January 2025

United Kingdom Cereal Pathogen Virulence Survey (UKCPVS) Annual Report 2024

Huw Davis, Amelia Hubbard, Adam Donaldson, Megan Burt, Charlotte Nellist, and Kostya Kanyuka

Niab, Park Farm, Villa Road, Histon, Cambridge CB24 9NZ

TABLE OF CONTENTS

1 Grower summary

1.1 Headline

The wheat yellow rust population remains diverse in the UK but most Recommended Lists (RL) varieties continued to perform as predicted from their RL rating at the adult plant stage. Approximately half of the wheat RL and candidate varieties showed resistance to yellow rust at the seedling stage.

The UK experienced a high wheat brown rust pressure in 2024. This was due to environmental conditions and RL varieties continued to perform as predicted from their RL ratings at the adult plant stage. Similar to the previous years, all RL and candidate varieties, with the exception of RGT Goldfinch, were shown to be susceptible to brown rust at the seedling stage.

1.2 Take Home Messages

Wheat Yellow Rust

The UK experienced a mild winter, followed by a wet spring, which resulted in missed fungicide applications, and the environmental and external factors were conducive for rust development. Yellow rust disease pressure in 2024 was consistent with previous years, however the survey received a lower number of yellow rust samples in comparison to previous years.

Wheat Brown Rust

In contrast, the survey received a high number of brown rust samples, over four times more than in 2023. This is believed to be a result of the brown rust overwintering, due to the mild winter, and the missed fungicide applications, due to the wet spring. Sightings of brown rust were earlier than usual and followed by a more severe epidemic late in the year compared to previous years.

1.3 On Farm Practical Advice

Note that even the most highly rated RL varieties could be susceptible to rusts at the young plant stage. Thus, for example, the 2024 yellow rust seedling tests identified one variety on the 2024 RL with the highest rating of 9, namely KWS Zealum, as susceptible to one of the tested isolates at the seedling stage. A total of fourteen RL varieties were susceptible to 4–64% of tested isolates at the seedling stage. Varieties that are susceptible to multiple isolates are more like to be under greater disease pressure in the field at the young plant stage and should be monitored closely and treated with fungicides, if necessary.

For more information, visit ahdb.org.uk/ukcpvs

Many factors affect disease development, such as weather, variety choice, location, and global climatic events. As 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.

Full sampling instructions are available on the Niab website:
niab.com/research/agricultural-crop-research/research-projects-agriculture/uk-cereal-pathogen-virulence

2 Scientific Summary

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 as exemplified by a broad range of virulence profiles identified amongst sampled isolates. Genotyping of a selection of *Pst* isolates between 2019 and 2023 highlighted the proportion of isolates belonging to the three genetic groups known as “Pink”, ‘Purple’ and ‘Red’, in the UK and as ‘PstS7 or Warrior’, ‘PstS8 or Kranich’, and ‘PstS10 or Warrior(-)’ in continental Europe. No funds were available for isolates genotyping in the 2024 season. However, based on the obtained virulence profiles it could be speculated that the UK *Pst* population continued to be dominated by the Warrior(-) / Red genetic group isolates. A total of 25 isolates were tested on the full set of RL and candidate varieties with 14 RL and 15 candidate varieties showing susceptibility to 1-16 isolates at the seedling stage. All varieties with a rating of 8 or 9 at the adult plant stage also performed well at the seedling stage in growth room-based studies. The highest % of virulence was detected for KWS Zyatt (rated 3). Differential set varieties carrying *Yr5*, *Yr8*, *Yr10* or *Yr15* remained resistant to all tested isolates at the seedling stage.

Wheat Brown Rust

All RL and candidate varieties, with two exceptions, were susceptible to at least 3 out of 10 tested *Pt* isolates. RGT Goldfinch (rated 9) was resistant to all 10 tested isolates, and candidate variety Diamond was resistant to 9 out of 10 isolates at the seedling stage. As seen in previous years, virulence was detected in *Pt* for many of the all-stage disease resistance genes tested. In 2022, virulence for the *Lr24* gene was recorded at 12%, increasing to 40% in 2023. However, in 2024 we saw the virulence for *Lr24* reduce to 10%, which is in line with findings from 2022. This highlights how the populations can change year on year. Some additional changes were also observed, for example, virulence for *Lr2c* increased in 2024 while virulence for *Lr10, Lr13, Lr14a, Lr15, Lr16, Lr17, Lr37* declined. It was also observed that virulence for *Lr3a*, *Lr3bg*, *Lr3ka, Lr20, Lr23, Lr26* declined which is a trend that has been occurring over recent years. While virulence for *Lr28* has been consistent in 2022 and 2023, there was a 20% decrease in 2024.

Wheat and Barley Powdery Mildew

Reports were received of higher-than-expected disease levels in *mlo*-possessing varieties in 2023 RL trials in Scotland, however no samples were received in 2024. No unusual sightings were reported for wheat powdery mildew.

3 Glossary

AIT	Average Infection Type score.
APR	Adult Plant Resistance; some varieties have resistance that becomes effective at later growth stages only.
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 lines	Varieties/accessions that have known disease resistance genes. If an isolate of a pathogen is able to infect a particular differential line, then it is said to carry the corresponding virulence gene, it has overcome the resistance gene carried by that differential line. Some differential lines carry more than one disease resistance gene.
Epidemic	Widespread occurrence of a disease at a particular time.
Genotyping	Determination of the differences in genetic make-up (DNA) of an individual.
Genetic group	Groups together physiological 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 with a pathogen artificially (by a human being).
Isolate	A pure culture isolated for study from infected leaf samples.
Pathogen	A bacterium, virus, fungus 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	Pathogen races are classified based on their virulence profiles, typically determined by their ability to overcome resistance in a set of differential host lines.
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 often gives incomplete resistance against all genotypes of a pathogen.
Resistance gene(s)	Genes in plant genomes that confer disease resistance against pathogens. NB: many varieties carry a combination of resistance genes to help them defend themselves against pathogen invasion.
RL	AHDB Recommended List.
Seedling	In the case of UKCPVS seedling tests this refers to seedlings infected at the one 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.

Susceptibility	A susceptible host is a plant that lacks effective resistance mechanisms to a specific pathogen, making it vulnerable to infection. Crop varieties can be resistant or susceptible to a particular pathogen, pathogen race, or pathogen isolate.
Variety	Variety 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 degree or the extent of damage a pathogen can cause to its host; and it is often used to describe the severity of disease caused by a specific pathogen strain, race, or isolate. Pathogen isolates can be virulent or avirulent.
Virulence gene(s)	A gene in a pathogen that contributes to its ability to infect, colonise, and cause disease in a host. In cereal rust pathogens, virulence genes in certain races allow them to infect wheat varieties that carry specific resistance genes.

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 commonly 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 could however be broken down due to the evolution of virulence in the fungal population, which should be monitored. For this reason, the UK Cereal Pathogen Virulence Survey (UKCPVS) was established in 1967 following an unexpected outbreak of yellow rust on the previously resistant wheat 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 powdery mildew, barley brown rust, barley leaf scald (*Rhynchosporium* or leaf blotch), barley net blotch, oat crown rust, oat leaf spot and oat powdery mildew. Over time, the list of target species has reduced but the principles remain the same and in its 57th year the survey continues to provide information to growers, breeders and other stakeholders on the populations of these important pathogens. The survey currently limits its activities to monitoring the virulence in pathogens causing yellow rust and brown rust diseases in wheat and up until recently also wheat and barley powdery mildew (**Figure 1**).

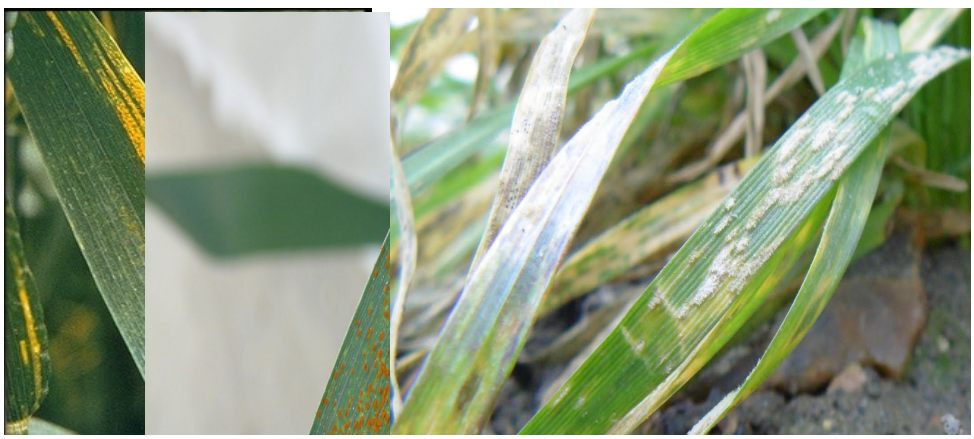

Figure 1: Classic symptoms of the cereal foliar pathogens yellow rust (left), brown rust (middle) and powdery mildew (right).

4.1.2.2 Timescale of characterisation

Once a leaf sample showing disease symptoms is received by the survey, the causal agent is isolated, multiplied, and preserved for further testing. Typically, by the end of July, when all or most of the samples have been received, the list is scrutinised and at least 25 isolates of yellow rust and ten of brown rust are selected for further characterisation by inoculation onto wheat differential lines. These tests follow a worldwide standard procedure where the different isolates of rust or mildew are inoculated onto a set of different varieties ('differential lines') whose gene(s) underlying disease resistance are known (designated *Yr, Lr, Pm,* or *Mla/mlo* for yellow rust, brown rust, wheat mildew and barley mildew, respectively). Additional, primarily UK, varieties carrying unnamed resistance genes are also included in these tests. Assessing whether the isolate can cause disease on individual differential lines (classified as virulent) or cannot (classified as avirulent) enables its characterisation and comparison with previously identified isolates within UKCPVS and with those studied by colleagues worldwide. 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

Over 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 *Yr7* had been seen before, but not in combination with virulence for *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 European population (Hovmøller *et al*., 2016; Hubbard *et al*., 2015). The Warrior race was also characterised by its high population genetic diversity, indicating that it was likely to be derived via sexual recombination, and not the asexual mutations 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 (or 'PstS7' or 'Pink') group of isolates in 2011, existing European populations have been replaced and the isolate members of the Warrior group become dominant (Hovmøller *et al*., 2016; Hubbard *et al*., 2015). In 2015, UKCPVS confirmed that an additional race had arrived in the UK, known as the 'Kranich' race (or 'PstS8' or 'Purple') (Hubbard *et al*., 2016). And another genetic group, known as 'Warrior(-)' (or 'PstS10' or 'Red'), first detected in 2016, was the most likely cause for substantial changes to AHDB Recommended List (RL) ratings that year (Hubbard *et al*., 2017). An unusual outbreak on wheat 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, an isolate belonging to the Red group 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 2024, no isolates carried virulence for *Yr5, Yr8, Yr10* and *Yr15.*

4.1.3.1 Changes in naming of races over the years

With the recent race changes affecting the UK and across Europe, 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 been proposed to take into consideration the genotyping data produced by the John Innes Centre as well as the pathotyping data generated by UKCPVS. The races were assigned a colour dividing the races into their genetic groups based on the genotyping data, and then a number was added to divide the isolates according to the pathotyping data. The colour is based on the genetically distinct clusters (or groups) of isolates identified following the genotyping data analysis using the population genetics software called 'STRUCTURE', while the number is assigned sequentially to each new pathotype (virulence profile). Colleagues at the Global Rust Reference Centre (GRRC) in Denmark developed a different naming system (Ali *et al*., 2017). Translation between the two naming systems has been attempted. As from 2024 yellow rust isolates are no longer genotyped in UKCPVS, it is not possible to accurately assign isolates to specific genetic groups, and we resort to classifying the isolates to physiological races only based on pathotyping (virulence profiling) against a reduced set of differential wheat lines.

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 the Institute of Biological, Environmental and Rural Sciences (IBERS) at 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 wheat line 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 was considered 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* (*Pt*) 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 often reduces too. One example is virulence for *Lr24*. The two varieties carrying this resistance gene, Warrior and Stigg, are no longer widely grown and the fungal population has therefore mirrored this and the frequency of detection of virulence for *Lr24* continues to decline. In 2014, a change in the population resulted in overcoming the moderate resistance in the variety Crusoe. However, it still remains unclear what resistance gene has been broken down. Over recent years *Pt* populations in the UK 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 for *Lr24,* which was accompanied by reports of higher-than-expected levels of disease in Theodore – a variety thought to possess *Lr24*.

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* + unknown
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
2019	KWS Firefly	*Lr28*
2022	Theodore	*Lr24*

* 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 UKCPVS project is to detect new virulent races of economically important pathogens for UK growers, thus providing an early warning system to aid effective on-farm disease management. To achieve this, UKCPVS currently monitors the populations of the fungal pathogens causing wheat yellow rust and brown rust and barley powdery mildew diseases. A subset of the fungal isolates collected is characterised to identify any new or emerging races. The reactions of the current RL varieties and Candidates are assessed using some of the newest isolates at the seedling stage 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 pathogens were tested in 2024 is depicted in **Figure 2**.

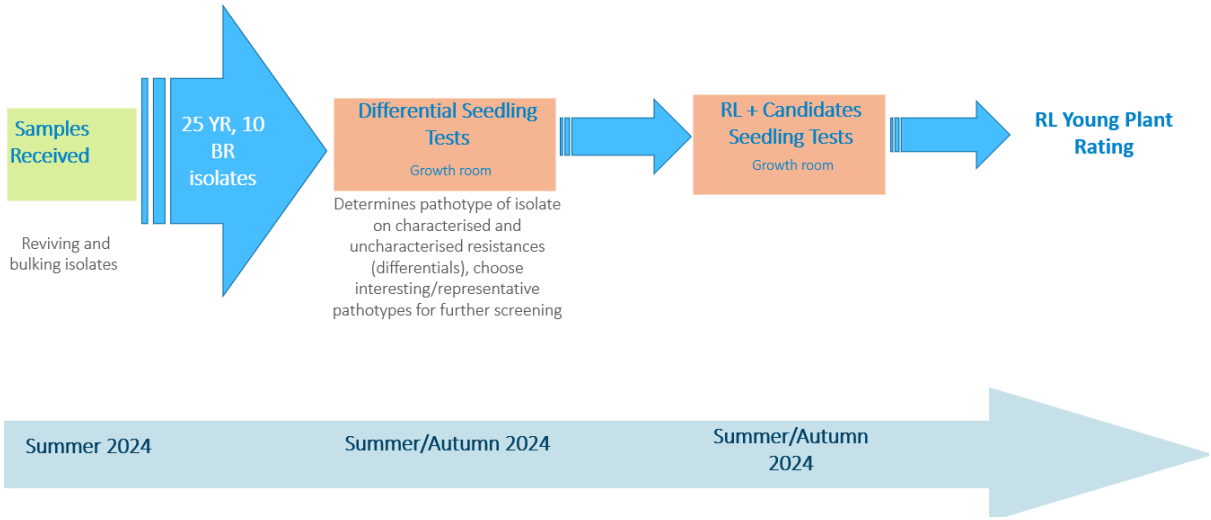

Figure 2: Wheat yellow rust and wheat brown rust sample processing pipeline in 2024.

In 2024, the pipeline used in previous years was modified by using a reduced differential set and including the full set of RL and Candidate varieties in the seedling tests. Additionally, no adult plant trials were performed in 2024. Twenty-five isolates of yellow rust and ten isolates of brown rust were analysed using the seedling inoculation tests.

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 onto 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 the differential lines set.

5.1.2 Characterisation of isolates using differential variety seedlings 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 differential lines 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 interaction with the plant considered to be resistant and the isolate considered to be avirulent, whilst a score of 2.4 - 2.6 represents a

Figure 3: Example of differential seedling test set up.

borderline reaction and should be treated with caution as it is difficult to be certain whether the interaction is compatible or incompatible. The scores of 2.7 – 4.0 indicate a compatible interaction with the plant considered to be susceptible and the isolate considered to be virulent.

5.1.3 Characterisation of isolates using RL variety seedling tests

The same 25 isolates selected for differential testing were also used to assess seedling reactions of RL and candidate varieties under growth room conditions. Timescales and scoring of these tests were carried out using the same methods and AIT scoring system as the differential tests.

5.2 Barley Powdery Mildew

5.2.1 Collection of samples and preparation of isolates

The methodology behind the preparation of isolates is as follows; Individual pustules taken from the infected samples are mounted on agar and when sporulation is seen the pustules are transferred onto fresh detached leaf sections using the universally susceptible barley variety Golden Promise. Subsequent transfers onto new detached leaves are conducted to maintain and increase the isolate. However, no new samples of barley powdery mildew were received in 2024.

6 Results and Discussion

6.1 Wheat Yellow Rust

6.1.1 Samples received

In 2024 the UKCPVS received 68 samples of wheat yellow rust from 17 different counties across the UK (**Figure 4**).

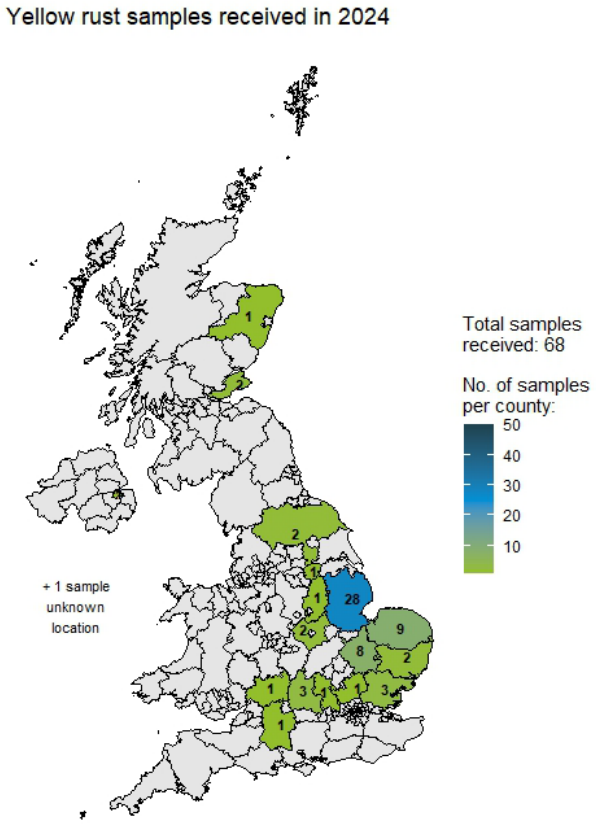

Figure 4: Map of the UK showing the counties where samples of wheat yellow rust were received from in 2024.

The UK experienced a mild winter which allowed rusts to overwinter, this was followed by a very wet spring resulting in preventative sprays being missed. These conditions were conducive for rust development. UKCPVS made several calls on social media requesting new samples, however we received 68 samples which is less than could have been expected for the relatively high disease year. This number is lower than the survey has previously seen. The most sampled variety was KWS Extase with fifteen samples, followed by Crusoe with six samples. We received samples from seventeen counties and one unknown location across the UK, predominantly from Lincolnshire, Norfolk and Cambridgeshire. In total, samples were received from twenty-five different varieties, mostly current RL varieties, but also some varieties that are no longer on the Recommended List as well as breeding lines.

The full sample register is provided in **Appendix I: 2024 Sample Register**. It is important to note that the host varieties in the sample register have been confirmed by the sampler. However, there is a possibility that a small number of samples may not be from the variety listed.

6.1.2 Pathotyping of isolates

6.1.2.1 Virulence for individual resistance genes and varieties with unnamed resistance genes

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 variety 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. Isolates with scores between 2.4 and 2.7 were considered borderline, however still classified as virulent. 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**). The changes in frequency of isolates carrying virulence for different wheat yellow rust resistance genes and varieties over the past five years can be found in **Table 3.**

No new virulences for individual *Yr* resistance genes were detected among the isolates collected in 2024 using the differential lines tested at the seedling stage. Like in previous years of the survey, no virulence was detected for the yellow rust resistance genes *Yr5, Yr8, Yr10* and *Yr15*.

No virulence was detected for *Yr8* which has been seen at low levels in 2020, 2021 and 2023. Virulence for Evolution, which has fluctuated widely over the years, remained at a similar level to that of 2023. Virulence for Apache, which carries the resistance genes *Yr7 and Yr17*, was recorded at a similar level to 2023. However, virulence for Ambition saw an increase in comparison to previous years.

Table 2: Pathotypes of the 2024 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 variety	Virulence Profile[1]																
		1	3	4	5	8	10	15	17	32	Ap	Re	Sp	Wa	St	Amb	Kr	Ev	Ca
24-002	KWS Extase	1	3						17	32	Ap		Sp	Wa		Amb			Ca
24-003	Crusoe	1	3	4					17	32	Ap		Sp	Wa	St	Amb	Kr		Ca
24-004	Gleam	1		4					17	32			Sp						
24-007	KWS Extase	1	3	4					17	32	Ap	Re	Sp	Wa	St	Amb	Kr		Ca
24-009	Graham	1	3	4					17	32	Ap		Sp		St	Amb			Ca
24-014	LG Redwald	1							17	32		Re	Sp			Amb	Kr		
24-019	Graham	1	3						17	32	Ap		Sp				Kr		Ca
24-020	Crusoe	1	3						17	32	Ap		Sp	Wa		Amb			Ca
24-023	Gallant	1	3	4					17	32	Ap		Sp	Wa	St	Amb	Kr		Ca
24-024	KWS Extase	1	3						17	32	Ap		Sp		St	Amb	Kr		
24-030	SY Cheer	1	3						17	32		Re	Sp	Wa	St	Amb			Ca
24-034	Bamford	1	3						17	32	Ap		Sp	Wa				Ev	Ca
24-036	Skyscraper	1	3						17	32	Ap	Re	Sp		St			Ev	Ca
24-038	Champion	1	3						17	32			Sp		St				Ca
24-040	LG Typhoon	1	3						17	32			Sp						Ca
24-042	Mayflower	1							17	32	Ap		Sp						Ca
24-044	KWS Ladium	1	3						17	32	Ap		Sp		St				Ca
24-045	KWS Extase	1	3						17	32	Ap	Re	Sp	Wa	St	Amb	Kr		Ca
24-046	Crusoe	1	3						17	32	Ap		Sp		St	Amb			Ca
24-048	LG Redwald	1	3						17	32			Sp						Ca
24-049	KWS Zyatt	1							17	32			Sp		St				Ca
24-058	Frenzy	1		4					17	32	Ap		Sp						Ca
24-062	Gleam	1	3						17	32	Ap		Sp						Ca
24-064	LG Redwald		3						17	32	Ap	Re	Sp	Wa	St	Amb	Kr	Ev	Ca
24-068	KWS Solitaire	1	3						17	32	Ap		Sp		St			Ev	Ca

[1] Numbers refer to previously designated *Yr* genes, Ap = Apache, Re = Rendezvous, Sp = Spaldings Prolific, Wa = Warrior, St = KWS Sterling, Amb = Ambition, Kr = Kranich, Ev = Evolution, Ca = Cadenza

Table 3: Frequency of detection of isolates carrying virulence to the different wheat yellow rust resistance genes and varieties over the past five years. Note: Cadenza and Hybrid 46 were not included in 2023

Virulence For Resistance Gene or Variety	Percentage of Isolates Identified with Virulence for Gene or Variety				
	2020	2021	2022	2023	2024
Yr1	100	100	100	100	100
Yr3	100	98	100	94	76
Yr4	87	68	92	80	20
Yr5	0	0	0	0	0
Yr7	93	100	96	54	72
Yr8	3.33	7.5	0	2.78	0
Yr10	0	0	0	0	0
Yr15	0	0	0	0	0
Yr17	100	100	100	100	100
Yr32	100	100	100	100	100
Rendezvous	86	72	72	53	24
Warrior	47	72	92	37	36
KWS Sterling	70	80	80	61	56
Ambition	33	25	16	30	48
Kranich	33	43	24	36	36
Evolution	73	38	40	22	16
Cadenza	83	87	92	-	84
Apache	93	100	96	53	72
Vilmorin	100	97	100	95	76
Hybrid 46	86	67	92	-	20

- Not tested.

6.1.2.2 Commonly detected isolates

In 2024 no common pathotypes were found, there are pathotypes with close similarities.

6.1.2.3 RL Variety Seedling tests

The same 25 isolates that were pathotyped against the differential variety set were also used for testing against the full set of RL and Candidate varieties at the seedling stage. Results can be seen in table 4. Seventeen of the 31 RL candidates and 8 out 23 of the candidate varieties were resistant to all 25 isolates at the seedling stage. Fourteen RL and 15 candidate varieties were susceptible to at least 1 and up to 16 out of the 25 isolates tested.

Table 4: Recommended list and candidate varieties' reaction to 25 yellow rust isolates. RL varieties are highlighted in blue and candidate varieties are highlighted in green. Varieties that are resistant are indicated with the letter r, while varieties that are susceptible are indicated with the letter s followed by the number of isolates the variety was susceptible to.

Variety	YR reaction	Variety	YR reaction
Costello	r	RGT Illustrious	s1
LG Astronomer	r	KWS Zealum	s1
KWS Cranium	r	Crusoe	s2
Champion	r	LG Skyscraper	s3
LG Typhoon	r	Bamford	s3
RGT Stokes	r	RGT Wilkinson	s4
RGT Bairstow	r	Skyfall	s5
RGT Rashid	r	Gleam	s5
Mayflower	r	LG Redwald	s6
KWS Dawsum	r	KWS Extase	s6
KWS Palladium	r	RGT Wolverine	s8
Oxford	r	Graham	s8
KWS Ultimatum	r	SY Insitor	s9
Blackstone	r	KWS Zyatt	s16
Almara	r	KWS Beste	s1
LG Beowulf	r	KWS Vibe	s2
SY Cheer	r	KWS Mongoose	s2
Diamond	r	RGT Goldfinch	s2
KWS Newbie	r	Energy	s3
KWS Vicarage	r	KWS Equipe	s3
Riley	r	SY Monza	s5
Memphis	r	KWS Scope	s7
Rufus	r	LG Shergar	s7
LG Henri	r	Frenzy	s7
Roma	r	LG Rebellion	s8
		KWS Solitaire	s9
		KWS Flute	s9
		RGT Hexton	s9
		KWS Arnie	s13

6.2 Wheat Brown Rust

6.2.1 Samples received

In 2024, the UKCPVS received 65 samples of wheat brown rust from ten different counties across the UK (**Figure 5**). Samples were received from thirty-one different varieties.

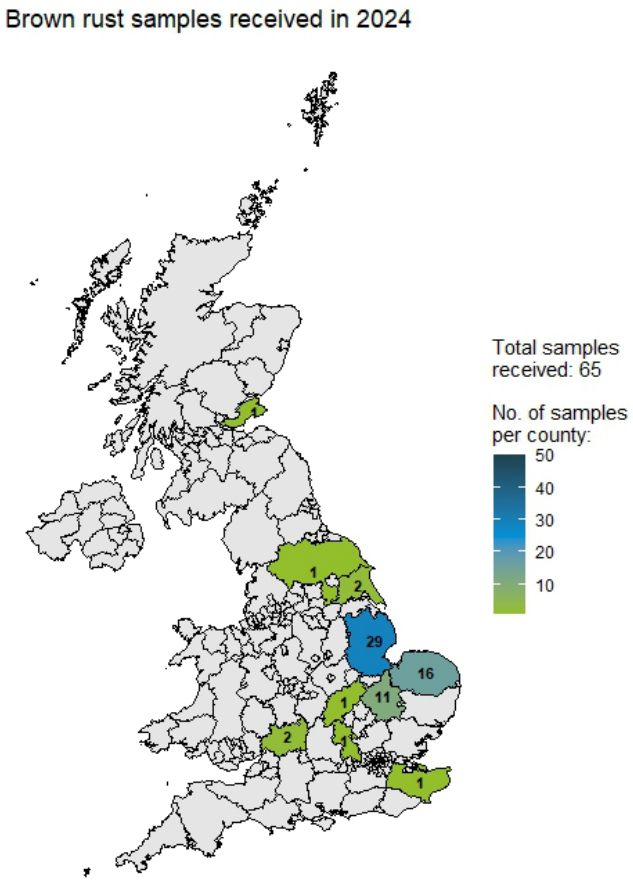

Figure 5: Map of the UK showing the counties where samples of wheat brown rust were received from in 2024.

The full sample register is provided in **Appendix I: 2024 Sample Register**. It is important to note that the host varieties in the sample register have been confirmed by the sampler. However, there is a possibility that a small number of samples may be not from the variety listed.

6.2.2 Pathotyping of isolates

6.2.2.1 Virulence for individual resistance genes and varieties with unnamed resistance genes

Ten isolates were selected for 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. Isolates with scores between 2.4 and 2.7 were considered borderline, however still classified as virulent. 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 5**). UKCPVS employed the use of the differential set which aligns the data with that from other virulence surveys across the world. The frequency of detection of virulence for the *Lr* genes monitored is shown in **Table 6**.

Table 5: Pathotypes of the 2024 wheat brown rust isolates based on the differential test results in **Supplementary Table 2**. Numbers refer to specific *Lr* resistance genes, AM=Armada, CR = Crusoe, *Lr17*= Maris Fundin, *Lr28*= Robigus, *Lr26*= Clement, *Lr1*= Glasgow, *Lr20*= Maris Halberd, *Lr20*= Sappo, *Lr3a*= Sterna, *Lr24*= Stigg, *Lr24*= Warrior, *Lr28*= KWS Firefly, *Lr24*= Theodore. Yellow shading = compatible reaction (virulence), blank = avirulence.

Isolate code	Host variety	Virulence profile																														
		1	2a	2b	2c	3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26	28	37	AM	CR	Lr17b	Lr28	Lr26	Lr1	Lr20	Lr20	Lr3a	Lr24	Lr24	Lr28	Lr24
24-001	Mayflower	1					3bg			13	14a											CR	Lr17b		Lr26	Lr1	Lr20		Lr3a	Lr24			
24-008	KWS Extase	1						3ka	10	13	14a	15	16	17				26	28	37	AM	CR	Lr17b	Lr28	Lr26	Lr1						Lr28	
24-009	Graham	1							10	13	14a	15	16	17		23				37	AM	CR	Lr17b	Lr28	Lr26	Lr1						Lr28	
24-013	Crusoe	1				3a			10		14a									37	AM	CR		Lr28		Lr1			Lr3a			Lr28	
24-014	LG Skyscraper	1					3bg			13	14a			17	20						AM					Lr1							
24-015	KWS Dawsum	1							10	13	14a	15	16	17				26	28	37	AM	CR	Lr17b	Lr28	Lr26	Lr1						Lr28	
24-019	Typhoon	1			2c		3bg	3ka	10	13	14a	15	16	17				26	28	37	AM	CR	Lr17b	Lr28	Lr26	Lr1						Lr28	
24-030	Crusoe	1					3bg		10		14a	15		17	20					37	AM	CR				Lr1		Lr20					
24-051	Bamford	1						3ka	10	13	14a	15					24	26			AM		Lr17b			Lr1	Lr20	Lr20	Lr3a	Lr24			Lr24
24-061	LG Beowulf	1							10		14a	15		17					28	37	AM	CR	Lr17b	Lr28	Lr26	Lr1						Lr28	

Virulence for *Lr1, Lr14a,* and for the additional cultivar Glasgow was detected in all isolates. No virulence was detected for the genes *Lr2a* and *Lr2b* which is consistent with previous years. Virulence for *Lr3a, Lr3bg, Lr3ka, Lr10, Lr13, Lr14a, Lr15, Lr16, Lr17, Lr20, Lr23, Lr24, Lr26, Lr28 and Lr37* all decreased. Virulence for Robigus which is thought to carry *Lr28* remained at the same level as 2023, with 60% of isolates virulent. Virulence for the additional cultivars Maris Fundin, Clement, Maris Halberd, Sappo, Sterna, Stigg, KWS Firefly and Theodore all decreased in comparison to previous years. No virulence was detected for Warrior with the *Lr* gene *Lr24*.

Table 6: Frequency of detection of isolates carrying virulence for the different brown rust resistance genes and varieties over the past five years. (Theodore was not included in 2020 and 2021).

Virulence for Resistance Gene or Variety	Percentage of Isolates Identified with Virulence for Gene or Variety				
	2020	2021	2022	2023	2024
Lr1	100	100	100	100	100
Lr2a	0	0	0	0	0
Lr2b	0	0	0	0	0
Lr2c	12	10	4	0	10
Lr3a	56	50	76	60	10
Lr3bg	56	50	72	60	40
Lr3ka	80	50	92	67	30
Lr10	96	100	100	100	80
Lr13	100	100	100	100	70
Lr14a	100	100	100	100	100
Lr15	100	100	100	100	70
Lr16	100	100	100	100	40
Lr17	100	100	100	100	70
Lr20	12	30	40	40	20
Lr23	32	50	36	33	10
Lr24	0	0	12	40	10
Lr26	92	60	96	87	40
Lr28	44	50	60	60	40
Lr37	100	100	100	100	70
Maris Fundin	100	100	100	100	70
Robigus	40	50	56	60	60
Clement	92	50	96	100	60
Glasgow	100	100	100	100	100
Maris Halberd	20	20	40	26	20
Sappo	20	30	40	40	30
Sterna	56	50	76	53	30
Stigg	0	0	12	40	30
Warrior	0	0	12	33	0
KWS Firefly	40	50	52	60	60
Theodore	na	na	12	33	10

6.2.2.2 Commonly detected races

In 2024 no common pathotypes were found between the ten brown rust isolates tested.

6.2.2.3 RL Variety Seedling tests

The same 10 isolates that were selected for the brown rust differential tests were used for testing the full RL and candidate varieties at the seedling stage in the controlled environment rooms at Niab. Many of the RL varieties and candidates tested were susceptible at the seedling stage to all 10 of the isolates tested. RGT Goldfinch, was the only one resistant to all 10 isolates. Table 7 shows the RL and candidate varieties and the seedling reactions to the ten isolates. The susceptible varieties were susceptible to at least 3 and up to 10 out of the 10 isolates. Candidate variety Diamond was found to be resistant to 9 out of 10 isolates tested.

Table 7: Recommended list and candidate varieties' reaction to ten brown rust isolates. RL varieties are highlighted in blue and candidate varieties are highlighted in green. Varieties that are resistant are indicated with the letter r, while varieties that are susceptible are indicated with the letter s followed by the number of isolates the variety was susceptible to.

Variety	Brown rust reaction	Variety	Brown rust reaction
KWS Zealum	**s3**	RGT Goldfinch	**r**
Skyfall	**s4**	Diamond	**s1**
RGT Bairstow	**s4**	LG Rebellion	**s5**
Oxford	**s4**	KWS Vicarage	**s6**
LG Typhoon	**s5**	RGT Hexton	**s6**
Almara	**s5**	Energy	**s8**
Costello	**s6**	KWS Vibe	**s8**
LG Astronomer	**s6**	Riley	**s8**
Champion	**s6**	Memphis	**s8**
RGT Rashid	**s6**	LG Shergar	**s8**
KWS Ultimatum	**s6**	SY Monza	**s8**
LG Redwald	**s6**	Roma	**s8**
Crusoe	**s7**	KWS Equipe	**s9**
RGT Illustrious	**s7**	KWS Scope	**s9**
KWS Extase	**s7**	KWS Arnie	**s9**
RGT Wolverine	**s7**	KWS Newbie	**s9**
Mayflower	**s7**	KWS Flute	**s9**
RGT Wilkinson	**s7**	KWS Mongoose	**s9**
Bamford	**s7**	LG Henri	**s9**
LG Beowulf	**s7**	Frenzy	**s10**
Gleam	**s8**	KWS Solitaire	**s10**
LG Skyscraper	**s8**	KWS Beste	**s10**
SY Insitor	**s8**	Rufus	**s10**
KWS Cranium	**s8**		
KWS Dawsum	**s8**		
KWS Palladium	**s8**		
RGT Stokes	**s9**		
Blackstone	**s9**		
Graham	**s10**		
KWS Zyatt	**s10**		
SY Cheer	**s10**		

6.3 Wheat Powdery Mildew

6.3.1 Samples received

No wheat powdery mildew samples were received in 2024.

6.4 Barley Powdery Mildew

6.4.1 Samples received

No barley powdery mildew samples were received in 2024.

7 Improvement of methodologies

The UKCPVS continually aims to improve current methodologies and test new approaches which may streamline the survey in the future. In 2024, Niab tested a mixture of three wheat yellow rust isolates compared against the data obtained from individual testing of the same three isolates against the differential lines set as well as against the entire set of RL varieties and candidates. *Pst* isolates 24-003, 24-004 and 24-007 were selected for testing. Results were unpredictable due to the competition between isolates or due to differential interactions with wheat genotypes within the mixture. Nevertheless, it was concluded that the highly resistant varieties and the highly susceptible varieties could be identified using the mixture of three isolates. AIT scores for the isolates mixture test *vs* scores for the individual isolates can be found in Table 8; a subset of RL varieties are shown to highlight the comparison between the mixture of 3 isolates and individual isolates.

Table 8: Wheat yellow rust AIT scores for isolates 24-003, 24-004 and 24-007 in comparison to a test of a mixture of the same three wheat yellow rust isolates.

Isolate code	Host variety	Location	Virulence profile	KWS Extase	Crusoe	KWS Zealum	RGT Illustrious	Skyfall	Graham	LG Redwald	Costello	KWS Cranium	Champion
24-003	Crusoe	Nottinghamshire	1,4,7,17,32,Sp,Wa,Ca,St,Amb,Kr,Ap	1.4	0.9	0.2	0.6	2.2	1.2	1.5	0.0	0.0	0.0
24-004	Gleam	Lincolnshire	1,17,32,Sp	0.0	0.0	0.2	0.0	3.0	3.0	1.5	0.0	0.0	0.0
24-007	KWS Extase	Oxfordshire	1,3,4,7,17,32,Re,Sp,Wa,Ap,St,Amb,Kr,Ca	3.0	3.0	3.0	2.8	3.0	3.0	2.1	0.0	0.0	0.0
Mix 3-4-7			1,3,4,17,32,Sp,Wa,St,Amb,Kr,Ca	3.0	2.4	1.4	1.7	2.8	3.0	2.8	0.0	0.0	0.0

In 2024, Niab also compared two scoring systems for assessing yellow rust on wheat seedlings under controlled growth room conditions. The comparison involved Niab's standard 0–4 scale, which is used to calculate the Average Infection Type (AIT), and the 1–9 scale used by the Global Rust Reference Centre (GRRC). The broader GRRC scale appears to allow finer resolution and greater differentiation between infection types. In most cases, varieties fell into the same general resistance

category across both scales – for example, susceptible varieties were consistently classified as such. However, a few discrepancies were noted: some varieties scored as resistant using the Niab scale were categorised as susceptible using the GRRC scale. This is likely due to the increased granularity of the 1–9 GRRC scale. While applying the GRRC scale initially requires more time per test, scoring efficiency is expected to improve with increased operator familiarity. Overall, the GRRC method may offer improved scoring accuracy and will be considered for future use.

Finally, also in 2024, Niab carried out field-based assessments of yellow rust resistance in winter wheat RL varieties and candidates as young plants to assess breakdown of seedling/all-stage disease resistance under field conditions. Winter wheat genotypes were drilled in mid-May in Cambridge. Randomised plot design used when setting up the trial, with each wheat line being represented by replicated 2 row x 1 m plots. A highly susceptible spreader variety Skyfall was sown between each two experimental plots to facilitate infection. The emerging seedlings were inoculated with the same mixture of three yellow rust isolates used in the growth room test described above, using the talc and spore puffer method approximately 2.5 weeks later. The data obtained from this trial was in good (although not perfect) agreement with data obtained from inoculation of seedlings of the same RL varieties, with the same isolate mixture, in controlled growth room tests. The most highly resistant and highly susceptible varieties, at the seedling stage, were easily distinguishable in both trials. Interestingly, most of the varieties that had intermediate AIT (Average Infection Type) scores in the growth room showed a considerable amount of disease when tested under field conditions, highlighting the role environmental conditions play in plant–pathogen interactions. As yellow rust spores are air-dispersed, we cannot rule-out spores of additional pathotypes being present in the field trial, arriving from surrounding fields. This method will be utilised in the future UKCPVS surveys.

8 Conclusions

The UK yellow rust population continues to show high levels of diversity. In 2024, there were no common pathotypes found between the 25 isolates tested. However, no new virulences for individual disease resistance *Yr* genes were detected in the isolates collected in 2024 using the differential lines tested at the seedling stage. Changes in frequency of virulence for known individual *Yr* resistance genes has fluctuated in 2024 in comparison to previous years. Further testing is required to verify this. Seventeen RL varieties and eight candidate varieties were found to be resistant to all 25 isolates tested at the seedling stage.

2024 saw a large number of brown rust samples submitted to UKCPVS from across the country due to the climatic conditions favouring this disease. As seen in previous years for brown rust, virulence was detected for many of the *Lr* genes tested. No virulence was detected for *Lr2a* and *Lr2b*. Many of the current RL varieties have moderate disease resistance ratings to brown rust at the adult plant stage, whilst all the RL varieties and all candidate varieties with one exception were susceptible to at least one isolate at the seedling stage.

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 continued to monitor this in 2024, however no samples were received.

9 Acknowledgements

Thank you to all the samplers who took part in the 2024 study and provided samples from across the UK.

10 Supplementary Material

Supplementary Table 1: Average infection type (AIT) scores for the selected yellow rust 2024 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 2024 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 3.1 & 3.2: Average infection type (AIT) scores for the selected yellow rust 2024 isolates against the full set of RL and candidate 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 4.1 & 4.2: Average infection type (AIT) scores for the selected brown rust 20234 isolates against the full set of RL and candidate 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 1: Wheat yellow rust UKCPVS differential AIT scores.

Isolate code	Host variety	Avocet 1	Vilmorin 23	Hybrid 46	Avocet 5	Avocet 8	Moro	Avocet 15	Avocet 17	Avocet 32	Apache	Rendezvous	Avocet Sp	Warrior	KWS Sterling	Ambition	Kranich	Evolution	Cadenza
		1	3a+	(3b)4b	5	8	10	15	17	32	7,17+	17+?	Sp	War	Ste	Amb	Kr	Ev	Ca
		1	3	4	5	8	10	15	17	32	Ap	Re	Sp	Wa	St	Amb	Kr	Ev	Ca
24-002	KWS Extase	3	2.8	1.1	0	0	0.2	0	3	2.8	3	1.5	3	2.4	2.1	2.7	1	1	2.7
24-003	Crusoe	3	2.6	3.3	0	0	0	0	3	3	3	1.2	3	3	3	3	3	1	3
24-004	Gleam	3	1.8	3	0	0	0	0	3	3	0.4	0.1	3	1.4	0	0	0	0	2.1
24-007	KWS Extase	3	3	3	0	0.6	0	0	3	3	2.8	2.7	3	3	3	3	3	2	3
24-009	Graham	3	3	3	0	0	0	0	3	3	3	2	3	2.2	3	3	2	0	3
24-014	LG Redwald	3	2.1	1	0	0	0.4	0	3	3	1.4	2.5	3	0.4	0	2.4	3	2	2
24-019	Graham	3	3	1.3	0	0	0	0	2.6	3	3	2.2	3	2.3	0.2	1	3	0	3
24-020	Crusoe	3	2.8	1.7	0	0	0.2	0	2.7	2.4	2.5	1.5	3	2.7	2.1	2.6	2.1	0	2.5
24-023	Gallant	3	2.8	2.4	0	0	0.1	1	3	2.7	3	2.3	3.7	3.6	3.3	3.5	3	2.2	2.5
24-024	KWS Extase	3	3	2	0	0.2	0.1	0	3	3	2.8	2.3	3	2	3	3	3	0	2.2
24-030	SY Cheer	3.5	2.8	0.2	0	0	1.4	0	3.5	3	2.2	2.5	3	2.7	3	2.5	1.5	0.5	3
24-034	Bamford	3	3	2.2	0	0.2	0	1	3	3	2.7	0	3	2.9	1	0	0	3	3
24-036	Skyscraper	3	1	2	0.1	0	0	0	3.7	3	2.4	2.7	3	2.3	3	1.4	1.3	2.5	3.7
24-038	Champion	3	3.2	1.7	0	0	1.2	0	3	3	2	2	3	1	3	0	0	1.7	3
24-040	LG Typhoon	3	2.7	0.8	0	0	0.1	0	2.7	3	1	0	3	1.8	0	0	0	0	2.8
24-042	Mayflower	3	0.6	0	0	0	0	0	3	2.8	2.4	0.3	3	1.6	1.6	1.3	1	0	2.6
24-044	KWS Ladium	3.3	3	2	0	0	0	0	3	3	3	2.2	3	1	3	0.8	0	2.1	2.8
24-045	KWS Extase	3	3	2	0	0	0	0	3	3	3	2.7	3	3	3	3	2.5	0	3
24-046	Crusoe	3	1	1.4	0	0	0.2	0	3	3	3	1.6	3	2.1	3	3	2.8	1	2.3
24-048	LG Redwald	3	2.8	0.4	0	0	0.2	0	3	2.8	1	2	3	1.7	2	0	0.5	2	2.8
24-049	KWS Zyatt	3	1.6	1	0	0	0	0	3	3	2	2	2.9	2	2.7	1.9	2	0	2.4
24-058	Frenzy	3	2	2.7	0	0	0.4	0	3	3	3	2	3	0.2	1.4	0	0.4	1.8	3
24-062	Gleam	3	3	1	0	0	0	0	3	3	2.8	0	3	0	0.3	1.5	0	0	3
24-064	LG Redwald	2	3	2	0	0	0.2	0	3	3	2.7	3	3	3	3	3	3	3	3
24-068	KWS Solitaire	3	2.8	2	0	0	0	0	3	3	2.7	2	3	1.8	3	0.2	1.7	2.5	2.6

Supplementary Table 2: Wheat brown rust UKCPVS differential AIT scores

Isolate code	Host variety	Thatcher *Lr 1*	Thatcher *Lr 2a*	Thatcher *Lr 2b*	Thatcher *Lr 2c*	Thatcher *Lr 3a*	Thatcher *Lr 3bg*	Thatcher *Lr 3ka*	Thatcher *Lr 10*	Thatcher *Lr 13*	Thatcher *Lr 14a*	Thatcher *Lr 15*	*Thatcher Lr 16*	Thatcher *Lr 17*	Thatcher *Lr 20*	Thatcher *Lr 23*	Thatcher *Lr 24*	Thatcher *Lr 26*	Thatcher *Lr 28*	Thatcher *Lr 37*	Armada	Crusoe	Maris Fundin (*Lr 17b*)	Robigus (*Lr28*)	Clement (*Lr26*)	Glasgow (*Lr 1*)	Maris Halberd (*Lr 20*)	Sappo (*Lr 20*)	Sterna (*Lr 3a*)	Stigg (*Lr 24*)	Warrior	KWS Firefly	Theodore
		1	2a	2b	2c	3a	3bg	3ka	10	13	14a	15	16	17	20	23	24	26	28	37	AM	CR	*Lr17b*	*Lr28*	*Lr26*	*Lr1*	*Lr20*	*Lr20*	*Lr3a*	*Lr24*	*Lr24*	*LR28*	*Lr24*
24/001	Mayflower	3	0	0	2	2	3	2	2	3	3	2	2	2	0.5	1.1	2	2	0	2	2	3	3	0	2.8	3	3	1	3	2.4	0	0	0.1
24-008-3	KWS Extase	3	0.6	1.1	1.4	1.5	1.7	3	3	3	3	3	3	3	1.7	2.1	1.8	3	3	3	3.5	3	3	3	3	3.3	0.9	1.0	2.0	1.4	0.5	3	0.5
24-009	Graham	3	0	0	0.2	1	0.2	2	3	3	3	3	2.8	3	2	2.5	1.3	2.3	2	3	3	3	3	2.8	3	3	2	2	1	2.4	0.4	3	0.5
24/013	Crusoe	3	0	0	0	2.8	2	2	2.4	2	2.4	2	2	1.5	1	1	2	1	2	2.4	3	3	2.2	2.5	1	3	0	1.6	3	1.8	0	3	0
24-014	LG Skyscraper	3	0	0.2	1	2	3	2	2	3	3	2	2	3	3	2	2.2	2	0	2	3	2	2	0	2	3	2	3	2	2.3	2	0	2
24/015	KWS Dawsum	3	0.6	0.8	1.9	1.6	0.6	2	3	3	2.9	3	3	3	2	2	1.3	2.9	3	3	3	3	3	3	3	3	1	1.5	0.8	1.4	0	3	0
24-019	Typhoon	3	1	2.2	2.5	2	2.5	3	3	3	3	3	3	3	1.2	2	1.4	2.6	3	3	2.8	3	3	3	3	3	3	1	1	1	1.6	0	3	0
24-030	Crusoe	3	0	0	0	2	2.4	1.7	3	2	3	3	2	3	3	1	1	2	0.2	3	3	3	2	0	2	3	2	3	2	0.4	0	0	0.2
24-051	Bamford	3	0	0.3	1	2	2	3	3	3	3	3	2	2	2	2	3	3	1	2	3	2	3	1.3	2	3	3	3	3	3	1	1	3
24-061	LG Beowulf	3	0	0.7	0.5	0.2	0	1.5	3	2	3	3	2	2.5	1.2	2	1.8	2	3	3	3	3	3	3	3	3	0.3	1	0	1.7	1	3	1.4

Supplementary Table 3.1: Wheat yellow rust RL variety AIT scores

Isolate code	Host variety	Crusoe	Skyfall	RGT Illustrious	Graham	Costello	KWS Zyatt	Gleam	LG Skyscraper	KWS Extase	SY Insitor	LG Astronomer	RGT Wolverine	KWS Cranium	Champion	LG Typhoon	RGT Stokes	RGT Bairstow	RGT Rashid	Mayflower	KWS Dawsum	KWS Palladium	Oxford	RGT Wilkinson	KWS Ultimatum	KWS Zealum	LG Redwald	Bamford	Blackstone	Almara	LG Beowulf	SY Cheer
24-002	KWS Extase	1.2	1.3	1.2	1.5	0	3.5	1	1.3	2.4	2.5	0	2.3	0	0	0	0	0	0	0	0	0	0	1.2	0	1.3	1.1	0	0	0	0	0
24-003	Crusoe	0.9	2.2	0.6	1.2	0.0	3.0	0.9	1.2	1.4	2.5	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.2	1.5	0.0	0.0	0.0	0.0	0.0
24-004	Gleam	0.0	3.0	0.0	3.0	0.0	0.0	3.0	2.2	0.0	2.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.5	0.0	0.0	0.0	0.0	0.0
24-007	KWS Extase	3.0	3.0	2.8	3.0	0.0	3.0	2.7	3.0	3.0	2.3	0.0	3.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.0	2.1	0.0	0.0	0.1	0.0	0.0
24-009	Graham	2.2	2.3	1	1.2	0	3	0.6	1.4	3	1.7	0	2.5	0	0	0	0	0	0	0	0	0	0	2	0	1.4	1.7	0	0	0	0	0
24-014	LG Redwald	0	0.4	0	2	0	2	0.5	1.4	2	2	0	2	0	0	0	0	0	0.2	0	0	0	0	1.3	0	0	2	0.4	0	0	0	0
24-019	Graham	0.2	0.7	0.4	1.6	0	2.4	2	2.1	1.2	1.5	0	2	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0.4	0.2	0	0	0	0
24-020	Crusoe	3	2.8	1.8	2.5	0	3.7	0.7	1.5	2.6	1.5	0.1	2.3	0	0	0	0	0	0	0	0	0	0	1.3	0	1.4	2.1	1	0.2	0	0	0
24-023	Gallant	1.2	2.7	0.9	2.8	0	2.8	1.1	2	1.7	2.5	0	2.6	0	0	0	0	1	0.3	0.2	0	0	0	1.7	0	1.9	2.9	1.5	0	0	0	0
24-024	KWS Extase	0.4	0.6	0	0	0	3	0	1.4	2.7	1	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
24-030	SY Cheer	0.2	1.4	1.3	1.1	0.1	3.2	0.5	1.3	0.4	1.2	0	2.9	0	0	0	0	0	0	0	0	0	0	1.1	0	0	1.5	0	0	0	0	0.1
24-034	Bamford	0	0.8	0	1.1	0	2	2.3	2.3	0	3	0	2.2	0	0	0	0	0	0	0	0	0	0	2.3	0	0	1	0.5	0	0	0.1	0
24-036	Skyscraper	0	0.5	0	1.5	0	1.8	2	1.2	0	2.5	0	1.7	0	0	0	0	0.3	0.1	0	0	0	0	2.8	0	0	3.3	2.8	0	0	0	0
24-038	Champion	0.3	1.5	1.1	3	0	2.7	2.3	3	0	2.1	0	2	0	0	0	0	0	0	0	0	0	0	2.3	0	0.1	3	3	0	0	0	0
24-040	LG Typhoon	0	0.3	0	2	0	0	2.8	0	0	2	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0.2	0	0	0	0	0
24-042	Mayflower	0.3	0	0.1	0.2	0	1.7	0	0.8	0	0	0	1.8	0	0	0	0	0	0	0	0	0	0	0.4	0	0.2	1	0	0	0	0	0
24-044	KWS Ladium	1.2	2.3	1.2	1	0	3.8	1	1.3	2.2	1.3	0	1.5	0	0	0	0	0	0	0	0	0	0	1.2	0	0.8	0.3	0	0	0	0	0
24-045	KWS Extase	0.5	1.1	1	1.3	0	3	0.3	0.6	1.9	0.8	0	2	0	0	0	0	0.2	0	0	0	0	0	1.6	0	0.5	2.5	0	0	0	0	0
24-046	Crusoe	0.8	2	2	0.8	0	3	0.6	1.5	2.4	2.7	0	2.8	0	0	0	0	0	0	0	0	0	0	0.5	0	1	2	0	0	0	0	0
24-048	LG Redwald	0	2	0	3	0	3	3	3	0	3	0.6	2	0	0	0	0.2	0	0.8	0	0	0	0	3	0.2	0	3	2.6	0	0	0	0
24-049	KWS Zyatt	1.5	1.8	1.5	2	0	3	0	0.1	2	1	0	1.5	0	0	0	0	0	0	0.1	0	0	0	0	0	0.4	1.4	0	0	0	0	0
24-058	Frenzy	0	2	1.1	3	0	0.8	2.7	3	0	3	0	2.4	0	0	0	0.8	0	0	0	0	0	0	2.4	0	0	3	1	0	0	0	0
24-062	Gleam	0	2.4	0	3	0	1.5	2	2	0.1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0
24-064	LG Redwald	1.7	2	2	0.4	0	3	0	1.7	2.5	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7	0.2	0	0	0	0
24-068	KWS Solitaire	0	1.7	0.1	0.4	1	1	1.2	0	0	2	1	1.6	0	0	0	0	0	0	0	0	0	0	2	0	0.1	2	1	0	0	0	0

Supplementary Table 3.2: Wheat yellow rust Candidate variety AIT scores

Isolate code	Host variety	Diamond	Energy	Frenzy	KWS Equipe	KWS Solitaire	KWS Beste	KWS Scope	KWS Arnie	KWS Newbie	KWS Vibe	KWS Flute	KWS Vicarage	KWS Mongoos	Riley	Memphis	Rufus	LG Shergar	LG Rebellion	LG Henri	RGT Goldfinch	RGT Hexton	SY Monza	Roma
24-002	KWS Extase	0	0.4	1.5	1.8	1	0.5	0.5	3.7	0	1.1	0	0	0.3	0	0	0	2.4	2.4	0	1.7	2.1	1	0
24-003	Crusoe	0.0	0.2	0.3	1.1	0.1	0.0	0.1	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	2.8	0.0	0.1	0.8	1.0	0.0
24-004	Gleam	0.0	0.0	2.7	0.0	3.0	0.1	3.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0
24-007	KWS Extase	0.0	2.4	2.1	3.0	2.2	2.0	1.3	3.0	0.0	2.7	1.3	0.0	1.3	0.0	0.0	0.2	3.0	3.0	0.0	3.0	2.7	3.0	0.0
24-009	Graham	0	0.7	1.2	0.7	1	0	0.3	2.5	0	0.7	0	0	0.3	0	0	0	2.7	2.2	0	0.5	0.4	1.2	0
24-014	LG Redwald	0	0.5	2	1	0	0	2	2	0	0	2.2	0	0.3	0	0	0	2	0.7	0	1	2	1.5	0
24-019	Graham	0	0	2	0	1.4	0	1.6	2	0	0.1	2.2	0	0	0	0	0	2.2	3	0.1	1.5	3	1	0
24-020	Crusoe	0	0.8	1.2	2.2	1.1	0.4	1.1	3	0	0.5	0.4	0	0.3	0	0	0	3	3.5	0	1.5	1.9	1.4	0
24-023	Gallant	0	2.1	2.6	2.5	2	1.5	2	3	0	0	1.5	0	2.2	0	0	0	3	3.2	0	1.5	3	2.7	0
24-024	KWS Extase	0	0	1.2	3	0.4	0	0.3	3	0	0	0	0	0	0	0	0	2	2	0	2.2	0	0.6	0
24-030	SY Cheer	0	1.5	2	1.5	1	0.7	1	2.1	0	1.3	2	0	0	0	0	0	2.1	0	0	0.5	1	0.4	0
24-034	Bamford	0	1.7	2.7	0	2.5	2.1	2.8	0.1	0	0	3	0	2.5	0	0	0	0.3	0	0	0	1.2	0.2	0
24-036	Skyscraper	0	2	3	0.2	3.1	1.6	2.5	0	0	0.5	3	0	0.3	0	0	0	0	0	0	2.7	3.3	3	0
24-038	Champion	0	2.2	2.4	0	3	1.3	3	0.2	0	2.4	3	0.1	3	0	0	0	0	0	0	1.7	3	2	0
24-040	LG Typhoon	0	0	0.4	0	2.6	0.6	1.7	0	0	0	3	0	0.4	0	0	0	0	0	0	0	3	0.6	0
24-042	Mayflower	0	0	1	1.8	0.2	0.2	0.2	3	0	0.3	0	0	0	0	0	0	0.9	0.4	0	0.3	0.4	0.3	0
24-044	KWS Ladium	0	1.2	1.3	0.5	0.4	0.4	0.3	3	0	0.1	0	0	0	0	0	0	2	1.5	0	1.2	0	0.5	0
24-045	KWS Extase	0	0.2	2	1.4	1.5	0	0.3	3.3	0	0	0.3	0	0.5	0	0	0	3	2.8	0	2	2.2	2	0
24-046	Crusoe	0	0.2	2	2	0	0.3	0	2.5	0	0	0	0	0	0	0	0	2	2.4	0	1.5	0.3	0.5	0
24-048	LG Redwald	0	3	3	0	3	3	3	0	0	0	3	0.4	1.6	0	0	0	0	0	0	0.6	1.6	2.3	0
24-049	KWS Zyatt	0	0.1	1	1.5	0	0.4	1	2.5	0	0.1	0	0	0	0	0	0	2.2	1.5	0	0	0.5	0.3	0
24-058	Frenzy	0	2.8	3	0	3	2	3	0	0	0	3	0	1.1	0	0	0	0	0	0	1.5	3	2	0
24-062	Gleam	0	1	2	0	2.4	2	2.3	0	0	0.2	3	0	0.9	0	0	0	0	0	0	0.1	3.1	3	0
24-064	LG Redwald	0	0	2	2	1.7	0	1	3	0	0.4	0	0	1	0	0	0	3	2	0	2	2	2	0
24-068	KWS Solitaire	0	0.3	1.8	0	3	2	3	0	0	0.2	2.8	0	2	0	0	0	0	0	0	2	1.9	2.4	0

Supplementary table 4.1: Wheat brown rust RL variety AIT scores

Isolate code	Host variety	Crusoe	Skyfall	RGT Illustrious	Graham	Costello	KWS Zyatt	Gleam	LG Skyscraper	KWS Extase	SY Insitor	LG Astronomer	RGT Wolverine	KWS Cranium	Champion	LG Typhoon	RGT Stokes	RGT Bairstow	RGT Rashid	Mayflower	KWS Dawsum	KWS Palladium	Oxford	RGT Wilkinson	KWS Ultimatum	KWS Zealum	LG Redwald	Bamford	Blackstone	Almara	LG Beowulf	SY Cheer
24/001	Mayflower	2.5	3	2	2.4	2.5	3	2	2.2	2	2	0	1.8	2	0	0	3	0	0	2	2	2	0	2.5	2	2	1.5	1.5	3	0.4	2	3
24-008-3	KWS Extase	3.0	1.1	3.0	3.0	3.0	3.0	3.3	3.0	3.0	3.0	3.0	3.0	3.2	3.0	3.0	3.4	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.3	3.0	3.0	3.0	3.0	3.0	3.0
24-009	Graham	3	1.8	3	3	2.7	3	3	2.6	2	2.4	2.9	2.7	3	3	3	2.9	2	2.5	3	3	2.7	2.6	2	2.6	2.3	3	3	3	2.5	2.7	3
24/013	Crusoe	3	3	3	3	2.1	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	2	3	2.6	2	3	3	3	3	3	3
24-014	LG Skyscraper	1.7	3	3	3	3	3	3	3	3	3	0	3	3	0	0	3	0	0	3	3	3	0	2.5	2.7	2.2	2	3	3	0	2	3
24/015	KWS Dawsum	2.7	1	3	3	2.2	3	3	3	3	3	3	2.9	3	3	3	3	3	3	3	3	3	3	3	3	2.2	3	2.8	2.8	3	3	3
24-019	Typhoon	3	1	2.9	3	2.3	3	3	3	3	3	2.8	2	2.8	3	2.3	2.6	2.5	3	2	3	3	3	3	2.7	3	3	3	3	2.2	2	3
24-030	Crusoe	3	3	2.6	3	3	3	3	3	3	3	0	3	3	0	0	3	0	0	3	3	3	0	3	2	3	3	3	3	0	3	3
24-051	Bamford	1.8	2	2.2	3	2.8	3	2	2	2	2	1.6	2	1.8	1.5	1.7	2	1	1.4	2	2	2	1	2	2	2	2	2.2	3	1	3	3
24-061	LG Beowulf	2	0.7	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2.3	2.2	3	3	3

Supplementary Table 4.2: Wheat brown rust candidate variety AIT scores

Isolate code	Host variety	Diamond	Energy	Frenzy	KWS Equipe	KWS Solitaire	KWS Beste	KWS Scope	KWS Arnie	KWS Newbie	KWS Vibe	KWS Flute	KWS Vicarage	KWS Mongoose	Riley	Memphis	Rufus	LG Shergar	LG Rebellion	LG Henri	RGT Goldfinch	RGT Hexton	SY Monza	Roma
24/001	Mayflower	2	3	3	3	3	3	2	2	3	2.2	2	0	2	1.6	2	3	2	2	3	0	2.8	2	3
24-008-3	KWS Extase	1.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.8	3.0	3.0	3.0	3.0	2.8	3.0	3.0	3.0	2.5	2.9	0.3	3.0	2.8	3.0
24-009	Graham	0	3	3	3	2.8	3	3	2.8	2	2.8	3	2.5	3	3	3	3	2.8	2.2	3	0	2.2	2.8	3
24/013	Crusoe	1.4	3	3	3	3	3	3	3	3	3	3	3	3	2	2	3	2.3	1.2	3	0	3	3	3
24-014	LG Skyscraper	1.7	2.4	3	3	3	3	3	3	3	2.7	3	0	3	2.8	3	3	3	1	2.5	0	2	2	2
24/015	KWS Dawsum	0.7	3	3	3	3	3	3	2.9	3	2.9	3	3	3	2.8	3	3	2.5	2.9	2.7	0.3	2.3	3	3
24-019	Typhoon	1	2	2.5	2	2.7	3	3	2.7	3	2.9	3	3	2.8	3	3	3	2.7	2.3	3	0	2.3	3	3
24-030	Crusoe	2	3	3	3	3	3	3	3	3	3	3	0	3	3	3	3	3	2.8	2.6	0	3	3	2
24-051	Bamford	3	3	3	3	3	3	3	3	3	2	3	2	3	3	3	3	3	2.8	2	0	3	3	3
24-061	LG Beowulf	0.3	2	3	3	3	3	3	3	3	2.4	3	3	3	2.8	3	3	3	2.6	3	0	3	3	3

11 Appendix I: 2024 Sample Register

2024 Wheat Yellow Rust Isolate Register

Isolate code	Host Variety	RL Rating 2024/25	Date sampled	County
24/001	KWS Extase	7	28.02.24	Cambridgeshire
24/002	KWS Extase	7	06.03.24	Leicestershire
24/003	Crusoe	8	04.03.24	Nottinghamshire
24/004	Gleam	5	09.04.24	Lincolnshire
24/005	Graham	7	10.04.24	Lincolnshire
24/006	Graham	7	10.04.24	Lincolnshire
24/007	KWS Extase	7	No date	Oxfordshire
24/008	Skyfall	3	No date	Oxfordshire
24/009	Graham	7	No date	Wiltshire
24/010	Gleam	5	10.04.24	Lincolnshire
24/011	Gleam	5	11.04.24	Lincolnshire
24/012	Graham	7	11.04.24	Lincolnshire
24/013	LG Redwald	7	14.04.24	Lincolnshire
24/014	LG Redwald	7	14.04.24	Lincolnshire
24/015	Crusoe	8	16.04.24	Lincolnshire
24/016	Skyfall	3	16.04.24	Lincolnshire
24/017	Fitzroy	NA	17.04.24	Lincolnshire
24/018	KWS Extase	7	No date	No location
24/019	Graham	7	No date	Cambridgeshire
24/020	Crusoe	8	01.04.24	Oxfordshire
24/021	KWS Extase	7	15.04.24	South Yorkshire
24/022	KWS Extase	7	17.04.24	Suffolk
24/023	Gallant	NA	25.04.24	Buckinghamshire
24/024	KWS Extase	7	26.04.24	Leicestershire
24/025	KWS Extase	7	26.04.24	Essex
24/026	SY Insitor	4	30.04.24	Norfolk
24/027	Skyfall	3	30.04.24	Norfolk
24/028	KWS Zyatt	3	30.04.24	Norfolk
24/029	Crusoe	8	01.05.24	Cambridgeshire
24/030	SY Cheer	7	07.05.24	Lincolnshire
24/031	KWS Zyatt	3	09.05.24	Lincolnshire
24/032	KWS Zyatt	3	09.05.24	Lincolnshire
24/033	Skyfall	3	09.05.24	Lincolnshire
24/034	Bamford	7	13.05.24	Cambridgeshire
24/035	KWS Extase	7	14.05.24	Hertfordshire

24/036	LG Skyscraper	7	15.05.24	Gloucestershire
24/037	KWS Extase	7	17.05.25	Suffolk
24/038	Champion	8	17.05.25	Norfolk
24/039	KWS Extase	7	17.05.25	Norfolk
24/040	LG Typhoon	9	17.05.25	Norfolk
24/041	Crusoe	8	17.05.25	Norfolk
24/042	Mayflower	9	17.05.25	Norfolk
24/043	KWS Zyatt	3	20.05.24	Essex
24/044	KWS Ladium (spring wheat)	7	21.05.24	Lincolnshire
24/045	KWS Extase	7	23.05.24	Norfolk
24/046	Crusoe	8	23.05.24	Yorkshire
24/047	KWS Extase	7	23.05.24	Yorkshire
24/048	LG Redwald	7	29.05.24	Fife
24/049	KWS Zyatt	3	03.06.24	Essex
24/050	KWS Zyatt	3	12.06.24	Lincolnshire
24/051	LG Redwald	7	12.06.24	Lincolnshire
24/052	KWS Extase	7	12.06.24	Lincolnshire
24/053	Gleam	5	12.06.24	Lincolnshire
24/054	SY Cheer	7	12.06.24	Lincolnshire
24/055	KWS Skateum	NA	12.06.24	Lincolnshire
24/056	LG Rebellion	NA	12.06.24	Lincolnshire
24/057	LG Shergar	NA	12.06.24	Lincolnshire
24/058	Frenzy	NA	12.06.24	Lincolnshire
24/059	RGT Wolverine	4	12.06.24	Lincolnshire
24/060	KWS Arnie	NA	12.06.24	Lincolnshire
24/061	Skyfall	3	12.06.24	Lincolnshire
24/062	Gleam	5	21.06.24	Aberdeen
24/063	KWS Palladium	9	24.06.24	Cambridgeshire
24-064	LG Redwald	7	24.06.24	Cambridgeshire
24-065	KWS Extase	7	24.06.24	Cambridgeshire
24-066	Bamford	7	24.06.24	Cambridgeshire
24-067	KWS Zyatt	3	25.06.27	Belfast
24-068	KWS Solitaire	NA	27.06.24	Fife

2024 Wheat Brown Rust Isolate Register

Isolate No	Host Variety	RL rating	Date sampled	County
24-001	Mayflower	6	25.03.24	Lincolnshire
24-002	KWS Zealum	5	25.03.24	Lincolnshire
24-003	KWS Cranium	4	25.03.24	Lincolnshire
24-004	Crusoe	3	25.03.24	Lincolnshire
24-005	Champion	5	25.03.24	Lincolnshire
24-006	KWS Scope	5	25.03.24	Lincolnshire
24-007	KWS Flute	5	25.03.24	Lincolnshire
24-008	KWS Extase	6	05.04.24	Norfolk
24-009	Graham	5	No date	Cambridgeshire
24-010	Crusoe	3	30.04.24	Norfolk
24-011	Crusoe	3	30.04.24	Norfolk
24-012	Crusoe	3	01.05.24	Cambridgeshire
24-013	Crusoe	3	15.05.24	Kent
24-014	LG Skyscraper	5	15.05.24	Gloucestershire
24-015	KWS Dawsum	7	17.05.24	Norfolk
24-016	KWS Dawsum	7	17.05.24	Cambridgeshire
24-017	KWS Extase	6	17.05.24	Cambridgeshire
24-018	KWS Parkin	NA	30.05.24	Norfolk
24-019	LG Typhoon	6	03.06.24	Norfolk
24-020	Bolinder ()	NA	12.06.24	Lincolnshire
24-021	Costello	NA	12.06.24	Lincolnshire
24-022	KWS Dawsum	7	12.06.24	Lincolnshire
24-023	KWS Vicarage	NA	12.06.24	Lincolnshire
24-024	Mayflower	6	12.06.24	Lincolnshire
24-025	Energy	NA	12.06.24	Lincolnshire
24-026	RGT Wilkinson	5	12.06.24	Lincolnshire
24-027	RGT Hexton	NA	12.06.24	Lincolnshire
24-028	KWS Flute	NA	12.06.24	Lincolnshire
24-029	LG Typhoon	6	12.06.24	Lincolnshire
24-030	Crusoe	3	23.06.24	Northamptonshire
24-031	Crusoe	3	23.06.24	Cambridgeshire
24-032	Crusoe	3	23.06.24	Gloucestershire
24-033	Fitzroy	NA	24.06.24	Cambridgeshire
24-034	Champion	5	24.06.24	Cambridgeshire
24-035	LG Beowulf	5	24.06.24	Cambridgeshire
24-036	KWS Dawsum	7	24.06.24	Cambridgeshire
24-037	KWS Extase	6	24.06.24	Cambridgeshire
24-038	Crusoe	3	24.06.24	Buckinghamshire

24-039	LG Tapestry	NA	24.06.24	Cambrideshire
24-040	LG Beowulf	5	26.06.24	Norfolk
24-041	KWS Palladium	5	26.06.24	Norfolk
24-042	Crusoe	3	26.06.24	Norfolk
24-043	SY Cheer	6	26.06.24	Norfolk
24-044	Champion	5	26.06.24	Norfolk
24-045	KWS Extase	6	26.06.24	Norfolk
24-046	Loxton	NA	26.06.24	Norfolk
24-047	Mayflower	6	26.06.24	Norfolk
24-048	KWS Colloseum	NA	26.06.24	Norfolk
24-049	LG Skyscraper	5	26.06.24	Norfolk
24-050	LG Beowulf	5	01.07.24	Lincolnshire
24-051	Bamford	6	01.07.24	Lincolnshire
24-052	Rufus	NA	01.07.24	Lincolnshire
24-053	Theodore	NA	01.07.24	Lincolnshire
24-054	Champion	5	01.07.24	Lincolnshire
24-055	Crusoe	3	04.07.24	North Yorkshire
24-056	KWS Parkin	NA	04.07.24	Lincolnshire
24-057	LG Typhoon	6	04.07.24	Lincolnshire
24-058	Champion	5	04.07.24	Lincolnshire
24-059	LG Typhoon	6	04.07.24	Lincolnshire
24-060	Graham	5	05.07.24	East Yorkshire
24-061	LG Beowulf	5	05.07.24	East Yorkshire
24-062	DSV 321121 (Casely)	NA	08.07.24	Fife
24-063	Crusoe	3	15.07.24	Lincolnshire
24-064	SY Insitor	6	15.07.24	Lincolnshire
24-065	Crusoe	3	15.07.24	Lincolnshire

12 References

Ali, S. et al. 2014. “Origin, Migration Routes and Worldwide Population Genetic Structure of the Wheat Yellow Rust Pathogen *Puccinia striiformis* f. sp. *tritici*.” *PLoS Pathogens* 10(1):e1003903.

Ali, S. et al. 2017. “Yellow Rust Epidemics Worldwide Were Caused by Pathogen Races from Divergent Genetic Lineages.” *Frontiers in Plant Science* 8:1057. Retrieved (http://journal.frontiersin.org/article/10.3389/fpls.2017.01057).

Hovmøller, M. S. et al. 2016. “Replacement of the European Wheat Yellow Rust Population by New Races from the Centre of Diversity in the Near-Himalayan Region.” *Plant Pathology* 65:402–11. Retrieved (http://dx.doi.org/10.1111/ppa.12433).

Hovmøller, M. S., A. F. Justesen, and J. K. M. Brown. 2002. “Clonality and Long-Distance Migration of *Puccinia striiformis* f. sp. *tritici* in North-West Europe.” *Plant Pathology* 51(1):24–32. Retrieved (http://dx.doi.org/10.1046/j.1365-3059.2002.00652.x).

Hubbard, A. J. et al. 2015. “Field Pathogenomics Reveals the Emergence of a Diverse Wheat Yellow Rust Population.” *Genome Biology* 16:23.

Hubbard, A., L. Pritchard, and S. Holdgate. 2016. *United Kingdom Cereal Pathogen Virulence Survey 2016 Annual Report Part 1: Wheat Yellow Rust, Wheat Powdery Mildew and Barley Powdery Mildew*.

Hubbard, A., S. Wilderspin, and S. Holdgate. 2017. *United Kingdom Cereal Pathogen Virulence Survey 2017 Annual Report*.