

**Watkins landraces contain novel sources of *Puccinia striiformis* f. sp. *tritici* (*Pst*) resistance effective against *Yr15*-breaking *Pst* isolates**

Clare M. Lewis<sup>1</sup>, Michelle Leverington-Waite<sup>1</sup>, Sarah Collier<sup>1</sup>, Simon Orford<sup>1</sup>, Noam Chayut<sup>1</sup>,  
Simon Griffiths<sup>1</sup>, Diane G.O. Saunders<sup>1\*</sup>,

<sup>1</sup>John Innes Centre, Norwich Research Park, Norwich NR4 7UH, UK.

\*Corresponding author: [Diane.Saunders@jic.ac.uk](mailto:Diane.Saunders@jic.ac.uk)

**Abstract**

In early 2025, *Puccinia striiformis* f. sp. *tritici* (*Pst*) isolates were detected in the UK that were able to overcome resistance conferred by the widely deployed yellow rust resistance gene, *Yr15*. As *Yr15* is highly prevalent in modern European wheat varieties, this placed approximately half of the UK wheat market share vulnerable to infection. Subsequently, it was shown that these emergent *Pst* isolates were derived from *Pst* isolates belonging to the ‘Warrior’ *Pst* race groups that dominate in Europe. Here, we set out to determine if thirty-three A.E. Watkins heritage wheat landraces previously shown to harbour resistance to ‘Warrior’ *Pst* race group isolates, could also confer resistance to *Yr15*-breaking *Pst* isolates. One *Yr15*-breaking *Pst* isolate found in the UK in 2025 was used to conduct infection assays with the 33 Watkins landraces, alongside 11 additional Watkins landraces known to be susceptible to ‘Warrior’ *Pst* isolates. We found that 32 of the 33 Watkins landraces displayed resistant phenotypes when inoculated with the emergent *Yr15*-breaking *Pst* isolate. These 32 wheat landraces now represent a rich and valuable resource for identifying potentially novel sources of *Pst* resistance that could be mobilized to diversify modern wheat resistance breeding and reduce the future risk of similar widespread single-gene breakdowns.

## Introduction

Wheat yellow rust – caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*) – is the most damaging of the three wheat rusts in Europe, including the UK<sup>1</sup>. Traditionally, integration of race-specific resistance (*R*) genes has been the most effective mechanism to control – the ‘polio of agriculture’ – the wheat rusts. However, *R*-genes are frequently overcome by emergence of new virulent pathogen races, so combining multiple *R*-genes is essential for achieving long-lasting resilience. In late May 2025, the UK Cereal Pathogen Virulence Survey (UKCPVS) raised the alarm that new *Pst* isolates had been detected with the ability to overcome resistance conferred by the yellow rust resistance gene, *Yr15*<sup>2</sup>. In mid-June 2025, the Global Rust Reference Centre confirmed presence of *Yr15*-breaking *Pst* isolates across multiple countries in Europe, including Belgium, Denmark, France<sup>3</sup>. The *Yr15* resistant gene was introgressed into European wheat varieties during the 1990s, and is highly prevalent in modern varieties<sup>3</sup>. Accordingly, at least 49% of the UK wheat market share was subsequently found reliant on this single gene (*Yr15*) for genetic protection against yellow rust, creating a severe vulnerability that is now exposed<sup>4</sup>. This includes the three dominant wheat varieties (KWS Dawsum, LG Beowulf and Champion) that account for 33% of UK market share and are now highly susceptible to *Pst* infection<sup>4</sup>. Thus, new diverse sources of yellow rust resistance are urgently needed for immediate incorporation into the UK wheat breeding pipelines.

Since incursion of the aggressive/multi-virulent ‘Warrior’ *Pst* race groups into Europe in 2011, these isolates have rapidly diversified and expanded their virulence profiles<sup>5</sup>. Genetic analysis of *Pst* isolates identified in the UK in early 2025 confirmed these “new” *Pst* isolates had emerged from further diversification in the Warrior *Pst* race group, rather than through an exotic incursion<sup>4</sup>. Here, we set out to evaluate the A.E. Watkins collection of 827 heritage wheat landraces to identify lines with resistance to *Yr15*-breaking *Pst* isolates. The A.E. Watkins collection is a rich geographically and phenotypically diverse resource, assembled in the 1920s and 1930s from collections derived from 32 countries<sup>6</sup>. Recent whole genome resequencing data revealed that this wheat landrace collection is comprised of seven ancestral groups. Comparison with genomic data from a global panel of modern wheat cultivars revealed that only two of the seven groups are highly represented in modern wheat, leaving behind a breadth of untapped diversity with potential to improve modern wheat varieties<sup>6</sup>. In addition, prior evaluation of the A.E. Watkins collection of wheat landraces had identified 33 lines (out of 827) with resistance to both *PstS10* and *PstS7*

isolates within the ‘Warrior’ *Pst* race group<sup>6</sup>. Thus, we focused on these 33 Watkins lines and found 32 retained resistances to *Yr15*-breaking *Pst* isolates. These 32 lines now represent a targeted rich resource of underexplored genetic diversity that could potentially harbour new *Pst* resistance sources that could be mobilized into wheat resistance breeding.

## Materials and methods

Urediniospores of the *Yr15*-breaking *Pst* isolate termed 25.0004 were independently resuspended in Novec<sup>TM</sup> 7100 engineered fluid (Sigma-Aldrich, UK) and used for spray inoculation of ten seedlings (biological replicates) of forty-four lines derived from the [Watkins Stabilised Collection of Tetraploid and Hexaploid Landrace Wheats](#) and the susceptible control line Vuka. Wheat seedlings were inoculated once they reached the three-leaf stage following described procedures<sup>7</sup>, misted with water and incubated in darkness at 10°C for 24 h under high relative humidity. Following incubation, plants were transferred to greenhouse rooms maintained at 17°C (day)/12°C (night), with a 16-h photoperiod of natural light supplemented with sodium light (100  $\mu\text{mol s}^{-1} \text{m}^{-2}$ ) and 8 h dark. At 14 days post-inoculation *Pst* infection types were scored on the second leaf of each seedling using a standard 0-4 infection scale, where 0 = immune: no uredinia or other macroscopic sign of infection, ; = nearly immune: no uredinia, but hypersensitive necrotic or chlorotic flecks present, 1 = highly resistant: small uredinia surrounded by necrosis, 2 = moderately resistant: small to medium uredinia surrounded by chlorosis or necrosis, 3 = moderately susceptible: medium-sized uredinia that may be associated with chlorosis, 4 = susceptible: large uredinia without chlorosis<sup>7</sup>.

## Results

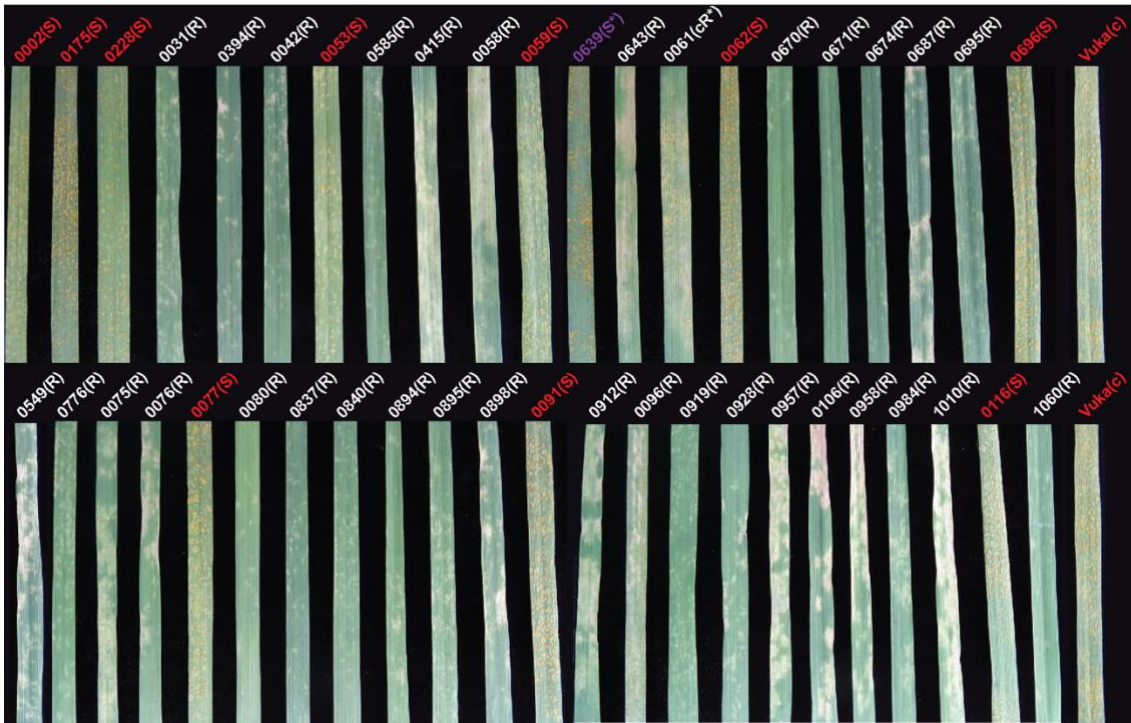
To determine if the 33 (out of 827) A.E. Watkins landraces with resistance to both *PstS10* and *PstS7* isolates within the Warrior *Pst* race group<sup>6</sup> (**Table 1**) had maintained resistance to *Yr15*-breaking *Pst* isolates, we conducted infection assays with one *Yr15*-breaking *Pst* isolate collected in the UK in 2025. Following multiplication, urediniospores of the *Pst* isolate were independently used to inoculate the 33 Watkins landraces and a subset of 11 additional Watkins landraces previously shown to be susceptible to *PstS10* and *PstS7* isolates. We also included the standard susceptible Vuka line as a further control. Disease severity was assessed for each of the forty-five

lines 14 days post-inoculation in seedling assays. This analysis revealed that 32 of the 33 lines that had previously displayed resistance to both *PstS10* and *PstS7* ‘Warrior’ race group isolates, retained resistance to the *Yr15*-breaking *Pst* isolates, with only two displaying minor pustule development (**Fig. 1**). In addition, among the 32 Watkins lines displaying resistant phenotypes, 11 exhibited small necrotic dots on the leaf (scored ;), 6 underlying chlorosis (scoring c or cc), 11 underlying necrosis (scoring n or nn) and four lines displayed both necrosis and chlorosis (scoring nc) (**Table 1**). These results were further substantiated through independent infection assays with two additional *Yr15*-breaking *Pst* isolates from the UK using subsets of the 33 Watkins landraces, which produced identical results.

**Table 1. *Pst* infection responses for 33 Watkins lines to two ‘Warrior’ race group isolates (19/501 and 16/342) and the *Yr15*-breaking isolate 25.0004.** 19/501, *PstS7* isolate; 16/342, *PstS10* isolate; 25.0004, *Yr15*-breaking *Pst* isolate; R/S, resistance/susceptible reactions. The ‘derived purified line’ name can be used to identify corresponding lines listed at the [Germplasm Resources Unit](#), Norwich, UK.

Derived purified line	Historic Accession name	Country of origin	19/501 <sup>6</sup>	R/S	16/342 <sup>6</sup>	R/S	25.0004	R/S
WATDE0031	1190238	Iran	0nc	R	0nc	R	0n	R
WATDE0042	1190308	Iran	0c	R	0c	R	0n	R
WATDE0058	1190444	China	1nc	R-	1+/-	R-	1-c	R
WATDE0075	1190579	Iran	0c/1	R-	0c/1	R-	0c	R
WATDE0076	1190580	Iran	0c	R	0c	R	0n	R
WATDE0080	1190627	Iran	0c	R	0c	R	0;	R
WATDE0096	1190704	Iran	1	R-	1cc	R-	1-n	R
WATDE0106	1190747	Ethiopia	0cc/1	R-	0nc/1	R(-)	0nc	R
WATDE0394	1190240	Iran	0nc	R	0c	R	0n	R
WATDE0415	1190257	Tunisia	1+	R-	2-	R-	0cc	R
WATDE0549	1190375	Iran	0	R	0	R	0nn	R
WATDE0585	1190407	India	0nc	R	0cc	R	0n	R
WATDE0639	1190453	Afghanistan	1+	R-	2+/-	R-	3	S
WATDE0643	1190456	Afghanistan	0cc	R	0c/1	R(-)	0cc	R
WATDE0670	1190486	USSR	0c/1	R(-)	0cc/1	R(-)	0;	R
WATDE0671	1190487	USSR	0c	R	0c	R	0;	R
WATDE0674	1190489	USSR	0nc	R	0	R	0;	R
WATDE0687	1190500	Iraq	0cc	R	0nc	R	0n	R
WATDE0695	1190506	Iran	0	R	0c/1	R(-)	0;	R
WATDE0776	1190576	Iran	0	R	0c/1	R(-)	0;	R
WATDE0837	1190628	Iran	0c	R	0	R	0;	R
WATDE0840	1190631	Iran	0c	R	0c	R	0;	R
WATDE0894	1190677	Spain	0cc	R	1	R-	0c	R
WATDE0895	1190678	Iran	0c	R	0c	R	0c	R
WATDE0898	1190681	Iran	0c/1	R(-)	0c	R	0n	R

Derived purified line	Historic Accession name	Country of origin	19/501 <sup>6</sup>	R/S	16/342 <sup>6</sup>	R/S	25.0004	R/S
WATDE0912	1190699	China	1	R-	1+/-	R-	0nc	R
WATDE0919	1190711	India	0c	R	0	R	0;	R
WATDE0928	1190718	China	0nc	R	0c	R	0n	R
WATDE0957	1190745	USSR	1+	R-	1	R-	0nc	R
WATDE0958	1190748	USSR	1	R-	1n	R-	0nn	R
WATDE0984	1190769	Algeria	0c	R	0c	R	0c	R
WATDE1010	1190793	USSR	1	R-	0cc	R	0nn	R
WATDE1060	1190903	India	0cc	R	0c	R	0;	R



**Figure 1. *Pst* infection assays reveal that 32 of the 33 Watkins lines that display resistance to ‘Warrior’ *Pst* isolates maintain resistance to *Yr15*-breaking *Pst* isolates. *Pst* infection assay with isolate 25.0004 is displayed, with infection types examined 14 days post-inoculation. A Watkins landrace resistant to ‘Warrior’ *Pst* isolates and susceptible to *Yr15*-breaking *Pst* isolates is indicated (S\*) and a Watkins landrace susceptible to ‘Warrior’ *Pst* isolates and moderately resistant to *Yr15*-breaking *Pst* isolates (cR\*). Abbreviated accession names: WATDExxxx. Phenotypes: R, resistant; S, susceptible. c, control.**

## Conclusion

Wheat cultivation is continually threatened by biotic stressors, such as the wheat rusts, which destroy ~15 million tons (\$2.9 billion) of wheat worldwide annually<sup>8</sup>. The emergence of new strains with expanded virulence profiles is especially damaging. This is exemplified by the recent emergence of *Pst* isolates that led to the breakdown of *Yr15* resistance in Europe, which has placed half of UK wheat market share vulnerable to infection<sup>4</sup>. Here, we utilised the vast untapped diversity in the Watkins landrace collection to identify 32 lines with resistance to these emergent *Yr15*-breaking *Pst* isolates. Future characterisation of these highly diverse Watkins landrace lines now has high potential to uncover multiple novel resistance loci (and associated markers) that could be mobilized to substantially diversify the UK resistance gene catalogue and reduce the future risk of similar widespread single-gene breakdowns.

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