	KWS Brium	July 2023	9	Midlothian	Y
23/022	KWS Dawsum	May 2023	9	Lincolnshire	Y
23/031	KWS Dawsum	May 2023	9	Herefordshire	Y
23/005	KWS Extase	April 2023	8	Lincolnshire	
23/007	KWS Extase	April 2023	8	East Yorkshire	Y
23/008	KWS Extase	April 2023	8	West Sussex	Y
23/024	KWS Extase	May 2023	8	North Yorkshire	
23/029	KWS Extase	May 2023	8	Cambridgeshire	
23/032	KWS Extase	May 2023	8	Cambridgeshire	
23/033	KWS Extase	May 2023	8	Cambridgeshire	
23/034	KWS Extase	May 2023	8	Worcestershire	
23/036	KWS Extase	May 2023	8	Lincolnshire	
23/048	KWS Extase	June 2023	8	Lincolnshire	
23/065	KWS Extase	June 2023	8	Cambridgeshire	
23/074	KWS Extase	June 2023	8	East Yorkshire	
23/089	KWS Extase	July 2023	8	Midlothian	
23/013	KWS Webbum	May 2023	-	Tyne and Wear	
23/025	KWS Webbum	May 2023	-	Cambridgeshire	
23/059	KWS Webbum	June 2023	-	Lincolnshire	
23/058	KWS Wrenum	June 2023	-	Lincolnshire	
23/001	KWS Zyatt	February 2023	3	Lincolnshire	
23/019	KWS Zyatt	May 2023	3	Tyne and Wear	
23/049	KWS Zyatt	June 2023	3	Lincolnshire	
23/069	KWS Zyatt	June 2023	3	East Yorkshire	Y
23/090	KWS Zyatt	July 2023	3	Midlothian	
23/030	LG Astronomer	May 2023	9	Nottinghamshire	Y
23/092	LG Astronomer	July 2023	9	Midlothian	Y
23/044	LG Partridge	June 2023	not published, Candidate	Cambridgeshire	
23/054	LG Partridge	June 2023	not published, Candidate	Lincolnshire	
23/064	LG Redrum	June 2023	9 Candidate	Cambridgeshire	

Isolate Number	Host Variety	Date Sampled	RL Rating 2023/24	Location	Genotyped
23/002	LG Redwald	February 2023	7	Lincolnshire	
23/017	LG Redwald	May 2023	7	Tyne and Wear	
23/023	LG Redwald	May 2023	7	Cambridgeshire	
23/037	LG Redwald	May 2023	7	Fife	Y
23/087	LG Redwald	July 2023	7	Midlothian	
23/047	LG Skyscraper	June 2023	7	Lincolnshire	
23/066	LG Skyscraper	June 2023	7	Cambridgeshire	Y
23/045	LG Typhoon	June 2023	9	Lincolnshire	Y
23/063	Mayflower	June 2023	9	Lincolnshire	Y
23/077	Paragon	June 2023	-	Essex	Y
23/003	RGT Bairstow	February 2023	8	Lincolnshire	
23/012	RGT Grouse	May 2023	-	Tyne and Wear	
23/056	RGT Grouse	June 2023	-	Lincolnshire	
23/010	RGT Wilkinson	May 2023	7	Tyne and Wear	
23/051	RGT Wilkinson	June 2023	7	Lincolnshire	Y
23/061	RGT Wolverine	June 2023	4	Lincolnshire	
23/078	Robigus	June 2023	-	Essex	
23/020	Skyfall	May 2023	3	Cambridgeshire	
23/021	Skyfall	May 2023	3	Cambridgeshire	Y
23/027	Skyfall	May 2023	3	Cambridgeshire	
23/040	Skyfall	May 2023	3	Dorset	
23/052	Skyfall	June 2023	3	Lincolnshire	
23/075	Skyfall	June 2023	3	Lincolnshire	
23/076	Skyfall	June 2023	3	Bedfordshire	Y
23/091	Skyfall	July 2023	3	Midlothian	
23/006	Skyfall	April 2023	3	Cambridgeshire	
23/068	Skyfall	June 2023	3	Warwickshire	
23/062	Swallow	June 2023	6	Lincolnshire	
23/014	SY Insitor	May 2023	5	Tyne and Wear	
23/060	SY Insitor	June 2023	5	Lincolnshire	
23/067	SY Insitor	June 2023	5	Midlothian	Y
23/070	SY Insitor	June 2023	5	Hampshire	Y
23/085	SY Insitor	July 2023	5	Aberdeenshire	
23/004	Talon	April 2023	-	Cambridgeshire	
23/018	Theodore	May 2023	9	Tyne and Wear	
23/083	Trane	June 2023	-	Essex	
23/028	unknown	May 2023	8	Leicestershire	

2023 Wheat Brown Rust Isolate Register

Isolate Number	Host Variety	Date Sampled	RL Rating 2023/24	Location
23/005	Champion	June 2023	5	Cambridgeshire
23/014	Champion	July 2023	5	Essex
23/008	Crusoe	June 2023	3	Cambridgeshire
23/010	Crusoe	June 2023	3	Bedfordshire
23/011	Crusoe	June 2023	3	Bedfordshire
23/015	Crusoe	July 2023	3	Essex
23/004	KWS Guium	June 2023	3	Cambridgeshire
23/002	KWS Zealum	May 2023	5	Cambridgeshire
23/013	Mayflower	July 2023	6	Devon
23/007	Merit	June 2023	7	Cambridgeshire
23/001	R12117	May 2023	-	Lincolnshire
23/006	RGT Rashid	June 2023	6	Cambridgeshire
23/003	Theodore	May 2023	8	East Yorkshire
23/009	Theodore	June 2023	8	Dorset
23/012	Theodore	July 2023	8	Devon

13 References

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