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# United Kingdom Cereal Pathogen Virulence Survey

# 2014 Annual Report

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## FOREWORD

As regular readers will notice, the format of the UKCPVS annual report is slightly different to previous years. In an effort to deliver information as quickly as possible to our stakeholders, we have decided to move the schedule of reporting from June to the autumn. Previously, isolates would be received one year, characterised, virulences reported at the stakeholders meeting the following spring to highlight any signs of a race change, and then adult plant tests would be done in the summer. These adult plant results would not be reported until the Stakeholders Meeting the following spring, with the annual report containing these data not being published until June (a full two years post sample submission). This information is important to highlight the effects of any new races on UK varieties in a scenario more reminiscent of on-farm conditions. In order to make sure that the relevant information is disseminated as quickly as possible, but maintaining the input of our interpretation, we propose to move the annual report forward to the autumn, thereby reducing the time to 18 months after the original samples are received. In addition to getting the information out faster, we hope the reader will be able to keep track of the isolates used as the reports will now only focus on isolates from one year, instead of two years as has previously been the case. This report contains all of the information (seedling and adult plant tests) on isolates collected in 2013. The future plan is for a report containing all information on isolates collected in 2014 to be published in autumn 2015. The Stakeholders Meeting will still be a key date in the calendar for the early seedling test results which normally alert us to the first signs of a change in race. As always, feedback on the reports is always welcome. The mildew results have also been omitted from this report as there are no adult plant trials for the mildew, so all results have been published in the previous report from June 2014.

Dr Sarah Holdgate
Project Manager

# 1. Abstract

The UK Cereal Pathogen Virulence Survey (UKCPVS) was established in 1967 to monitor the pathogen populations which could have a detrimental effect on UK crop production. In its 47th year the survey continues to monitor some of the key UK arable diseases and the characterisation of isolates collected in 2013 are reported. A large number of yellow rust samples were received by the UKCPVS in 2013 despite low levels of disease. The low disease levels led to a more modest number of brown rust samples being received. No new virulence changes were detected in either yellow or brown rust, however small variations in the frequency of existing virulences were detected in the brown rust population. Adult plant field trials using isolates collected in 2013 for yellow rust and brown rust were conducted in 2014. The yellow rust trial contained isolates typical of the Warrior yellow rust population and one isolate which appeared to be similar to the Solstice race. Differences were seen in the reaction of Rendezvous and related varieties to the two groups of isolates, with the previously susceptible variety Brigadier displaying apparent resistance when challenged with the Warrior isolates. These results have helped to explain the increase in the yellow rust resistance rating on the Recommended List for the variety KWS Santiago. Brown rust trials were complicated by natural infection making it difficult to draw firm conclusions on variety-isolate interactions.

# 2. Introduction

## 2.1. General Introduction to the United Kingdom Cereal Pathogen Virulence Survey (UKCPVS)

### 2.1.1. 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 thrive. Warm summers can also lead to the presence of brown (leaf) rust at the end of the season which can be serious if left unchecked on susceptible cultivars. Current methods of control are based principally on fungicidal inputs, however for the latter two diseases, host resistance plays a part due to the high levels offered in some UK wheat varieties. Host resistance is, however, subject to change and should be monitored as part of a virulence survey due 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. The survey was initiated in response to an unexpected outbreak of yellow rust on the previously resistant variety Rothwell Perdix.

### 2.1.2. Targets of the Survey and Pipeline for Pathotyping

#### 2.1.2.1. Targets

Known originally as the Physiologic Race Survey of Cereal Pathogens, the survey was established 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*), oat crown rust, oat leaf spot and oat mildew. Over time, the list of target species has reduced but the principals still remain the same and in its 47$^{th}$ year the survey continues to provide information to growers, breeders and other interested parties on the population of some of these important plant pathogens. The survey currently limits its activities to monitoring the populations of wheat yellow and brown rust and wheat and barley mildew. A close eye is also kept on barley yellow rust, which although currently rare, has been a problem in the past.

#### 2.1.2.2. Pipeline of characterisation

The UKCPVS monitors the pathogen population through samples of diseased leaves which are sent in by post. Once an infected leaf sample is received, the pathogen spores from the pustules are multiplied and stored for further testing. At the end of July when all the samples have been received, the list of samples is scrutinised and out of all of the samples received, at least 25 are selected for further characterisation using a differential test. Samples are chosen based on the current host resistance rating and geographic location. The differential tests follow a worldwide standard procedure where the different isolates of rust are inoculated onto a set of different

varieties ("differentials") whose underlying resistance genes are known. 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 also 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. Following the differential tests, five of the 25 characterised isolates are tested in field trials to assess the reactions of the varieties currently on the Recommended List (RL). This will establish how any new races affect resistance ratings and this early information can help growers and agronomists plan disease management programmes.

### 2.1.3. Key virulence changes over the years

Pathogen populations are always evolving but it is only since the UKCPVS was set up that these changes have been monitored. Changes in the rust and mildew populations have tended to follow a similar pattern in their emergence, with higher than expected levels of disease being seen in one or two locations in the UK at low frequencies. Depending on the prevalence of the host variety, the new races appeared in one year and then slowly increased until the following season when it was seen more widely. Eventually, these new races would start to be more widely dispersed and therefore noted in virulence surveys of other European countries, such as France, Germany and Denmark. Some of the key race changes for yellow rust are summarised in Table 1.

Table 1: Key wheat yellow rust race changes

| Year | Variety | Key Resistance Gene Combination |
|---|---|---|
| 1988 | Hornet | *Yr6, Yr9* |
| 1994 | Brigadier | *Yr9, Yr17* |
| 1996 | Madrigal | *Yr6, Yr9, Yr17* |
| 2000 | Robigus | *Yr9, Yr17, Yr32* |
| 2008 | Solstice | *Yr6, Yr9, Yr17, Yr32* |
| 2011 | Warrior | *Yr6, Yr7, Yr9, Yr17, Yr32, Spaldings Prolific* |

Race changes for yellow rust have been associated with the accumulation of virulences for different yellow rust resistance genes. The additional virulence was normally for a resistance gene which had been overcome before, but importantly not in this combination. For example, virulence for the resistance gene *Yr9* had been seen as far back as 1967, but it was only in combination with *Yr6* in 1988. The European yellow rust populations were widely publicised as being clonal and reproducing asexually (Hovmøller et al., 2002) and this step-wise mutation pattern agrees with these findings. The most recent change in the yellow rust population is the emergence of the Warrior race. Whilst the virulence profile appears to be another accumulation, with additional virulence for the gene *Yr7* and the variety Spaldings Prolific, there were other signs that this race

was different to race changes seen before. The disease produced looked slightly different in the field, with abundant production of the sexual stage spores (teliospores) and in contrast to previous race changes, the Warrior race was detected in multiple locations across Europe in the same year. Subsequent molecular genotyping of isolates of the Warrior race has shown that this new race was not related to the UK isolates, and therefore not a stepwise mutation such as before, but rather an exotic incursion (Hubbard *et al*. In Press).

In addition to highlighting changes in the pathogen population using the differential seedling tests, the UKCPVS also performs trials to assess the reaction of current UK Recommended List varieties to the newest isolates, including those which are suspected to be of a new race. In the past, the reaction of varieties has been severe to new races, with catastrophic crashes in resistance ratings as so-called major genes have been overcome. The Hornet race caused the RL yellow rust rating for Hornet drop from a 9 to a 2 in the space of a year, and a similar drop was seen for Brigadier (9 to 2). More recent race changes have seen more modest drops in ratings, for example Solstice changed from a 9 to a 4 in response to the Solstice race and Beluga from a 9 to a 5 and Claire from a 9 to a 6, both in response to the Warrior race. This suggests that some of the current varieties have other background resistance unaffected by the new races which soften the breakdown. It is for this reason that it is difficult to predict the likely effect of a new race on different varieties and that a complete breakdown should never be assumed.

### 2.2. Disease summary for 2012–13

Levels of yellow and brown rust in the UK are dependent on environmental conditions in the autumn and winter as well as spore load from the previous season. A cool and wet autumn in 2012, followed by cold and drier winter into 2013 meant that levels of yellow and brown rust were lower than in previous years. Results from the annual Defra survey of commercial crops (reported through CropMonitor.com) showed that only 0.7% of all surveyed crops were affected by yellow rust, much lower than the 6% affected in 2011 when the Warrior population arrived (Anon, 2013). Yellow rust was only found in the West Midlands and South East of England. Brown rust was also found in 0.7% of the surveyed crop, confined only to the East and South West regions. Again, levels were much lower than in 2012 where 17.2% of the surveyed crops were affected.

# 3. Materials and methods

## 3.1. Collection of Samples and Preparation of Isolates: Wheat Yellow and Brown Rust

Infected wheat leaves were received from growers, agronomists and trials operators for the Recommended List trials. Spores from the infected samples were transferred onto plants of the universally susceptible varieties Victo (wheat yellow rust) and 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.

## 3.2. Characterisation of Isolates using Differential Tests

Seedlings of the differential set were inoculated with spores from the new isolates, using a complete set of plants for each isolate under test. The differentials used and the resistance genes they carry are listed in Table 2 and Table 7. Each differential is represented by 10 plants with no replication. This is to ensure that the maximum amount information is obtained using the small amount of spores available. Approximately 14 days post inoculation, the plants were scored using a 0–4 scale. The scores for each of the 10 plants per differential were then converted into an average infection type score (a.i.t.). An average infection type score of 0–2.5 indicates an incompatible (avirulent) reaction, 2.5–3.0 represents a borderline reaction and should be treated with caution as it is difficult to be certain whether the reaction is one of virulence or avirulence, and scores of 3–4 indicate a compatible reaction, and the isolate is virulent on that differential.

## 3.3. Characterisation of Isolates using Adult Plant Field Trials

Varieties from the current Recommended List, Recommended List candidate and UKCPVS control varieties were hand sown into tussock trials to evaluate the isolate-variety interaction at the adult plant stage under field conditions. Each trial consisted of three replicates and one trial was used for each of the isolates under test. Susceptible "spreader" variety tussocks were sown at multiple points throughout the trial and these were inoculated with the individual isolates in the spring using infected seedlings produced under controlled environment conditions. Assessments were made at the onset of disease development on the upper leaves until senescence.

## 3.4. Characterisation of Isolates using Variety Seedlings

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 inoculated and assessed in the same way as the differential tests described in 4.2.

# 4. Results and Discussion

## 4.1. Wheat Yellow Rust

### 4.1.1. Samples Received

In 2013, the UKCPVS received 178 samples of wheat yellow rust from 16 different counties across the UK, with the majority of samples being received from East Anglia (Figure 1). The full list of samples received is given in Appendix 1.


Figure 1: Map of the UK with the number of samples of wheat yellow rust received in 2013 from the different counties.

This very high number of samples is surprising considering the low levels of disease in untreated crops nationally and reflects the increased effort in collecting samples which has included obtaining samples through the HGCA Recommended List trials. In addition, the NIAB-TAG network

sites provided approximately half of all of the samples received, helping to ensure that the samples were from a wider geography than in previous years. Samples were received from a wide range of varieties with RL ratings of 4 and the unclassified varieties such as Torch and Oakley, through to the more resistant varieties rated 8 and above. As in previous years the survey was particularly interested in samples from varieties with a high RL rating as rust on these varieties could indicate a change in the pathogen population. The host varieties listed 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 mislabelled. 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. Samples that were of note for the UKCPVS were from the varieties Cougar, Crusoe, JB Diego, KWS Sterling and Mulika which all have RL ratings of 8 or above (2013/14 ratings).

### 4.1.2. Pathotyping of Isolates

Twenty five isolates were selected for further pathotyping (Table 2). The isolates were selected based on their county of origin and the resistance rating of the host. Isolates from known susceptible varieties were also selected to investigate whether the same or similar isolates are on the different varieties across the resistance spectrum. Isolates were assessed for their reactions on a differential set and the average infection type (a.i.t.) scores are listed in Table 2. Using the a.i.t. scores, pathotypes for each of the isolates were determined (Table 3).

The differential tests showed that the virulence profile indicative of the Warrior pathotype is widely found, the key indicator being virulence for the variety Spaldings Prolific. Virulence for the resistance genes *Yr1*, *Yr2*, *Yr3*, *Yr4*, *Yr6*, *Yr9* and *Yr32*, as well as Robigus and Solstice was found in almost every isolate tested, suggesting that these virulences are now fixed in the population. Virulence to *Yr7* was seen in most isolates, although about 40% of these were borderline suggesting there is still a degree of variation in the population for virulence to this gene. Within the group of isolates classified as the Warrior pathotype, there is variation in virulence to varieties Warrior and Ambition. There is also variation in the reaction to the *Yr17* differentials. Three differentials are used in the tests. The first is a near-isogenic line Avocet-Yr17, which is the universally susceptible variety Avocet with the *Yr17* gene added into it. The second is the variety Rendezvous, which is thought to carry the gene *Yr17*. The third differential line is the line VPM1. This is one of the parents of the variety Rendezvous and also carries the gene *Yr17*. In the results of these tests it is common to see isolates which are virulent on the Avocet line and VPM1, but not Rendezvous suggesting that there is an additional resistance gene or genes in Rendezvous which some isolates are not able to overcome. This phenomenon has been reported by other yellow rust surveys (X. Chen, *pers. comm.*). Using the variation in virulence to Warrior, Ambition and Rendezvous, the Warrior isolates have been divided into four different pathotype groups in Table 3.

Table 2: Average infection type (a.i.t.) scores for the 25 selected isolates against the UKCPVS differential set. Yellow shading indicates a compatible reaction, orange indicates borderline. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Numbers next to the differential variety name indicate the known resistance genes carried by the variety. + indicates additional uncharacterised resistance genes present in the differential line.

| Isolate No. | Host Variety | *Yr1* | *Yr2* | *Yr3a+* | *Yr3a+* | *Yr3b,Yr4b* | *Yr5* | *Yr6* | *Yr2,Yr6* | *Yr2,Yr6* | *Yr7* | *Yr7* | *Yr6,Yr7* | *Yr7,Yr17* | *Yr8* | *Yr9* | *Yr9* | *Yr10* | *Yr15* | *Yr17* | *Yr17* | *Yr17* | *Yr24* | *Yr2,Yr25* | *Yr25* | *Yr32* | *Yr32* | *Yr32* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Chinese 166 | Kalyansona | Vilmorin 23 | Nord Desprez | Hybrid 46 | Avocet Yr5 | Avocet Yr6 | Heines Kolben | Heines Peko | Lee | AV x Yr 7 NIL | Cadenza | Apache | Compair | Kavkaz x 4 fed | Clement | Moro | AVS x yr15 | VPM 1 | Rendezvous | AV x Yr17 | Avocet Yr24 | Heines VII | Strubes Dickkopf | Carstens V | Talon | Av x Yr32 | Spaldings Prolific | Suwon Omar | Robigus | Solstice | Warrior | KWS Sterling | Claire | Ambition | Stigg | Crusoe | Vuka |
| 13/20 | KWS Rowan | 3.0 | 3.1 | 3.0 | 3.0 | 4.0 | 0.0 | 3.0 | 3.0 | 3.5 | 3.0 | 4.0 | 2.9 | 3.0 | 0.0 | 3.0 | 3.0 | 0.0 | 0.0 | 3.0 | 2.0 | 3.0 | 0.0 | 3.5 | 3.0 | 4.0 | 3.0 | 3.5 | 3.0 | 4.0 | 3.5 | 3.5 | 2.0 | 1.8 | 3.0 | 1.0 | 0.0 | 0.0 | 3.0 |
| 13/21A | Solstice | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 0.0 | 4.0 | 3.0 | 3.0 | 1.1 | 2.1 | 0.0 | 0.0 | 0.0 | 3.1 | 3.0 | 0.0 | 0.0 | 4.0 | 4.0 | 3.0 | 0.0 | 3.0 | 3.0 | 4.0 | 3.5 | 3.5 | 0.0 | 3.1 | 4.0 | 4.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 13/23 | KWS Sanitago | 3.0 | 3.0 | 3.0 | 2.7 | 4.0 | 0.0 | 3.0 | 3.0 | 4.0 | 0.7 | 2.2 | 0.0 | 0.0 | 0.0 | 3.0 | 2.7 | 0.0 | 0.0 | 4.0 | 4.0 | 3.9 | 0.0 | 3.0 | 3.0 | 4.0 | 4.0 | 3.5 | 0.0 | 3.0 | 3.5 | 3.5 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 13/24 | KWS Kielder | 3.1 | 3.2 | 3.1 | 3.2 | 3.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 3.0 | 0.0 | 3.2 | 3.2 | 0.0 | 0.0 | 3.0 | 2.2 | 3.0 | 0.0 | 3.0 | 3.2 | 3.2 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 3.1 | 1.8 | 0.2 | 2.5 | 0.6 | 0.0 | 0.0 | 3.5 |
| 13/26 | Horatio | 3.0 | 4.0 | 3.5 | 3.9 | 3.5 | 0.0 | 4.0 | 3.0 | 3.5 | 3.0 | 3.2 | 3.5 | 3.0 | 0.0 | 4.0 | 4.0 | 0.0 | 0.0 | 3.0 | 1.2 | 3.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 4.0 | 3.0 | 3.5 | 3.0 | 3.5 | 4.0 | 0.0 | 2.5 | 3.0 |
| 13/29 | Solstice | 3.1 | 4.0 | 3.0 | 3.5 | 3.1 | 0.0 | 3.2 | 3.0 | 4.0 | 3.2 | 3.2 | 3.0 | 3.0 | 0.0 | 4.0 | 3.0 | 0.0 | 0.0 | 4.0 | 2.8 | 4.0 | 0.0 | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.1 | 3.1 | 3.1 | 2.1 | 2.6 | 3.1 | 0.4 | 0.0 | 0.0 | 3.0 |
| 13/61 | KWS Sterling | 3.2 | 4.0 | 3.5 | 3.5 | 3.1 | 0.0 | 4.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 0.0 | 4.0 | 3.0 | 0.0 | 0.0 | 4.0 | 3.3 | 3.2 | 0.0 | 3.0 | 3.0 | 3.5 | 4.0 | 3.0 | 0.0 | 3.2 | 4.0 | 3.3 | 2.0 | 3.0 | 3.2 | 0.1 | 0.0 | 0.1 | 4.0 |
| 13/65 | Claire | 3.3 | 4.0 | 4.0 | 3.8 | 3.5 | 0.1 | 4.0 | 3.0 | 3.1 | 3.5 | 3.4 | 3.0 | 3.0 | 0.0 | 4.0 | 3.3 | 0.0 | 0.0 | 2.7 | 1.9 | 3.0 | 0.0 | 4.0 | 4.0 | 4.0 | 3.5 | 3.2 | 3.1 | 3.3 | 4.0 | 3.0 | 3.3 | 3.0 | 4.0 | 4.0 | 0.0 | 2.2 | 3.0 |
| 13/80 | JB Diego | 3.0 | 3.0 | 3.0 | 4.0 | 3.0 | 0.0 | 3.0 | 3.0 | 3.5 | 3.0 | 3.1 | 3.0 | 3.0 | 0.0 | 3.0 | 3.0 | 0.0 | 0.0 | 4.0 | 3.0 | 3.0 | 0.0 | 1.8 | 3.0 | 4.0 | 4.0 | 3.0 | 3.5 | 3.0 | 4.0 | 3.2 | 2.1 | 3.0 | 3.0 | 0.1 | 0.0 | 0.0 | 3.2 |
| 13/88 | JB Diego | 3.0 | 3.5 | 3.2 | 3.5 | 3.0 | 0.0 | 3.2 | 3.0 | 3.1 | 3.0 | 4.0 | 3.0 | 3.0 | 0.0 | 4.0 | 3.1 | 0.0 | 0.0 | 3.0 | 3.0 | 3.0 | 0.0 | 3.0 | 4.0 | 4.0 | 3.2 | 3.2 | 3.0 | 3.0 | 3.2 | 3.2 | 3.0 | 3.0 | 3.2 | 4.0 | 0.0 | 0.8 | 4.0 |
| 13/92 | Gallant | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 0.0 | 3.0 | 3.0 | 3.1 | 3.0 | 4.0 | 3.1 | 2.9 | 0.0 | 4.0 | 3.2 | 0.0 | 0.0 | 3.0 | 2.0 | 3.1 | 0.1 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 3.0 | 2.7 | 1.9 | 3.0 | 3.0 | 0.0 | 1.1 | 4.0 |
| 13/98 | Mulika | 4.0 | 4.0 | 3.2 | 4.0 | 3.0 | 0.0 | 4.0 | 3.0 | 3.0 | 3.0 | 3.1 | 4.0 | 3.0 | 0.0 | 3.2 | 3.2 | 0.0 | 0.0 | 3.0 | 2.0 | 4.0 | 0.0 | 3.0 | 3.5 | 4.0 | 3.2 | 4.0 | 3.0 | 4.0 | 3.1 | 3.0 | 1.8 | 2.8 | 3.1 | 0.0 | 0.0 | 0.0 | 3.0 |
| 13/104 | KWS Podium | 3.2 | 3.0 | 4.0 | 4.0 | 3.0 | 0.0 | 3.0 | 3.5 | 4.0 | 3.0 | 4.0 | 3.0 | 3.0 | 0.0 | 3.5 | 3.0 | 0.0 | 0.0 | 3.0 | 3.0 | 3.2 | 0.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.5 | 3.0 | 2.8 | 2.4 | 3.0 | 3.0 | 0.0 | 2.1 | 4.0 |
| 13/105 | Cordiale | 3.0 | 3.0 | 3.2 | 4.0 | 3.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.1 | 3.3 | 3.0 | 3.0 | 0.0 | 3.2 | 3.1 | 0.0 | 0.0 | 3.0 | 2.3 | 3.0 | 0.0 | 3.1 | 4.0 | 4.0 | 3.5 | 4.0 | 4.0 | 3.5 | 3.0 | 3.0 | 2.0 | 2.1 | 3.0 | 1.5 | 0.0 | 0.0 | 3.5 |

| Isolate No. | Host Variety | *Yr1* | *Yr2* | *Yr3a+* | *Yr3a+* | *Yr3b,Yr4b* | *Yr5* | *Yr6* | *Yr2,Yr6* | *Yr2,Yr6* | *Yr7* | *Yr7* | *Yr6,Yr7* | *Yr7,Yr17* | *Yr8* | *Yr9* | *Yr9* | *Yr10* | *Yr15* | *Yr17* | *Yr17* | *Yr17* | *Yr24* | *Yr2,Yr25* | *Yr25* | *Yr32* | *Yr32* | *Yr32* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Chinese 166 | Kalyansona | Vilmorin 23 | Nord Desprez | Hybrid 46 | Avocet Yr5 | Avocet Yr6 | Heines Kolben | Heines Peko | Lee | AV x Yr 7 NIL | Cadenza | Apache | Compair | Kavkaz x 4 fed | Clement | Moro | AVS x yr15 | VPM 1 | Rendezvous | AV x Yr17 | Avocet Yr24 | Heines VII | Strubes Dickkopf | Carstens V | Talon | Av x Yr32 | Spaldings Prolific | Suwon Omar | Robigus | Solstice | Warrior | KWS Sterling | Claire | Ambition | Stigg | Crusoe | Vuka |
| 13/110 | Denman | 4.0 | 4.0 | 3.0 | 3.0 | 3.0 | 0.0 | 4.0 | 3.0 | 4.0 | 2.6 | 2.8 | 3.2 | 3.0 | 0.0 | 4.0 | 2.7 | 0.0 | 0.0 | 3.0 | 2.3 | 3.0 | 0.0 | 3.0 | 3.2 | 4.0 | 3.0 | 3.5 | 4.0 | 3.0 | 4.0 | 3.5 | 3.0 | 3.1 | 3.1 | 3.0 | 0.0 | 2.9 | 4.0 |
| 13/127 | JB Diego | 3.0 | 3.0 | 3.1 | 3.0 | 4.0 | 0.0 | 4.0 | 3.0 | 4.0 | 3.0 | 4.0 | 3.0 | 3.0 | 0.0 | 4.0 | 2.6 | 0.0 | 0.0 | 3.0 | 2.1 | 3.0 | 0.0 | 3.1 | 3.2 | 3.0 | 3.2 | 3.1 | 3.0 | 3.1 | 3.1 | 3.1 | 0.5 | 2.5 | 3.0 | 0.1 | 0.0 | 0.0 | 3.0 |
| 13/128 | Cordiale | 3.0 | 3.0 | 3.0 | 3.1 | 3.1 | 0.0 | 3.2 | 3.0 | 3.1 | 3.0 | 3.1 | 2.9 | 2.1 | 0.0 | 3.0 | 3.0 | 0.0 | 0.0 | 3.2 | 2.5 | 3.0 | 0.0 | 3.0 | 3.1 | 4.0 | 4.0 | 3.1 | 3.0 | 3.0 | 3.1 | 3.1 | 0.7 | 0.2 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 13/134 | Cocoon | 3.0 | 3.0 | 3.0 | 3.2 | 4.0 | 0.0 | 4.0 | 3.0 | 4.0 | 2.5 | 3.0 | 2.2 | 0.0 | 0.0 | 3.5 | 3.0 | 0.0 | 0.0 | 4.0 | 2.5 | 3.5 | 0.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.2 | 3.1 | 3.2 | 4.0 | 4.0 | 2.2 | 1.4 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 |
| 13/145 | KWS Santiago | 3.3 | 3.0 | 3.0 | 3.0 | 3.0 | 0.0 | 4.0 | 3.1 | 3.0 | 2.7 | 3.0 | 2.0 | 2.3 | 0.0 | 3.2 | 3.2 | 0.0 | 0.0 | 3.0 | 3.1 | 3.2 | 0.0 | 3.0 | 4.0 | 4.0 | 3.5 | 4.0 | 3.1 | 3.1 | 3.0 | 4.0 | 1.7 | 1.9 | 3.1 | 0.0 | 0.0 | 0.0 | 3.5 |
| 13/160 | Paragon | 3.1 | 3.1 | 3.5 | 3.1 | 3.2 | 0.0 | 4.0 | 3.0 | 3.2 | 3.0 | 3.0 | 3.0 | 3.0 | 0.0 | 3.1 | 3.0 | 0.0 | 0.0 | 3.1 | 3.1 | 3.0 | 0.0 | 3.3 | 4.0 | 4.0 | 3.3 | 3.5 | 0.0 | 4.0 | 3.5 | 4.0 | 0.0 | 2.9 | 3.1 | 0.0 | 0.0 | 0.0 | 3.0 |
| 13/166 | Invicta | 3.1 | 3.0 | 3.1 | 3.0 | 3.5 | 0.0 | 4.0 | 3.0 | 3.0 | 3.5 | 4.0 | 3.5 | 3.0 | 0.0 | 4.0 | 3.2 | 0.0 | 0.0 | 4.0 | 2.8 | 3.5 | 0.0 | 3.0 | 4.0 | 3.2 | 3.0 | 3.1 | 3.1 | 4.0 | 4.0 | 3.5 | 2.0 | 2.3 | 3.3 | 1.8 | 0.0 | 0.0 | 3.0 |
| 13/174 | KWS Evoke | 3.0 | 3.0 | 3.0 | 3.0 | 3.1 | 0.0 | 4.0 | 3.0 | 3.1 | 3.0 | 3.0 | 3.1 | 2.8 | 0.0 | 3.1 | 3.1 | 0.0 | 0.0 | 3.0 | 3.0 | 4.0 | 0.0 | 3.0 | 3.0 | 3.1 | 3.1 | 4.0 | 3.1 | 4.0 | 3.0 | 3.5 | 2.1 | 3.0 | 3.0 | 0.5 | 0.0 | 0.2 | 3.5 |
| 13/176 | Chilton | 3.0 | 3.5 | 3.0 | 4.0 | 4.0 | 0.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.0 | 3.0 | 3.0 | 0.0 | 4.0 | 3.0 | 0.0 | 0.0 | 3.0 | 2.2 | 3.2 | 0.0 | 3.0 | 3.1 | 4.0 | 4.0 | 3.0 | 3.5 | 4.0 | 3.1 | 3.2 | 1.8 | 2.7 | 3.0 | 0.0 | 0.0 | 0.0 | 4.0 |
| 13/178 | Cubanita | 3.0 | 4.0 | 3.2 | 3.1 | 3.5 | 0.0 | 3.0 | 3.1 | 3.5 | 3.2 | 3.0 | 4.0 | 3.0 | 0.0 | 3.5 | 3.1 | 0.0 | 0.0 | 3.0 | 2.6 | 3.4 | 0.0 | 4.0 | 3.1 | 4.0 | 3.2 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.0 | 2.1 | 4.0 | 2.7 | 0.0 | 0.0 | 3.0 |
| 13/182 | Crusoe | 3.2 | 3.1 | 3.0 | 3.1 | 3.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.1 | 3.2 | 3.0 | 2.0 | 0.0 | 4.0 | 3.5 | 0.0 | 0.0 | 3.0 | 3.3 | 4.0 | 0.0 | 2.1 | 4.0 | 4.0 | 4.0 | 3.5 | 0.0 | 3.0 | 4.0 | 3.0 | 1.9 | 3.0 | 3.0 | 0.0 | 0.0 | 0.1 | 3.0 |

Table 3: Pathotypes of the 2013 wheat yellow rust isolates based on the differential test results in Table 2. Yellow shading indicates a compatible reaction; orange indicates borderline or incompatibility with one of the differentials but not the other. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Blank cells indicate an incompatible reaction (avirulence).

| Isolate code | Host | Location | Pathotype Group[1] | Virulence Profile | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 15 | 17 | 24 | 25 | 27 | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/26 | Horatio | Gloucestershire | Warrior 1 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/65 | Claire | Cambridgeshire | Warrior 1 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/178 | Cubanita | Dorset | Warrior 1 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | Wa | (Am) | Ca | |
| 13/92 | Gallant | Lincolnshire | Warrior 1 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | (Wa) | Am | Ca | |
| 13/110 | Denman | North Yorkshire | Warrior 1 | 1 | 2 | 3 | 4 | | 6 | (7) | | (9) | | | (17) | | 25 | | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/88 | JB Diego | Lincolnshire | Warrior 2 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | 17 | | 25 | | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/104 | KWS Podium | North Yorkshire | Warrior 2 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | 17 | | 25 | | 32 | Sp | Ro | So | (Wa) | Am | Ca | |
| 13/105 | Cordiale | North Yorkshire | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | Ca | |
| 13/166 | Invicta | Herefordshire | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | Ca | |
| 13/98 | Mulika | Hampshire | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | Ca | (St) |
| 13/176 | Chilton | Norfolk | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | Ca | (St) |
| 13/29 | Solstice | Oxfordshire | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | Ca | (St) |
| 13/127 | JB Diego | Essex | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | 7 | | (9) | | | (17) | | 25 | | 32 | Sp | Ro | So | | | Ca | (St) |
| 13/128 | Cordiale | Essex | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | (Ca) | |
| 13/20 | KWS Rowan | Hampshire | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | (Ca) | |
| 13/24 | KWS Kielder | Lincolnshire | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | (Ca) | |
| 13/134 | Cocoon | Essex | Warrior 3 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | (17) | | 25 | | 32 | Sp | Ro | So | | | | |
| 13/80 | JB Diego | Warwickshire | Warrior 4 | 1 | (2) | 3 | 4 | | 6 | 7 | | 9 | | | 17 | | (25) | | 32 | Sp | Ro | So | | | Ca | St |
| 13/145 | KWS Santiago | Essex | Warrior 4 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | 17 | | 25 | | 32 | Sp | Ro | So | | | | |
| 13/174 | KWS Evoke | Norfolk | Warrior 4 | 1 | 2 | 3 | 4 | | 6 | (7) | | 9 | | | 17 | | 25 | | 32 | Sp | Ro | So | | | Ca | St |
| 13/61 | KWS Sterling | Cambridgeshire | Solstice | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | 17 | | 25 | | 32 | | Ro | So | | | Ca | St |
| 13/160 | Paragon | Cambridgeshire | Solstice | 1 | 2 | 3 | 4 | | 6 | 7 | | 9 | | | 17 | | 25 | | 32 | | Ro | So | | | Ca | (St) |
| 13/182 | Crusoe | Cambridgeshire | Solstice | 1 | (2) | 3 | 4 | | 6 | (7) | | 9 | | | 17 | | (25) | | 32 | | Ro | So | | | Ca | St |
| 13/21A | Solstice | Norfolk | Solstice | 1 | 2 | 3 | 4 | | 6 | | | 9 | | | 17 | | 25 | | 32 | | Ro | So | | | | |
| 13/23 | KWS Sanitago | Lincolnshire | Solstice | 1 | 2 | 3 | 4 | | 6 | | | 9 | | | 17 | | 25 | | 32 | | Ro | So | | | | |

[1] Pathotype group: Isolates classified as Warrior are virulent on Spaldings Prolific. Isolates classified as Solstice are virulent on *Yr6, Yr9, Yr17* and *Yr32* but avirulent on Spaldings Prolific. Warrior isolates are further divided by reactions on Warrior and *Yr17*.

Sp = Spaldings Prolific, Ro = Robigus, So = Solstice, Wa = Warrior, Am = Ambition, Ca = Cadenza, St = KWS Sterling.

Table 4: Virulence frequencies of key resistance genes from 2002–2013.

| Virulence for Resistance Gene | Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** |
| *Yr1* | 97 | 100 | 100 | 100 | * | * | 100 | 100 | 100 | 100 | 100 | **100** |
| *Yr2* | 97 | 100 | 100 | 100 | * | * | 100 | 100 | 100 | 100 | 100 | **100** |
| *Yr3* | 97 | 100 | 93 | 100 | * | * | 91 | 99 | 100 | 100 | 100 | **100** |
| *Yr4* | 63 | 86 | 50 | 87 | 100 | 100 | 81 | 98 | 100 | 100 | 100 | **100** |
| *Yr5* | | | | | | | | | | | | **0** |
| *Yr6* | 31 | 50 | 42 | 10 | 19 | 4 | 19 | 90 | 98 | 95 | 100 | **100** |
| *Yr7* | 3 | 36 | 4 | 8 | 11 | 4 | 0 | 0 | 24 | 65 | 100 | **90** |
| *Yr8* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| *Yr9* | 88 | 93 | 100 | 95 | 100 | 94 | 93 | 93 | 99 | 98 | 100 | **100** |
| *Yr10* | | | | | | | | | | | | **0** |
| *Yr15* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| *Yr17* | 88 | 93 | 85 | 97 | 100 | 88 | 83 | 87 | 97 | 96 | 100 | **100** |
| *Yr24* | | | | | | | | | | | | **0** |
| *Yr25* | | | | | | | | | | | | **100** |
| *Yr32* | 73 | 64 | 38 | 85 | 89 | 92 | 79 | 94 | 95 | 98 | 100 | **100** |
| Spaldings Prolific ‘Sp’ | 0 | 7 | 0 | 0 | * | * | * | * | * | * | 79 | **80** |
| Robigus ‘Rob’ | | | 31 | 79 | 89 | 84 | 81 | 81 | 100 | 100 | 100 | **100** |
| Solstice ‘Sol’ | | | | | | | 10 | 69 | 98 | 96 | 100 | **100** |
| Timber ‘Tim’ | | | | | 7 | 0 | 5 | 2 | 0 | 48 | 75 | **28** |
| Warrior ‘War’ | | | | | | | | | 3 | 52 | 61 | **28** |
| KWS Sterling ‘Ster’ | | | | | | | | | | | 29 | **50** |
| Cadenza | | | | | | | | | 3 | 48 | 79 | **80** |
| Claire | | | | 23 | 0 | 4 | 14 | 43 | 83 | 93 | * | **92** |
| Stigg | | | | | | | | | | | 0 | **0** |
| Crusoe | | | | | | | | | | | 0 | **4** |
| Suwon Omar | | | | | | | | | | | | **100** |
| Strubes Dickkopf | | | | | | | | | | | | **100** |
| Rendezvous | | | | | | | | | | | 25 | **52** |
| **No. isolates** | **36** | **14** | **48** | **39** | **27** | **25** | **21** | **42** | **40** | **27** | **28** | **25** |

The group Warrior 1 is more typical of the first isolates collected in 2011 which were described as the Warrior race. These isolates are virulent on Warrior and Ambition, but avirulent on Rendezvous. Isolates classed as Warrior 2 are virulent on Warrior, Ambition and Rendezvous. Warrior 3 isolates make up the majority of the isolates tested and are typically avirulent on Warrior, Ambition and Rendezvous. It is easy to see how this may lead to confusion as these isolates are classified as Warrior isolates, yet they are avirulent on the original host variety. Warrior 4 isolates are the final category and show virulence for Rendezvous and avirulence for Warrior and Ambition. A fifth category was assigned for the remaining isolates which are avirulent in Spaldings Prolific. The virulence in these isolates for *Yr6*, *Yr9*, *Yr17*, *Yr32*, Solstice and Robigus suggests that they are similar to the UK Solstice race.

Other virulences of note in the dataset are for Cadenza and KWS Sterling. Virulence for KWS Sterling was found in a number of isolates, both with and without virulence to Spaldings Prolific, indicating that both Warrior and Solstice pathotypes are capable of infecting KWS Sterling at the seedling stage. As in previous years, no virulence was detected to *Yr5*, *Yr8*, *Yr10*, *Yr15* and *Yr24*. The frequency of the detection of virulence to the individual resistance genes was compared to previous years (Table 4) and this showed a reduction on the frequency for virulence to Warrior but an increase in frequency for virulence to KWS Sterling and Rendezvous.

#### 4.1.1. Adult Plant Tests

*Isolates selected*

Five isolates were selected for trial at adult plant stage. These were considered to be representative of the diversity of the isolates collected and pathotyped for virulence on seedlings (Table 5). The isolates were chosen to represent the different pathotype groups listed in Table 3. Isolate 13/65 was selected from the group Warrior 1, isolate 13/88 represents the group Warrior 2, isolate 13/105 was chosen from the group Warrior 3 and 13/145 represents the group Warrior 4. Isolate 13/61 was selected to represent isolates of the Solstice pathotype group.

*Data collection*

The five isolates were evaluated in the UKCPVS tussock trials at NIAB in the summer of 2014. Assessments were made starting at growth stage 34 at the end of April through to growth stage 64 at the start of June. The percentage leaf area infected was measured and the mean was taken of all assessments except the first, where disease levels were considered too low to be informative. At the same time as the field trials were being carried out, seedling tests of the five isolates were conducted measuring their effects on the varieties included in the adult plant tests. Both of these data sets are presented in Table 6. Varieties are ordered in level of disease at adult plant stage for the isolates in order from left to right and shading has been applied to aid interpretation of the results.

Table 5: Virulence profile of isolates selected for testing at adult plant stage in 2014. Yellow shading indicates a compatible reaction: orange indicates borderline result or incompatibility with one of the differentials but not the other. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

| Isolate code | Host | Pathotype Group[1] | Virulence Profile (*Yr* genes or other resistance factors) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 6 | 7 | 9 | 17 | 25 | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/65 | Claire | Warrior 1 | 1 | 2 | 3 | 4 | 6 | 7 | 9 | (17) | 25 | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/88 | JB Diego | Warrior 2 | 1 | 2 | 3 | 4 | 6 | 7 | 9 | 17 | 25 | 32 | Sp | Ro | So | Wa | Am | Ca | St |
| 13/105 | Cordiale | Warrior 3 | 1 | 2 | 3 | 4 | 6 | 7 | 9 | (17) | 25 | 32 | Sp | Ro | So | | | Ca | |
| 13/145 | KWS Santiago | Warrior 4 | 1 | 2 | 3 | 4 | 6 | (7) | 9 | 17 | 25 | 32 | Sp | Ro | So | | | | |
| 13/61 | KWS Sterling | Solstice | 1 | 2 | 3 | 4 | 6 | 7 | 9 | 17 | 25 | 32 | | Ro | So | | | Ca | St |

[1] Pathotype group: Isolates classified as Warrior are virulent on Spaldings Prolific. Isolates classified as Solstice are virulent on *Yr6, Yr9, Yr17* and *Yr32* but avirulent on Spaldings Prolific. Warrior isolates are further divided by reactions on Warrior and *Yr17*.

Sp = Spaldings Prolific, Ro = Robigus, So = Solstice, Wa = Warrior, Am = Ambition, Ca = Cadenza, St = KWS Sterling.

Table 6: Seedling and adult plant reactions to the five isolates selected for further characterisation. Seedling results are shown as average infection types on a scale of 04. Adult plant results are given as a percentage leaf area infected averaged over five assessments. Shading has been applied to the seedling test data to highlight compatibility (yellow) and possible compatibility (orange). Shading on the adult plant test data divides the data into four categories: green = 0–2 %, yellow = 2.1–5%, orange = 5.1–20% and red = 20.1% and over.

| Variety | RL Rating | Seedling (average infection type) | | | | | Adult Plant (% leaf area infected) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13/65 | 13/88 | 13/105 | 13/145 | 13/61 | 13/65 | 13/88 | 13/105 | 13/145 | 13/61 |
| Costello | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| KWS Tempo | 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ruskin | 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Relay | 8.9 | 0.9 | 0.2 | 1.0 | 2.0 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Delphi | 8.7 | 2.8 | 1.8 | 0.4 | 2.8 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Revelation | 8.9 | 0.1 | 1.8 | 2.0 | 2.2 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dickens | 8.4 | 1.9 | 2.3 | 0.5 | 3.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| KWS Cashel | 8.6 | 3.0 | 3.0 | 3.0 | 3.0 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| KWS Trinity | 9 | 0.0 | 0.0 | 0.8 | 0.5 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Zulu | 8.8 | 1.3 | 3.0 | 1.7 | 0.5 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Scout | 8.8 | 0.5 | 0.4 | 0.2 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Paragon | 7 | 3.0 | 3.0 | 2.8 | 2.4 | 3.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Crusoe | 8.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 |
| Icon | 8.7 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cadenza | | 2.1 | 3.3 | 2.8 | 2.0 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rendezvous | | 0.7 | 1.0 | 1.9 | 2.5 | 3.0 | 0.0 | 0.0 | 0.0 | 1.6 | 4.3 |
| Mulika | 8 | 3.0 | 3.0 | 3.0 | 2.1 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| KWS Gator | 8.8 | 0.6 | 0.7 | 0.0 | 0.0 | 2.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Cocoon | 7.7 | 2.3 | 2.2 | 3.0 | 3.0 | 3.0 | 0.0 | 0.6 | 1.0 | 0.9 | 0.5 |
| KWS Croft | 8.7 | 2.4 | 2.1 | 0.5 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |

| Variety | RL Rating | Seedling (average infection type) | | | | | Adult Plant (% leaf area infected) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13/65 | 13/88 | 13/105 | 13/145 | 13/61 | 13/65 | 13/88 | 13/105 | 13/145 | 13/61 |
| Napier | | 0.0 | 0.0 | 1.5 | 1.6 | 2.8 | 0.1 | 0.1 | 0.0 | 0.4 | 6.0 |
| Evolution | 8.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cougar | 8.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.1 | 0.0 | 0.0 |
| KWS Sterling | | 0.8 | 0.7 | 1.5 | 2.1 | 2.7 | 0.2 | 0.1 | 0.0 | 0.1 | 8.7 |
| Invicta | 7.7 | 2.8 | 3.0 | 3.0 | 2.2 | 2.3 | 0.3 | 0.8 | 0.8 | 1.9 | 0.4 |
| Britannia | 9 | 3.0 | 1.6 | 1.0 | 0.3 | 3.0 | 0.3 | 0.4 | 0.1 | 0.2 | 0.1 |
| Alchemy | 6.7 | 2.8 | 2.9 | 1.7 | 3.0 | 3.0 | 0.5 | 0.4 | 0.0 | 0.7 | 0.1 |
| Jorvik | 9 | 3.0 | 3.2 | 3.0 | 3.0 | 3.2 | 0.6 | 0.1 | 0.0 | 0.1 | 0.1 |
| Myriad | 8.4 | 0.0 | 2.0 | 2.1 | 0.0 | 0.3 | 0.7 | 0.1 | 0.1 | 0.6 | 0.5 |
| JB Diego | 7.7 | 3.0 | 2.9 | 1.4 | 2.2 | 1.3 | 0.8 | 0.6 | 0.3 | 0.7 | 1.1 |
| KWS Santiago | 4.4 | 3.0 | 2.1 | 3.0 | 1.0 | 3.2 | 1.3 | 3.6 | 2.3 | 8.4 | 17.7 |
| Apache | | 2.0 | 3.0 | 3.0 | 0.8 | 2.2 | 2.3 | 2.2 | 1.2 | 1.3 | 12.7 |
| RGT Conversion | 7 | 2.3 | 0.7 | 1.3 | 0.7 | 0.5 | 2.5 | 0.7 | 0.0 | 0.4 | 0.1 |
| Panorama | 8 | 2.0 | 2.1 | 2.0 | 3.0 | 2.0 | 4.5 | 2.1 | 11.1 | 6.7 | 10.0 |
| Leeds | 6.9 | 0.2 | 2.1 | 1.7 | 2.0 | 0.4 | 4.6 | 4.6 | 0.2 | 1.3 | 0.8 |
| Hustler | | Data not available | | | | | 4.8 | 10.2 | 1.4 | 3.2 | 4.8 |
| Grafton | 6.2 | 1.5 | 3.0 | 2.7 | 1.6 | 3.0 | 6.5 | 7.0 | 6.0 | 7.3 | 2.7 |
| Conqueror | 5.9 | 4.0 | 3.0 | 3.0 | 3.0 | 3.2 | 7.1 | 2.8 | 0.4 | 3.9 | 10.2 |
| Energise | 8 | 3.0 | 2.2 | 1.9 | 1.5 | 2.8 | 7.7 | 0.5 | 0.5 | 4.5 | 0.6 |
| Brigadier | | 2.5 | 3.0 | 3.0 | 3.0 | 3.1 | 7.9 | 1.2 | 2.1 | 12.2 | 19.6 |
| Skyfall | 6.2 | 0.2 | 3.0 | 1.1 | 0.1 | 1.5 | 8.4 | 7.5 | 4.8 | 5.7 | 7.0 |
| Twister | 6.4 | 1.6 | 1.3 | 2.9 | 1.8 | 3.0 | 9.2 | 12.6 | 4.1 | 9.1 | 4.1 |
| Cordiale | 5.5 | 2.9 | 2.8 | 2.5 | 3.0 | 2.8 | 10.3 | 11.4 | 14.0 | 12.4 | 10.4 |

| Variety | RL Rating | Seedling (average infection type) | | | | | Adult Plant (% leaf area infected) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13/65 | 13/88 | 13/105 | 13/145 | 13/61 | 13/65 | 13/88 | 13/105 | 13/145 | 13/61 |
| Viscount | 4.6 | 3.0 | 3.0 | 3.0 | 3.0 | 3.1 | 12.6 | 12.1 | 11.9 | 15.9 | 15.8 |
| Cubanita | 6.2 | 2.5 | 2.5 | 3.0 | 1.5 | 3.0 | 13.7 | 6.1 | 4.8 | 6.0 | 0.2 |
| Claire | 5.4 | 3.0 | 3.2 | 3.0 | 3.0 | 2.3 | 14.1 | 12.2 | 0.8 | 0.7 | 0.6 |
| Talon | | 3.0 | 2.5 | 3.0 | 3.0 | 3.0 | 14.4 | 21.3 | 5.8 | 15.1 | 9.3 |
| Reflection | 5 | 3.0 | 3.0 | 2.2 | 2.5 | 1.4 | 14.9 | 16.1 | 2.0 | 7.2 | 3.2 |
| Monterey | 7.4 | 0.7 | 0.4 | 1.7 | 0.5 | 0.0 | 16.2 | 12.6 | 1.9 | 3.6 | 4.0 |
| Chilton | 6.2 | 3.2 | 3.0 | 3.0 | 0.2 | 3.1 | 17.0 | 16.5 | 13.6 | 17.8 | 6.2 |
| Warrior | | 3.0 | 2.3 | 1.6 | 1.5 | 0.3 | 17.6 | 9.6 | 1.0 | 7.2 | 7.0 |
| Gallant | 4.9 | 3.0 | 3.0 | 3.0 | 1.5 | 2.3 | 18.3 | 10.2 | 11.3 | 14.4 | 12.4 |
| Horatio | 5.9 | 3.0 | 2.2 | 3.0 | 1.0 | 3.0 | 18.4 | 17.5 | 6.2 | 15.3 | 9.4 |
| Beluga | 5.3 | 3.1 | 1.2 | 1.1 | 0.3 | 3.1 | 18.8 | 15.4 | 1.7 | 14.1 | 3.3 |
| KWS Lili | 7 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 19.7 | 11.7 | 14.8 | 16.3 | 12.1 |
| Brock | | 2.7 | 3.3 | 3.5 | 2.2 | 3.0 | 20.5 | 15.7 | 25.0 | 16.8 | 13.2 |
| RGT Scrummage | | 2.8 | 3.0 | 2.5 | 3.0 | 2.0 | 20.9 | 18.8 | 13.2 | 12.3 | 8.1 |
| KWS Kielder | 3.8 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 22.7 | 22.9 | 18.1 | 20.4 | 14.8 |
| Solstice | 4 | 3.0 | 3.1 | 3.0 | 4.0 | 4.0 | 30.4 | 40.4 | 36.4 | 30.4 | 31.6 |
| Hobbit | | 2.5 | 2.6 | 2.1 | 3.5 | 3.0 | 32.7 | 19.5 | 23.7 | 31.4 | 14.8 |
| Panacea | 4.3 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 37.0 | 37.3 | 23.3 | 33.0 | 25.3 |
| Hornet | | 3.0 | 3.0 | 3.0 | 3.5 | 3.0 | 37.3 | 37.5 | 38.0 | 33.6 | 31.1 |
| Robigus | | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 44.0 | 43.0 | 39.3 | 41.7 | 36.2 |
| Ambition | | 3.0 | 3.0 | 0.1 | 1.0 | 0.0 | 46.6 | 45.2 | 26.8 | 30.5 | 22.6 |

*Trial controls*

The main aim of the adult plant trials is to assess the reaction of the varieties currently on the recommended list and candidate varieties undergoing testing for recommendation. Used in conjunction with the Recommended List ratings, this information will assist growers in mitigating the risk from yellow rust by alerting them to any possible reduction in resistance. The trials produced high levels of disease, with known susceptible varieties showing the highest percent leaf area infected. In addition to the Recommended List varieties and candidates, a number of varieties are included in the adult plant trials as controls. The variety Cadenza has remained resistant to yellow rust over many years, and although seedling susceptibility is now evident, the adult plant resistance appears undiminished, with only trace levels of disease evident. Rendezvous and the related varieties, Brigadier and Napier, were included to look at the effect of the Warrior isolates on the Rendezvous resistance. In the seedling tests, there was variation in the Warrior isolates in their virulence to Rendezvous. In the adult plant tests, Rendezvous and Napier are resistant to all of the Warrior isolates and slightly susceptible to the Solstice isolate. This suggests that although there is variation in ability to cause disease at the seedling stage, all of the Warrior isolates are unable to cause disease at the adult plant stage in Rendezvous (and therefore Napier). This adult plant resistance appears to be race-specific however, as when Rendezvous is challenged with the Solstice isolate, a small amount of disease is observed. When considering another related variety, Brigadier, the results were less clear cut. The levels of disease vary when challenged with the Warrior isolates; however the highest levels of disease were seen in the trial inoculated with the Solstice isolate.

Other controls in the trials included Hustler and Hobbit, which contain the genes *Yr13* and *Yr14*, respectively. Hustler shows limited amounts of disease when challenged with all isolates, but is particularly susceptible to 13/88, which is the Warrior isolate with the most virulences. This suggests that *Yr13* is unable to provide protection against some of the Warrior isolates. Hobbit shows susceptibility to all isolates demonstrating that *Yr14* is ineffective against the current yellow rust population. Talon (*Yr32*), Hornet (*Yr6*, *Yr9*), and Brock (*Yr7*) all show susceptibility to all isolates which is expected as these genes individually have been ineffective for a number of years.

*KWS Santiago appears more resistant than in previous years*

Just under half of the varieties trialled showed either no disease or trace levels to the different isolates. Complete susceptibility was only seen in five of the varieties tested: Panacea, Solstice, Ambition, Hornet and Robigus, three of which are included in this trial as susceptible controls. The remaining 32 varieties differed in their response to the different isolates and it is difficult to make broad conclusions concerning the resistance in these varieties. The exception to this is the group of varieties consisting of Rendezvous, Napier, KWS Sterling, KWS Santiago and Apache which generally show good levels of resistance to the Warrior isolates but a degree of susceptibility to the Solstice isolate 13/61. This could indicate a common resistance gene between these varieties. As

discussed above, Napier is a descendant of Rendezvous and KWS Santiago has Rendezvous in its pedigree, meaning that it is possible that these varieties also carry the uncharacterised Rendezvous resistance. The survey received verbal reports of KWS Santiago looking cleaner than expected on-farm this year, even when grown next to other susceptible varieties. A possible explanation for these observations is that if the Warrior isolates are unable to overcome the Rendezvous resistance, any variety with the Rendezvous resistance will look clean. The Rendezvous resistance has been overcome in the past, however, which is seen when it is challenged with the Solstice isolate in the adult plant tests reported here. Therefore, when KWS Santiago was first registered, the Solstice race would have been dominant, and it appeared susceptible. Move forward to 2014 when the Warrior race dominates and the isolates are unable to cause disease to the same extent which now means that the variety is more resistant. This change in the pathogen population was reflected in the Recommended List ratings this year which has seen the KWS Santiago yellow rust rating increase from a 4 (2014/15 RL) to a 6 (2015/16 RL). Further work on isolates collected in 2014 should provide additional information in this area.

*Limited grouping of remaining varieties*

For the remaining varieties there does not seem to be a logical explanation of the reactions seen in the adult plants in response to the different isolates. A good example of this is Warrior. Isolates 13/65 and 13/88 are both virulent on Warrior at the seedling stage, whereas the isolates 13/105, 13/145 and 13/61 are not. It should follow that disease would only be found in the adult plant tests with the first two isolates as it is not possible to have disease at noticeable levels at the adult plant stage if the seedlings cannot be infected substantially. The adult plant results agree for 13/65 and 13/88 with moderate levels of disease seen in these two trials. For 13/105 there is no disease, again in agreement with the seedling test results, however, low to moderate levels of disease were seen in the trials with the isolates 13/145 and 13/61, which in theory should not happen. It is possible that there was an error in the seedling test, however it is much more likely that natural yellow rust inoculum has blown into the trial, infecting any varieties which were clean up until that point. Similar contradictions are seen for the varieties KWS Santiago (13/145), Cubanita (13/145), Grafton (13/65 and 13/145), Twister (13/65, 13/88, 13/145), Monterey (13/65 and 13/88), Beluga (13/88, 13/145), Panorama (13/105 and 13/61), and also one of the susceptible controls, Ambition (13/105, 13/145 and 13/61). The high disease pressure seen in 2014 suggests that natural infection is the most likely cause for these anomalies. To investigate any similar effects in future trials, we propose to sample from varieties showing adult plant symptoms which disagree with the seedling results in future years to ascertain whether the isolate present is the inoculated isolate or a natural incursion.

*Comparison of adult plant and seedling reactions to the different isolates*

A large proportion of the varieties were classed as resistant to all isolates in these trials at the adult plant stage. It is important not to classify all of these as having the same resistance mechanism, however. Different reactions at the seedling stage suggest there are a variety of resistance mechanisms underpinning these varieties. For example, some varieties are susceptible to all of the isolates at the seedling stage and then completely clean at the adult plant stage, some are resistant at all stages and some are a mixture of the two. Unfortunately there is no way to predict which mechanism will be the most durable and it is for this reason that this information is provided for information only, rather than as a predictor for future varietal performance.

## 4.2. Wheat Brown Rust

### 4.2.1. Samples Received

In 2013, the UKCPVS received 42 samples of wheat brown rust from five different UK counties, with the majority of samples being received from East Anglia (Figure 2). The full list of samples received is given in Appendix 1.


Figure 2: Map of the UK with the number of samples of wheat brown rust received in 2013 from the different counties.

This modest number of samples is in line with the low levels of disease in 2013 after the cold and dry winter. Samples from a good range of varieties were received, with brown rust found on some of the more resistant varieties, for example Revelation (RL rating 9 on 2013/14 list) and Tuxedo (rating 8). As with the yellow rust samples, it is important to note that the host varieties are not

verified for every sample received and the sample register must not be interpreted as a list of varieties which have a weakness for brown rust at this stage.

### 4.2.2. Pathotyping of Isolates

Twenty five isolates were selected for further pathotyping (Table 7). The isolate selection was based on the county of origin and the resistance rating of the host. As for the yellow rust isolates, a differential set was used to establish the virulence profiles of the isolates, with the reactions measured as a.i.t. scores (Table 7). The brown rust differential set used by the UKCPVS is not as comprehensive as the yellow rust set, with only eight of the known *Lr* genes monitored, compared to the yellow rust differential set which monitors 16 *Yr* genes. Virulence to a particular gene is monitored using up to four differentials per resistance gene and in the interpretation of these results virulence to a particular gene is only classified if virulence is seen to all differentials for a particular gene. In addition to the known genes, a number of other varieties with uncharacterised resistance are also included and taken together these results can be translated into a virulence profile (Table 8). In contrast to the yellow rust results, the brown rust virulence profiles show more diversity across the different genes with no obvious grouping of the isolates. Key virulences of interest to the survey included virulence for *Lr1*, the resistance found in Glasgow, *Lr24*, the resistance gene which became ineffective with the Stigg race, and virulence for Robigus (hypothesized to carry *Lr28*). Virulence for all of these genes is found in the different isolates, however no single isolate carries virulence for all three genes. The frequency of detection of different virulences over the past 10 years (Table 9) shows an increase in frequency for virulence for *Lr1*, *Lr3a* and *Lr26*, whilst virulence frequencies have decreased for virulence for *Lr24* and a slight decrease for virulence against *Lr28.* Virulence for *Lr20* remains about the same.
To make the brown rust results more informative we have plans to include the use of the Thatcher near-isogenic series for the differential tests in order to give results which are more directly comparable with other surveys worldwide. In the USA for example, 20 *Lr* genes are monitored using on the Thatcher NILs (Kolmer and Hughes, 2014). The same lines are also in use by others in France (Goyeau and Lannou, 2011).

Table 7: Average infection type (a.i.t.) scores for the 25 selected isolates against the UKCPVS differential set. Yellow shading indicates a compatible reaction, orange indicates borderline. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Numbers next to the differential variety name indicate the known resistance genes carried by the variety. APR = Adult Plant Resistance

| Isolate Number | Host Variety | Sample Location | Lr1 | Lr1 | Lr3a | Lr17b + APR | Lr20 | Lr20 | Lr20 | Lr24 | Lr24 | Lr24 | Lr26 | Lr26 | Robigus (Lr28) | Robigus (Lr28) | Robigus (Lr28) | Robigus (Lr28) | Lr37 + APR | APR | APR | | | | | APR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thatcher Lr1 | Glasgow | Sterna | Fundin | Thatcher Lr20 | Sappo | Halberd | Thatcher Lr24 | Stigg | Warrior | Clement | Thatcher Lr26 | Robigus | Scout | Horatio | Leeds | Thatcher Lr37 | Alchemy | Cocoon | Tuxedo | KWS-Sterling | Crusoe | Cougar | Dickens | Revelation | Chronicle | Armada |
| 12/501 | Stigg | Cambs | 0.8 | 1.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 0.3 | 3.0 | 3.0 | 2.0 | 2.0 | 3.0 | 0.0 | 0.0 | 0.5 | 2.0 | 2.0 | 2.5 | 2.0 | 2.0 | 2.0 | 0.0 | 2.0 | 2.0 | 3.0 | 2.0 |
| 12/502 | Timber | Cambs | 3.0 | 3.0 | 3.0 | 2.0 | 2.5 | 2.5 | 2.0 | 0.0 | 3.0 | 3.0 | 2.0 | 2.5 | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 0.5 | 2.0 | 2.0 | 2.8 | 2.0 |
| 12/503 | Glasgow | Cambs | 2.0 | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 | 3.0 | 0.5 | 1.0 | 0.0 | 3.0 | 2.0 | 1.0 | 0.0 | 0.8 | 0.8 | 2.5 | 2.5 | 3.0 | 3.0 | 3.0 | 3.0 | 0.5 | 2.0 | 2.0 | 2.0 | 2.0 |
| 12/504 | Mascot | Cambs | 2.8 | 3.0 | 2.0 | 2.5 | 1.0 | 3.0 | 2.0 | 0.0 | 0.3 | 0.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 2.0 | 2.8 | 2.5 | 3.0 | 2.0 | 0.0 | 2.5 | 2.8 | 2.0 | 2.0 |
| 12/505 | Robigus | Cambs | 0.0 | 0.0 | 1.0 | 3.0 | 0.3 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.3 | 1.0 | 2.0 | 2.8 | 2.0 | 2.8 | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | 2.8 | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 |
| 12/506 | Robigus | Cambs | 0.0 | 0.0 | 2.0 | 3.0 | 1.0 | 0.3 | 0.0 | 0.0 | 0.5 | 3.0 | 3.0 | 2.0 | 0.0 | 3.0 | 3.0 | 2.8 | 3.0 | 3.0 | 3.0 | 2.3 | 2.0 | 2.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| 12/507 | Warrior | Cambs | i | 0.0 | 3.0 | 3.0 | 2.0 | 2.5 | 2.5 | 3.0 | 3.0 | 3.0 | 3.0 | 2.9 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 3.0 | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 3.0 | 3.5 |
| 13/01 | Stigg | Lincs | 0.0 | 0.0 | 2.0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.0 | 3.0 | 3.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 2.0 | 2.5 | 2.0 | 2.0 | 2.0 | 0.0 | 2.0 | 2.5 | 2.5 | 2.5 |
| 13/02 | Torch | Cambs | 0.0 | 0.0 | 0.5 | 1.0 | 0.0 | 0.5 | 0.0 | 3.0 | 3.0 | 3.0 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 | 0.0 | 2.0 | 3.0 | 3.0 | 3.0 |
| 13/03 | Beluga | Dorset | 0.0 | i | 2.5 | 3.0 | 0.0 | 0.1 | 0.0 | 1.0 | 0.4 | 1.0 | 3.0 | 3.0 | 0.0 | i | i | i | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 | 3.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| 13/06 | Denman | Lincs | 3.0 | 3.0 | 0.8 | 3.0 | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | 2.0 | 0.0 | 0.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 0.3 | 3.0 | 3.0 | 3.0 | 3.0 |
| 13/07 | Claire | Lincs | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 3.0 | 3.0 | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | i | 0.0 | i | 0.0 | 3.0 | 3.0 | 3.0 | 2.5 | 2.5 | 3.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| 13/10 | KWS Croft | Cambs | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | 3.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 | 3.0 | 2.0 | 2.5 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 | 3.0 | 3.0 |
| 13/11 | KWS Rowan | Cambs | 1.0 | 0.5 | 1.0 | 3.0 | 2.0 | 3.0 | 3.0 | 0.0 | 0.0 | 0.0 | 1.0 | 1.0 | 3.0 | 2.0 | 2.5 | 2.0 | 2.0 | 3.0 | 2.0 | 2.0 | 1.0 | 2.0 | 2.5 | 2.0 | 2.0 | 3.0 | 3.0 |
| 13/16 | Conquerer | Cambs | 3.0 | 3.0 | 0.2 | 3.0 | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 3.0 | 2.0 | 3.0 | 3.0 | 2.0 | 3.0 | 2.5 | 2.5 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| 13/17 | KWS Dali | Cambs | 0.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| 13/19 | Panacea | Cambs | 1.0 | 1.0 | 3.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 1.3 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 2.5 | 2.5 | 2.5 |

| Isolate Number | Host Variety | Sample Location | Lr1 | Lr1 | Lr3a | Lr17b + APR | Lr20 | Lr20 | Lr20 | Lr24 | Lr24 | Lr24 | Lr26 | Lr26 | Robigus (Lr28) | Robigus (Lr28) | Robigus (Lr28) | Robigus (Lr28) | Lr37 + APR | Claire, APR | APR | | | | | APR | | RO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thatcher Lr1 | Glasgow | Sterna | Fundin | Thatcher Lr20 | Sappo | Halberd | Thatcher Lr24 | Stigg | Warrior | Clement | Thatcher Lr26 | Robigus | Scout | Horatio | Leeds | Thatcher Lr37 | Alchemy | Cocoon | Tuxedo | KWS-Sterling | Crusoe | Cougar | Dickens | Revelation | Chronicle | Armada |
| 13/20 | Viscount | Cambs | 0.0 | 0.0 | 0.1 | 3.0 | 0.0 | 0.1 | 0.0 | 0.1 | i | i | i | 0.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.8 | 2.0 | 3.0 | 2.0 | 3.0 | 3.0 | 3.0 |
| 13/23 | Revelation | Cambs | 3.0 | 3.0 | 0.0 | 2.0 | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 2.0 | 3.0 | 1.0 | 0.0 | 0.0 | 1.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.0 | 2.0 | 2.5 | 2.5 | 3.0 |
| 13/24 | Icebreaker | Cambs | 0.0 | 0.0 | 1.5 | 3.0 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 0.0 | 3.0 | i | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 3.0 | 3.0 |
| 13/28 | Leeds | Cambs | 2.5 | 3.0 | 0.5 | 3.0 | 2.5 | 0.3 | 0.0 | 0.0 | 2.5 | 2.0 | 1.5 | 0.0 | 2.0 | 2.0 | 2.0 | 2.5 | 0.0 | 0.0 | 2.0 | 2.0 | 2.5 | 2.5 | 2.0 | 2.0 | 2.5 | 2.5 | 3.0 |
| 13/29 | Icon | Cambs | 0.0 | 0.0 | 0.0 | 3.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | i | 2.5 | 2.0 | 3.0 | 2.0 | 3.0 | 3.0 | 2.5 | 2.5 | 2.5 | 2.0 | 2.5 | 2.0 | 3.0 | 3.0 | 3.0 |
| 13/30 | Scout | Cambs | 0.0 | i | 0.2 | 3.0 | 0.2 | 0.2 | 0.3 | 0.1 | i | 0.0 | 0.0 | 0.8 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | 2.5 | 3.0 | 2.5 | 3.0 | 3.0 | 3.0 |
| 13/33 | Invicta | Cambs | 0.0 | 0.0 | 3.0 | 3.0 | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | 3.0 | 3.0 | 3.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 3.0 | 2.5 | 3.0 |
| 13/34 | Crusoe | Hamps | 2.5 | 3.0 | 1.0 | 3.0 | 1.0 | 1.0 | 1.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | i | 0.0 | 0.0 | 0.0 | 2.0 | 2.0 | 2.5 | 2.0 | 2.0 | 2.0 | 0.0 | 2.5 | 2.5 | 2.5 | 2.0 |

Table 8: Pathotypes of the 2013 wheat brown rust isolates based on the differential test results in Table 7. Yellow shading indicates a compatible reaction, orange indicates borderline. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety. Al = Alchemy, Co = Cocoon, Tu = Tuxedo, St = KWS Sterling, Cr = Crusoe, Cou = Cougar, Di = Dickens, Re = Revelation, Ch = Chronicle.

| Isolate Number | Host Variety | Sample Location | Virulence Profile | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 3a | 17b | 20 | 24 | 26 | 28 | 37 | Al | Co | Tu | St | Cr | Cou | Di | Re | Ch |
| 12-501 | Stigg | Cambridgeshire | | | | | (24) | | (28) | | | (Co) | | | | | | | Ch |
| 12-502 | Timber | Cambridgeshire | 1 | 3a | | (20) | (24) | (26) | 28 | | | | | | | | | | (Ch) |
| 12-503 | Glasgow | Cambridgeshire | (1) | 3a | 17b | (20) | | (26) | | (37) | (Al) | Co | Tu | St | Cr | | | | |
| 12-504 | Mascot | Cambridgeshire | (1) | | (17b) | (20) | | | | | | (Co) | (Tu) | St | | | (Di) | (Re) | |
| 12-505 | Robigus | Cambridgeshire | | | 17b | | | | (28) | 37 | Al | Co | Tu | | (Cr) | | | | |
| 12-506 | Robigus | Cambridgeshire | | | 17b | | (24) | (26) | (28) | 37 | Al | Co | | | | | | Re | Ch |
| 12-507 | Warrior | Cambridgeshire | | 3a | 17b | (20) | 24 | 26 | 28 | (37) | Al | Co | | | | | | Re | Ch |
| 13-01 | Stigg | Lincolnshire | | | | (20) | 24 | | | | | (Co) | | | | | | (Re) | (Ch) |
| 13-02 | Torch | Cambridgeshire | | | | | 24 | | | | Al | Co | Tu | | Cr | | | Re | Ch |
| 13-03 | Beluga | Dorset | | (3a) | 17b | | | 26 | | 37 | Al | Co | | St | Cr | | | Re | Ch |
| 13-06 | Denman | Lincolnshire | 1 | | 17b | | | 26 | | 37 | Al | Co | Tu | St | Cr | | | Re | Ch |
| 13-07 | Claire | Lincs | 1 | 3a | 17b | (20) | | 26 | | 37 | Al | Co | (Tu) | (St) | Cr | | | Re | Ch |
| 13-10 | KWS Croft | Cambridgeshire | | | 17b | (20) | | | (28) | 37 | Al | | (Tu) | | | | | (Re) | Ch |
| 13-11 | KWS Rowan | Cambridgeshire | | | 17b | (20) | | | (28) | | Al | | | | | (Cou) | | | Ch |
| 13-16 | Conquerer | Cambridgeshire | 1 | | 17b | | | (26) | (28) | (37) | (Al) | Co | Tu | St | Cr | Cou | | Re | Ch |
| 13-17 | KWS Dali | Cambridgeshire | | | 17b | | | | 28 | 37 | Al | Co | Tu | St | Cr | Cou | | Re | Ch |
| 13-19 | Panacea | Cambridgeshire | | 3a | 17b | | | 26 | 28 | 37 | Al | Co | Tu | St | Cr | Cou | (Di) | (Re) | (Ch) |
| 13-20 | Viscount | Cambridgeshire | | | 17b | | | | 28 | 37 | Al | Co | Tu | (St) | | Cou | | Re | Ch |
| 13-23 | Revelation | Cambridgeshire | 1 | | | | | (26) | | 37 | Al | Co | Tu | St | Cr | | | (Re) | (Ch) |
| 13-24 | Icebreaker | Cambridgeshire | | | 17b | | | (26) | 28 | 37 | Al | Co | Tu | St | Cr | Cou | | (Re) | Ch |
| 13-28 | Leeds | Cambridgeshire | (1) | | 17b | (20) | (24) | | (28) | | | | | (St) | (Cr) | | | (Re) | (Ch) |
| 13-29 | Icon | Cambridgeshire | | | 17b | | | | (28) | 37 | Al | (Co) | (Tu) | (St) | | (Cou) | | Re | Ch |
| 13-30 | Scout | Cambridgeshire | | | 17b | | | | 28 | 37 | Al | Co | Tu | | (Cr) | Cou | (Di) | Re | Ch |
| 13-33 | Invicta | Cambridgeshire | | 3a | 17b | | | 26 | (28) | 37 | Al | Co | Tu | St | Cr | Cou | (Di) | Re | (Ch) |
| 13-34 | Crusoe | Hampshire | (1) | | 17b | | 24 | (26) | | | | (Co) | | | | | (Di) | (Re) | (Ch) |

Table 9: Virulence frequencies of key resistance genes from 2003-2013.

| Virulence for Differential | Postulated Resistance Gene | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2003** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** |
| Glasgow | *Lr1* | | | 32 | 17 | 19 | 18 | 0 | 10 | 7 | **40** |
| Thatcher x *Lr1* | *Lr1* | 0 | 28 | 32 | 13 | 14 | 18 | 0 | 10 | 7 | **24** |
| Sterna | *Lr3a* | 68 | 56 | 68 | 8 | 14 | 0 | 90 | 0 | 7 | **24** |
| Fundin | *Lr17b*, APR | 73 | 100 | 100 | 100 | 86 | 91 | 70 | 86 | 89 | **76** |
| Sappo | *Lr20* | 0 | 13 | 28 | 8 | 5 | 0 | 0 | 14 | 19 | **24** |
| Halberd | *Lr20* | 0 | 13 | 24 | 8 | 10 | 9 | 0 | 10 | 22 | **12** |
| Thatcher x *Lr20* | *Lr20* | | | | | | | | | 7 | **4** |
| Thatcher x *Lr24* | *Lr24* | | | | | | | | | 37 | **16** |
| Timber | *Lr24* | | | | 0 | 0 | 0 | 0 | 19 | 48 | ***** |
| Stigg | *Lr24* | | | | | | | | 24 | 41 | **24** |
| Warrior | *Lr24* | | | | | | | 0 | 5 | 44 | **28** |
| Clement | *Lr26* | 73 | 69 | 44 | 21 | 24 | 0 | 70 | 5 | 11 | **44** |
| Thatcher x *Lr26* | *Lr26* | 73 | 69 | 44 | 17 | 33 | 0 | 40 | 5 | 11 | **28** |
| Robigus | *Lr28*, Robigus | | | 32 | 30 | 10 | 18 | 0 | 52 | 59 | **48** |
| Scout | *Lr28*, Robigus | | | | | 14 | 18 | 0 | 43 | 59 | **44** |
| Horatio | *Lr28*, Robigus | | | | | | | | 38 | 56 | **44** |
| Leeds | *Lr28*, Robigus | | | | | | | | | 48 | **44** |
| Thatcher x *Lr37* | *Lr37,* APR | | | 100 | 30 | 91 | 27 | 100 | 91 | 59 | **56** |
| Alchemy | Claire | | | 100 | 58 | 100 | 100 | 100 | 91 | 85 | **68** |
| Chronicle | | | | | | | | | | 67 | **64** |
| Cocoon | | | | | | | | | | 74 | **68** |
| Cougar | | | | | | | | | | 33 | **28** |
| Crusoe | | | | | | | | | | 67 | **48** |
| Dickens | | | | | | | | | | 33 | **28** |
| KWS Sterling | | | | | | | | | | 33 | **44** |
| Revelation | | | | | | | | | | 82 | **52** |
| Tuxedo | | | | | | | | | | 59 | **48** |
| Armada | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | **72** |
| **No. isolates** | | **22** | **32** | **25** | **24** | **21** | **11** | **10** | **21** | **27** | **25** |

### 4.2.1. Adult Plant Tests

*Isolates selected*

Five isolates were selected for trial at adult plant stage and these were considered to be representative of the diversity of the isolates collected and pathotyped (Table 10). Isolate 12/502 is a Robigus-type isolate, with virulence for all of the *Lr28* differentials, 12/507 combined Robigus virulence with virulence for *Lr24* and *Lr26*, isolate 13/03 is virulent on *Lr26* and also Crusoe at the seedling stage, 13/10 lacks virulence for any of *Lr24*, *Lr26*, or *Lr28*, and 13/34 has virulence for *Lr24* but not *Lr28*. Virulence for *Lr26* in this isolate is questionable. Isolate 13/34 was of interest to the survey as it was isolated from Crusoe. Although Crusoe is not rated as highly resistant in the 2013/14 RL ratings, reports have come to the survey of higher than expected levels of disease and so samples of Crusoe were of particular interest.

*Data collection*

The five isolates were evaluated in the UKCPVS tussock trials at NIAB in the summer of 2014. Assessments were made starting at growth stage 57 at the end of the May through to growth stage 80 at the end of June. The percentage of leaf area infected was measured and the mean was taken of the last three assessments. The first two assessments were omitted from the analysis as disease levels were considered too low to be informative. At the same time as the field trials were being carried out, seedling tests of the five isolates were conducted measuring their effects on the varieties included in the adult plant tests. Both of these data sets are presented in Table 11. Varieties are ordered in level of disease at adult plant stage for the isolates in order from left to right.

*Anomalous results show high levels of natural infection*

As with the yellow rust trials, the main aim of the adult plant trials is to assess the reaction of the varieties currently on the recommended list and candidate varieties undergoing testing for recommendation. Used in conjunction with the Recommended List ratings, this information will assist growers in mitigating the risk from brown rust by alerting them to any possible reduction in resistance. High levels of disease were recorded in the susceptible controls in the trial, however there were a few anomalies between expected results and disease levels recorded. For example, isolate 13/34 is avirulent on Crusoe at the seedling stage in the differential test but shows high levels of disease on Crusoe at the adult plant stage. As discussed before, it is unlikely that there is a seedling-specific resistance and it is expected that this infection on Crusoe in the field is due to an external inoculum source. Further evidence of natural infection within the trial is found when looking at the Warrior-13/03 interaction. Isolate 13/03 is avirulent on *Lr24*, but still manages to cause high levels of disease on Warrior and Stigg, both *Lr24*-containing varieties which were previously resistant to brown rust.

Table 10: Virulence profile of isolates selected for testing at adult plant stage in 2014. Yellow shading indicates a compatible reaction, orange indicates borderline. Compatible interactions classify the isolate as virulent against a particular resistance gene or variety.

| Isolate Number | Host Variety | Sample Location | Virulence Profile | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 3a | 17b | 20 | 24 | 26 | 28 | 37 | Al | Co | Tu | St | Cr | Cou | Di | Re | Ch |
| 12-502 | Timber | Cambridgeshire | 1 | 3a | | (20) | (24) | (26) | 28 | | | | | | | | | | (Ch) |
| 12-507 | Warrior | Cambridgeshire | | 3a | 17b | (20) | 24 | 26 | 28 | (37) | Al | Co | | | | | | Re | Ch |
| 13-03 | Beluga | Dorset | | (3a) | 17b | | | 26 | | 37 | Al | Co | | St | Cr | | | Re | Ch |
| 13-10 | KWS Croft | Cambridgeshire | | | 17b | (20) | | | (28) | 37 | Al | | (Tu) | | | | | (Re) | Ch |
| 13-34 | Crusoe | Hampshire | (1) | | 17b | | 24 | (26) | | | | (Co) | | | | | (Di) | (Re) | (Ch) |

Table 11: Seedling and adult plant reactions to the five isolates selected for further characterisation. Seedling results are shown as average infection types on a scale of 0-4. Adult plant results are given as a percentage leaf area infected averaged over three assessments. Red text denotes discrepancies between the seedling tests conducted as part of the original differential test for an isolate and the varietal seedling test presented here.

| Variety | RL Rating | Seedling Test (average infection type) | | | | | Adult Plant (% leaf area infected) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12/502 | 12/507 | 13/03 | 13/10 | 13/34 | 12/502 | 12/507 | 13/03 | 13/10 | 13/34 |
| Maris Ranger | | 1.0 | 0.0 | 2.5 | 1.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Reflection | 9 | 0.0 | 0.0 | i | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cougar | 8.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| KWS Kielder | 8.1 | 3.0 | 3.0 | 2.8 | 2.3 | 2.0 | 0.1 | 0.1 | 0.0 | 0.0 | 4.2 |
| Revelation | 8.6 | 3.0 | 2.5 | 2.0 | 2.5 | 2.0 | 0.2 | 0.2 | 0.1 | 0.1 | 0.9 |
| KWS Trinity | 9 | 2.5 | 2.5 | 0.0 | 2.0 | 3.0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Ruskin | 9 | 3.0 | 2.5 | 2.0 | 2.0 | 2.0 | 0.2 | 1.2 | 0.4 | 4.3 | 1.1 |
| Evolution | 8.6 | 0.8 | 2.0 | 2.0 | 2.0 | 2.3 | 0.3 | 0.3 | 3.5 | 0.3 | 3.5 |
| Sterna | | 3.0 | 2.5 | 2.0 | 2.5 | 3.0 | 0.3 | 1.0 | 0.1 | 0.1 | 0.0 |
| Glasgow | | 0.0 | 0.3 | i | 0.0 | 1.0 | 0.8 | 0.9 | 0.0 | 0.0 | 17.7 |
| Robigus | | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.8 | 1.7 | 0.8 | 0.0 | 0.0 |
| Maris Halberd | | 3.0 | 2.5 | 0.0 | 3.0 | 3.0 | 0.9 | 4.4 | 1.7 | 0.0 | 2.6 |
| Viscount | 6.6 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | 0.0 | 0.0 | 0.1 |
| Costello | | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 0.9 | 4.3 | 2.6 | 9.4 | 5.3 |
| KWS Sterling | | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 | 1.0 | 4.3 | 1.0 | 2.6 | 16.8 |
| Tuxedo | 8.2 | 2.5 | 2.5 | 2.0 | 2.0 | 2.0 | 1.1 | 1.0 | 2.1 | 10.4 | 19.5 |
| Dickens | 8.4 | 2.5 | 2.5 | 2.0 | 2.0 | 2.0 | 1.2 | 3.6 | 2.0 | 4.4 | 1.1 |
| Relay | 7.7 | 2.5 | 2.0 | 2.0 | 2.0 | 3.0 | 1.2 | 4.3 | 1.2 | 2.0 | 2.5 |
| KWS Cashel | 8.7 | 2.5 | 3.0 | 1.0 | 1.0 | 3.0 | 1.3 | 3.5 | 6.0 | 0.1 | 4.3 |
| Solstice | 4.1 | 2.0 | 3.0 | 2.5 | 3.0 | 3.0 | 1.7 | 3.5 | 2.6 | 2.5 | 4.4 |
| Timber | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 2.5 | 2.5 | 5.9 | 13.4 |
| Horatio | 5.5 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 1.8 | 2.7 | 2.1 | 13.5 | 1.8 |
| Gallant | 5.4 | 3.0 | 3.0 | 2.0 | 2.5 | 3.0 | 1.8 | 10.1 | 6.1 | 1.7 | 4.3 |
| RGT Conversion | 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 1.9 | 3.4 | 16.1 | 5.2 |
| Cordiale | 3.2 | 2.5 | 3.0 | 2.5 | 2.0 | 3.0 | 2.7 | 5.9 | 7.5 | 19.3 | 5.0 |
| Icon | 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 | 2.8 | 3.7 | 14.4 | 17.0 |

| VARIETY | RL Rating | Seedling Test (average infection type) | | | | | Adult Plant (% leaf area infected) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12/502 | 12/507 | 13/03 | 13/10 | 13/34 | 12/502 | 12/507 | 13/03 | 13/10 | 13/34 |
| Skyfall | 8.4 | 2.0 | 2.5 | 2.5 | 2.0 | 2.0 | 2.7 | 3.7 | 0.9 | 7.6 | 1.8 |
| KWS Santiago | 6.4 | 3.0 | 2.0 | 2.0 | 2.0 | 2.5 | 2.7 | 6.0 | 9.3 | 15.3 | 20.2 |
| Scout | 7.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.8 | 17.7 | 3.6 | 16.0 | 2.0 |
| RGT Scrummage | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 6.9 | 5.9 | 27.9 | 13.3 |
| Delphi | 7.6 | 2.0 | 2.0 | 3.0 | 2.0 | 2.0 | 3.5 | 6.8 | 8.5 | 3.5 | 7.0 |
| Soissons | | 3.0 | 2.5 | 2.3 | 2.5 | 3.0 | 3.5 | 37.6 | 7.7 | 40.2 | 42.6 |
| Panorama | 5.6 | 3.0 | 3.0 | 2.5 | 2.0 | 3.0 | 3.6 | 2.1 | 2.7 | 14.3 | 2.8 |
| KWS Croft | 5.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.6 | 13.0 | 10.1 | 16.9 | 14.3 |
| Conqueror | 6.8 | 3.0 | 2.5 | 2.8 | 3.0 | 2.3 | 3.6 | 4.5 | 17.0 | 23.6 | 21.0 |
| Invicta | 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.6 | 5.1 | 2.8 | 15.0 | 2.7 |
| Britannia | 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.2 | 6.8 | 2.7 | 29.0 | 16.4 |
| Gamin | | 2.5 | 2.5 | 2.0 | 2.3 | 2.5 | 4.2 | 9.2 | 8.5 | 7.6 | 5.1 |
| JB Diego | 5.4 | 3.0 | 3.0 | 2.0 | 2.0 | 2.0 | 4.3 | 5.4 | 6.9 | 26.9 | 29.4 |
| Grafton | 4.2 | 2.5 | 2.5 | 2.5 | 2.5 | 2.0 | 4.4 | 5.4 | 3.7 | 12.6 | 23.5 |
| Jorvik | 5 | 2.0 | 2.5 | i | 3.0 | 3.0 | 4.4 | 12.6 | 4.4 | 27.7 | 27.2 |
| Cubanita | 4.4 | 3.0 | 3.0 | 2.5 | 2.5 | 3.0 | 4.5 | 10.2 | 9.2 | 22.6 | 22.0 |
| Alchemy | 3.8 | 2.5 | 3.0 | 3.0 | 2.5 | 2.8 | 4.6 | 7.7 | 16.1 | 21.3 | 26.2 |
| Panacea | 5.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.1 | 5.9 | 6.7 | 33.0 | 7.5 |
| Reaper | | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 5.2 | 12.8 | 15.0 | 6.0 | 26.8 |
| Crusoe | 6.2 | 3.0 | 2.0 | 3.0 | 2.0 | 3.0 | 6.7 | 21.7 | 16.0 | 20.1 | 35.8 |
| Chilton | 3.5 | 3.0 | 2.5 | 3.0 | 2.0 | 2.5 | 6.8 | 13.4 | 7.7 | 22.7 | 4.6 |
| Mascot | | 2.5 | 2.0 | 2.0 | 2.0 | 2.0 | 6.8 | 9.2 | 34.3 | 16.7 | 32.6 |
| KWS Tempo | 8 | 2.0 | 2.0 | i | 2.0 | 2.0 | 7.1 | 4.5 | 1.2 | 6.8 | 5.7 |
| Claire | 4.8 | 2.0 | 2.5 | 3.0 | 2.0 | 3.0 | 7.7 | 7.8 | 2.7 | 21.3 | 6.1 |
| Energise | 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.7 | 15.7 | 13.6 | 40.9 | 23.4 |
| Leeds | 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.8 | 13.7 | 17.6 | 44.4 | 28.5 |
| Zulu | 4.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.0 | 8.0 | 17.6 | 9.4 | 25.2 | 16.3 |
| KWS Lili | 6 | 2.5 | 2.0 | 2.0 | 2.3 | 3.0 | 8.1 | 8.6 | 9.4 | 12.6 | 28.3 |
| KWS Target | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.4 | 10.7 | 16.2 | 23.4 | 16.8 |
| Monterey | 4.1 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 8.6 | 12.8 | 30.5 | 49.2 | 28.5 |

| VARIETY | RL Rating | Seedling Test (average infection type) | | | | | Adult Plant (% leaf area infected) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 12/502 | 12/507 | 13/03 | 13/10 | 13/34 | 12/502 | 12/507 | 13/03 | 13/10 | 13/34 |
| Twister | 3.9 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 9.3 | 13.5 | 24.3 | 40.5 | 25.1 |
| Myriad | 4.3 | 0.8 | 0.3 | 0.0 | 0.0 | 0.0 | 11.0 | 17.3 | 6.9 | 33.3 | 17.0 |
| Consort | | 2.0 | 2.5 | 2.0 | 3.0 | 3.0 | 11.8 | 35.8 | 12.8 | 43.3 | 35.1 |
| KWS Gator | 2.5 | 3.0 | 2.5 | 3.0 | 2.0 | 3.0 | 12.3 | 17.7 | 25.2 | 45.0 | 29.3 |
| Armada | | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 14.5 | 21.7 | 14.4 | 17.7 | 7.8 |
| Warrior | | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 15.1 | 26.0 | 31.3 | 38.5 | 38.3 |
| Avalon | | 2.5 | 2.5 | 2.0 | 2.0 | 2.5 | 18.4 | 23.0 | 28.5 | 36.0 | 25.9 |
| Maris Huntsman | | 2.5 | 2.0 | i | 2.0 | 2.5 | 19.3 | 30.5 | 18.3 | 27.8 | 28.5 |
| Beluga | 3.2 | 3.0 | 2.5 | 2.5 | 2.0 | 3.0 | 21.4 | 6.8 | 12.2 | 30.9 | 15.9 |
| Stigg | | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 25.2 | 20.1 | 26.7 | 36.0 | 23.6 |
| Sappo | | 3.0 | 2.0 | 1.0 | 1.0 | 3.0 | 26.8 | 26.9 | 16.8 | 34.4 | 28.4 |
| Maris Fundin | | 2.5 | 3.0 | i | 2.3 | 3.0 | 30.8 | 7.6 | 20.2 | 27.6 | 20.9 |

The reaction of Crusoe in the varietal seedling test also highlights another anomaly within the seedling tests. When comparing the virulence profiles of the isolates on the varieties under test with the differential test results (Table 7), some of the varieties common to both tests showed different results in the two tests (text highlighted red). There are several reasons why this discrepancy may have arisen. Firstly, the multiplication of brown rust for the differential tests is more labour-intensive than for yellow rust and therefore requires more cycles of multiplication. This could lead to spontaneous mutations in the isolates. We are currently investigating alternative methods in collaboration with other rust researchers to reduce the amount of spores required to do a differential test, thereby limiting the chance for mutations. The second alternative is that a different seed stock has been used for the two tests. This is a more plausible explanation and will be remedied in future as we switch to using the Thatcher NILs which are currently being multiplied under strict conditions which aim to limit the possibility of cross-pollination. With these discrepancies this dataset should be interpreted with extreme caution as it is not possible to be sure that the isolate is correct or the host is correct. There will be no further interpretation of the second seedling test as part of this report.

Within the adult plant trials, known susceptible varieties showed the highest percent leaf area infected. Only about 20% of the varieties trialled showed either no disease or trace levels to the different isolates. This included Robigus, which showed no disease in any of the trials. The plants in the field were confirmed as being Robigus by experts at NIAB which leads us to conclude that although some of the isolates were virulent on Robigus at the seedling stage; we cannot label any of them as Robigus-virulent isolates. Complete susceptibility was seen in 10 of the varieties tested. The remaining 32 varieties differed in their response to the different isolates and it is difficult to make broad conclusions concerning the resistance in these varieties considering their reactions and the possibility of the introduction of an unknown isolate(s) into the trials.

## 5. Acknowledgements

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## 6. References

Anon. 2013. Winter wheat commercial crops survey 2013 [Online] http://www.cropmonitor.co.uk/cmsReport.cfm?id=25 (verified 09/02/15).

Goyeau, H., and C. Lannou. 2011. Specific resistance to leaf rust expressed at the seedling stage in cultivars grown in France from 1983 to 2007. Euphytica 178:45-62.

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 51:24-32.

Kolmer, J.A., and M.E. Hughes. 2014. Physiologic Specialization of Puccinia triticina on Wheat in the United States in 2012. Plant Disease 98:1145-1150.

# 7. Appendix 1: Sample Register

## 2013 Wheat Yellow Rust UKCPVS Sample Register

| Isolate Number | Host Variety | Location | 2013/14 RL Rating |
|---|---|---|---|
| 13/524 | Ambition | Cambridgeshire | |
| 13/501 | Apache | Cambridgeshire | |
| 13/502 | Apache | Cambridgeshire | |
| 13/519 | Apache | Cambridgeshire | |
| 13/521 | Apache | Cambridgeshire | |
| 13/525 | Apache | Cambridgeshire | |
| 13/529 | Cadenza | Cambridgeshire | |
| 13/530 | Cadenza | Cambridgeshire | |
| 13/531 | Cadenza | Cambridgeshire | |
| 13/60 | Chilton | Cambridgeshire | 6.6 |
| 13/65 | Claire | Cambridgeshire | 5.8 |
| 13/57 | Cordiale | Cambridgeshire | 5.9 |
| 13/97 | Cougar | Cambridgeshire | 8.3 |
| 13/182 | Crusoe | Cambridgeshire | 8.5 |
| 13/53 | Denman | Cambridgeshire | 4.2 |
| 13/54 | Fugue | Cambridgeshire | |
| 13/58 | Gallant | Cambridgeshire | 5.4 |
| 13/167 | Gallant | Cambridgeshire | 5.4 |
| 13/52 | Goldengun | Cambridgeshire | |
| 13/66 | Horatio | Cambridgeshire | 5.7 |
| 13/79 | KWS Dali | Cambridgeshire | |
| 13/78 | KWS Kielder | Cambridgeshire | 4 |
| 13/62 | KWS Podium | Cambridgeshire | 6.5 |
| 13/51 | KWS Santiago | Cambridgeshire | 4.7 |
| 13/61 | KWS Sterling | Cambridgeshire | 8 |
| 13/503 | KWS Sterling | Cambridgeshire | 8 |
| 13/504 | KWS Sterling | Cambridgeshire | 8 |
| 13/04 | Oakley | Cambridgeshire | |
| 13/55 | Oakley | Cambridgeshire | |
| 13/518 | Oakley | Cambridgeshire | |
| 13/160 | Paragon | Cambridgeshire | 7.6 |
| 13/56 | Solstice | Cambridgeshire | 4.3 |
| 13/59 | Solstice | Cambridgeshire | 4.3 |
| 13/63 | SY110110 | Cambridgeshire | |
| 13/03 | Torch | Cambridgeshire | |
| 13/64 | Torch | Cambridgeshire | |
| 13/511 | Victo | Cambridgeshire | |
| 13/512 | Victo | Cambridgeshire | |
| 13/513 | Victo | Cambridgeshire | |
| 13/514 | Victo | Cambridgeshire | |

| Isolate Number | Host Variety | Location | 2013/14 RL Rating |
|---|---|---|---|
| 13/515 | Victo | Cambridgeshire | |
| 13/516 | Victo | Cambridgeshire | |
| 13/517 | Victo | Cambridgeshire | |
| 13/505 | Vuka | Cambridgeshire | |
| 13/506 | Vuka | Cambridgeshire | |
| 13/507 | Vuka | Cambridgeshire | |
| 13/508 | Vuka | Cambridgeshire | |
| 13/509 | Vuka | Cambridgeshire | |
| 13/510 | Vuka | Cambridgeshire | |
| 13/520 | Warrior | Cambridgeshire | |
| 13/116 | Torch | Devon | |
| 13/177 | Beluga | Dorset | 4.8 |
| 13/180 | Cordiale | Dorset | 5.9 |
| 13/178 | Cubanita | Dorset | |
| 13/179 | KWS Kielder | Dorset | 4 |
| 13/181 | Solstice | Dorset | 4.3 |
| 13/144 | Chilton | Essex | 6.6 |
| 13/134 | Cocoon | Essex | 7.5 |
| 13/128 | Cordiale | Essex | 5.9 |
| 13/147 | Denman | Essex | 4.2 |
| 13/149 | Duxford | Essex | 4.6 |
| 13/133 | Gallant | Essex | 5.4 |
| 13/131 | Goldengun | Essex | |
| 13/139 | Grafton | Essex | 6.1 |
| 13/148 | Horatio | Essex | 5.7 |
| 13/127 | JB Diego | Essex | 8 |
| 13/129 | KWS Bonai | Essex | |
| 13/140 | KWS Dali | Essex | |
| 13/143 | KWS Kielder | Essex | 4 |
| 13/130 | KWS Podium | Essex | 6.5 |
| 13/132 | KWS Rowan | Essex | |
| 13/145 | KWS Santiago | Essex | 4.7 |
| 13/146 | Panacea | Essex | |
| 13/138 | Skyfall | Essex | |
| 13/135 | Solstice | Essex | 4.3 |
| 13/142 | SY110110 | Essex | |
| 13/137 | Torch | Essex | |
| 13/150 | Twister | Essex | |
| 13/136 | Weaver | Essex | |
| 13/11 | Horatio | Gloucestershire | 5.7 |
| 13/26 | Horatio | Gloucestershire | 5.7 |
| 13/05 | Oakley | Gloucestershire | |
| 13/10 | Oakley | Gloucestershire | |
| 13/27 | Oakley | Gloucestershire | |

| Isolate Number | Host Variety | Location | 2013/14 RL Rating |
|---|---|---|---|
| 13/28 | Solstice | Gloucestershire | 4.3 |
| 13/20 | KWS Rowan | Hampshire | |
| 13/98 | Mulika | Hampshire | 7.8 |
| 13/164 | Fugue | Herefordshire | |
| 13/165 | Gallant | Herefordshire | 5.4 |
| 13/166 | Invicta | Herefordshire | 7.8 |
| 13/163 | KWS Dali | Herefordshire | |
| 13/161 | KWS Kielder | Herefordshire | 4 |
| 13/162 | Solstice | Herefordshire | 4.3 |
| 13/188 | Cordiale | Kent | 5.9 |
| 13/185 | Duxford | Kent | 4.6 |
| 13/186 | Horatio | Kent | 5.7 |
| 13/117 | Oakley | Kent | |
| 13/187 | Solstice | Kent | 4.3 |
| 13/120 | Ambition | Lincolnshire | |
| 13/123 | Ambition | Lincolnshire | |
| 13/87 | Beluga | Lincolnshire | 4.8 |
| 13/83 | Cordiale | Lincolnshire | 5.9 |
| 13/95 | Denman | Lincolnshire | 4.2 |
| 13/82 | Duxford | Lincolnshire | 4.6 |
| 13/92 | Gallant | Lincolnshire | 5.4 |
| 13/12 | Goldengun | Lincolnshire | |
| 13/93 | Goldengun | Lincolnshire | |
| 13/94 | Gravitas | Lincolnshire | 4.8 |
| 13/86 | Horatio | Lincolnshire | 5.7 |
| 13/88 | JB Diego | Lincolnshire | 8 |
| 13/25 | KWS Dali | Lincolnshire | |
| 13/96 | KWS Dali | Lincolnshire | |
| 13/24 | KWS Kielder | Lincolnshire | 4 |
| 13/90 | KWS Kielder | Lincolnshire | 4 |
| 13/23 | KWS Santiago | Lincolnshire | 4.7 |
| 13/85 | KWS Santiago | Lincolnshire | 4.7 |
| 13/01 | Oakley | Lincolnshire | |
| 13/09 | Oakley | Lincolnshire | |
| 13/14 | Oakley | Lincolnshire | |
| 13/41 | Oakley | Lincolnshire | |
| 13/84 | Oakley | Lincolnshire | |
| 13/171 | Oakley | Lincolnshire | |
| 13/43 | Oakley | Lincolnshire | |
| 13/48 | Oakley | Lincolnshire | |
| 13/170 | Robigus | Lincolnshire | |
| 13/22 | Solstice | Lincolnshire | 4.3 |
| 13/81 | Solstice | Lincolnshire | 4.3 |
| 13/91 | Solstice | Lincolnshire | 4.3 |

| Isolate Number | Host Variety | Location | 2013/14 RL Rating |
|---|---|---|---|
| 13/89 | Torch | Lincolnshire | |
| 13/08 | Victo | Lincolnshire | |
| 13/13 | Victo | Lincolnshire | |
| 13/31 | Victo | Lincolnshire | |
| 13/45 | Victo | Lincolnshire | |
| 13/49 | Victo | Lincolnshire | |
| 13/176 | Chilton | Norfolk | 6.6 |
| 13/175 | Invicta | Norfolk | 7.8 |
| 13/174 | KWS Evoke | Norfolk | |
| 13/21 | Solstice | Norfolk | 4.3 |
| 13/50 | Solstice | Norfolk | 4.3 |
| 13/172 | Solstice | Norfolk | 4.3 |
| 13/173 | Torch | Norfolk | |
| 13/77 | Chilton | North Yorkshire | 6.6 |
| 13/07 | Claire | North Yorkshire | 5.8 |
| 13/105 | Cordiale | North Yorkshire | 5.9 |
| 13/110 | Denman | North Yorkshire | 4.2 |
| 13/100 | Gallant | North Yorkshire | 5.4 |
| 13/106 | Goldengun | North Yorkshire | |
| 13/103 | JB Diego | North Yorkshire | 8 |
| 13/108 | KWS Dali | North Yorkshire | |
| 13/104 | KWS Podium | North Yorkshire | 6.5 |
| 13/102 | KWS Santiago | North Yorkshire | 4.7 |
| 13/111 | Oakley | North Yorkshire | |
| 13/99 | Panacea | North Yorkshire | |
| 13/109 | Skyfall | North Yorkshire | |
| 13/101 | SY110110 | North Yorkshire | |
| 13/06 | Torch | North Yorkshire | |
| 13/107 | Twister | North Yorkshire | |
| 13/112 | Victo | North Yorkshire | |
| 13/169 | Denman | Northern Ireland | 4.2 |
| 13/168 | Torch | Northern Ireland | |
| 13/156 | Chilton | Oxfordshire | 6.6 |
| 13/157 | Claire | Oxfordshire | 5.8 |
| 13/155 | Cordiale | Oxfordshire | 5.9 |
| 13/152 | Denman | Oxfordshire | 4.2 |
| 13/154 | Gallant | Oxfordshire | 5.4 |
| 13/159 | Grafton | Oxfordshire | 6.1 |
| 13/29 | Solstice | Oxfordshire | 4.3 |
| 13/158 | Solstice | Oxfordshire | 4.3 |
| 13/153 | Torch | Oxfordshire | |
| 13/02 | Oakley | Shropshire | |
| 13/16 | Cubanita | Suffolk | |
| 13/17 | Duxford | Suffolk | 4.6 |

| Isolate Number | Host Variety | Location | 2013/14 RL Rating |
|---|---|---|---|
| 13/18 | KWS Dali | Suffolk | |
| 13/19 | Panacea | Suffolk | |
| 13/15 | Torch | Suffolk | |
| 13/80 | JB Diego | Warwickshire | 8 |
| 13/70 | Oakley | Yorkshire | |
| 13/72 | Victo | Yorkshire | |

## 2013 Wheat Brown Rust UKCPVS Sample Register

| Isolate Number | Host Variety | Location | 2013/14 RL Rating |
|---|---|---|---|
| 13/22 | Beluga | Cambridgeshire | 4 |
| 13/14 | Chilton | Cambridgeshire | 4 |
| 13/16 | Conqueror | Cambridgeshire | 6 |
| 13/26 | Duxford | Cambridgeshire | 4 |
| 13/15 | Fugue | Cambridgeshire | 4 |
| 13/21 | Gravitas | Cambridgeshire | 5 |
| 13/24 | Icebreaker | Cambridgeshire | 5 |
| 13/29 | Icon | Cambridgeshire | 5 |
| 13/33 | Invicta | Cambridgeshire | 6 |
| 13/12 | KWS Bonham | Cambridgeshire | 3 |
| 13/10 | KWS Croft | Cambridgeshire | 6 |
| 13/17 | KWS Dali | Cambridgeshire | 6 |
| 13/25 | KWS Gator | Cambridgeshire | 3 |
| 13/11 | KWS Rowan | Cambridgeshire | 6 |
| 13/32 | KWS Target | Cambridgeshire | 4 |
| 13/27 | Lancaster | Cambridgeshire | 4 |
| 13/28 | Leeds | Cambridgeshire | 5 |
| 13/09 | Monterey | Cambridgeshire | 5 |
| 13/19 | Panacea | Cambridgeshire | 5 |
| 13/13 | Panorama | Cambridgeshire | 5 |
| 13/23 | Revelation | Cambridgeshire | 9 |
| 13/30 | Scout | Cambridgeshire | 8 |
| 13/02 | Torch | Cambridgeshire | |
| 13/18 | Twister | Cambridgeshire | 4 |
| 13/20 | Viscount | Cambridgeshire | 7 |
| 13/31 | Zulu | Cambridgeshire | 4 |
| 13/03 | Beluga | Dorset | 4 |
| 13/35 | Cordiale | Hampshire | 3 |
| 13/34 | Crusoe | Hampshire | 6 |
| 13/37 | Invicta | Hampshire | 6 |
| 13/38 | JB Diego | Hampshire | 4 |
| 13/36 | KWS Gator | Hampshire | 3 |
| 13/40 | KWS Santiago | Hampshire | 6 |
| 13/41 | KWS Target | Hampshire | 4 |
| 13/39 | Relay | Hampshire | 7 |
| 13/42 | Tuxedo | Hampshire | 8 |
| 13/04 | Cordiale | Kent | 3 |
| 13/07 | Claire | Lincolnshire | 5 |
| 13/06 | Denman | Lincolnshire | 5 |
| 13/05 | Solstice | Lincolnshire | 4 |
| 13/01 | Stigg | Lincolnshire | |
| 13/08 | Torphins | Lincolnshire | 6 |