RUSTWATCH

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EXECUTIVE SUMMARY

In this study, 250 winter wheat varieties and breeding lines were tested for susceptibility to novel emerging races of yellow rust (YR), leaf rust (LR) and stem rust (SR) under field conditions. The nurseries were conducted in DK (AU), UK (NIAB), DE (JKI), IT (AS.A.R), FR (ARVALIS) and at three locations of the breeders' network in DE (BREUN), SW (LANTMÄNNEN) and UK (RAGT). The methodology used for this is described in the milestone report M3.13 'Sharing protocols between partners for evaluating adult plant resistance of varieties and breeding lines to rust diseases under field conditions'.

The results of the 2019/2020 field nurseries were analysed using the Field Nursery Data Management System (FNDMS), a collaborative effort between WP3 and WP4. This system, described in the annex of this deliverable report, checks, analyses, visualises and stores the data.

A total of 88 % of the varieties tested across all locations reacted with low susceptibility to YR, 97 % to LR and 26 % to SR. The higher infestation pressure after artificial YR inoculation enabled a more stringent selection of resistant varieties.

LR was tested in three locations with only natural infestations. Due to the extremely high pressure of infestation at the ARVALIS location, only 8% of the varieties reacted with low susceptibility, while the insufficient natural infestation at the locations of BREUN and AS.A.R did not allow effective selection auf LR resistant varieties.

Susceptibility to SR was tested both, with artificial inoculations of a mixture of races at the JKI site in Germany and under natural infection conditions at the AS.A.R site in Sicily. With both methods, a proportion of 26% varieties with low susceptibility to SR could be determined indicating that efficient selection of resistant varieties is even possible under optimal conditions of natural infections.

Field nurseries under natural conditions of infection are suitable for an initial selection of rust-resistant varieties, but are heavily dependent on the weather conditions and the infection potential of the existing rust populations. Additional artificial inoculations with individual races or mixtures of races can significantly increase the success of selection and thus accelerate the development of rust-resistant varieties.

The Field Nursery Data Management System (FNDMS) will be further developed and used for the dissemination of results to stakeholders, breeders and seed suppliers.

Materials and Methods

In this study, up to 250 winter wheat varieties and breeding lines were tested under field conditions for susceptibility to emerging races of yellow rust (YR), leaf rust (LR) and stem rust (SR) in Europe. The nurseries were conducted in DK (AU), UK (NIAB), DE (JKI), IT (AS.A.R), FR (ARVALIS) and at three locations of the breeders' network in DE (BREUN), SW (LANTMÄNNEN) and UK (RAGT) (Figure 1, Table 1, Table 2). Field nurseries in DK and UK were inoculated with individual races of YR and trials in DE with a mixture of YR races followed by an inoculation of SR races on the same plot. For the other locations, spontaneous infections emerging from natural rust populations were assessed.
The methodologies used at the different trial sites have been presented in milestone report M3.13 'Sharing protocols between partners for evaluating adult plant resistance of varieties and breeding lines to rust diseases under field conditions'.

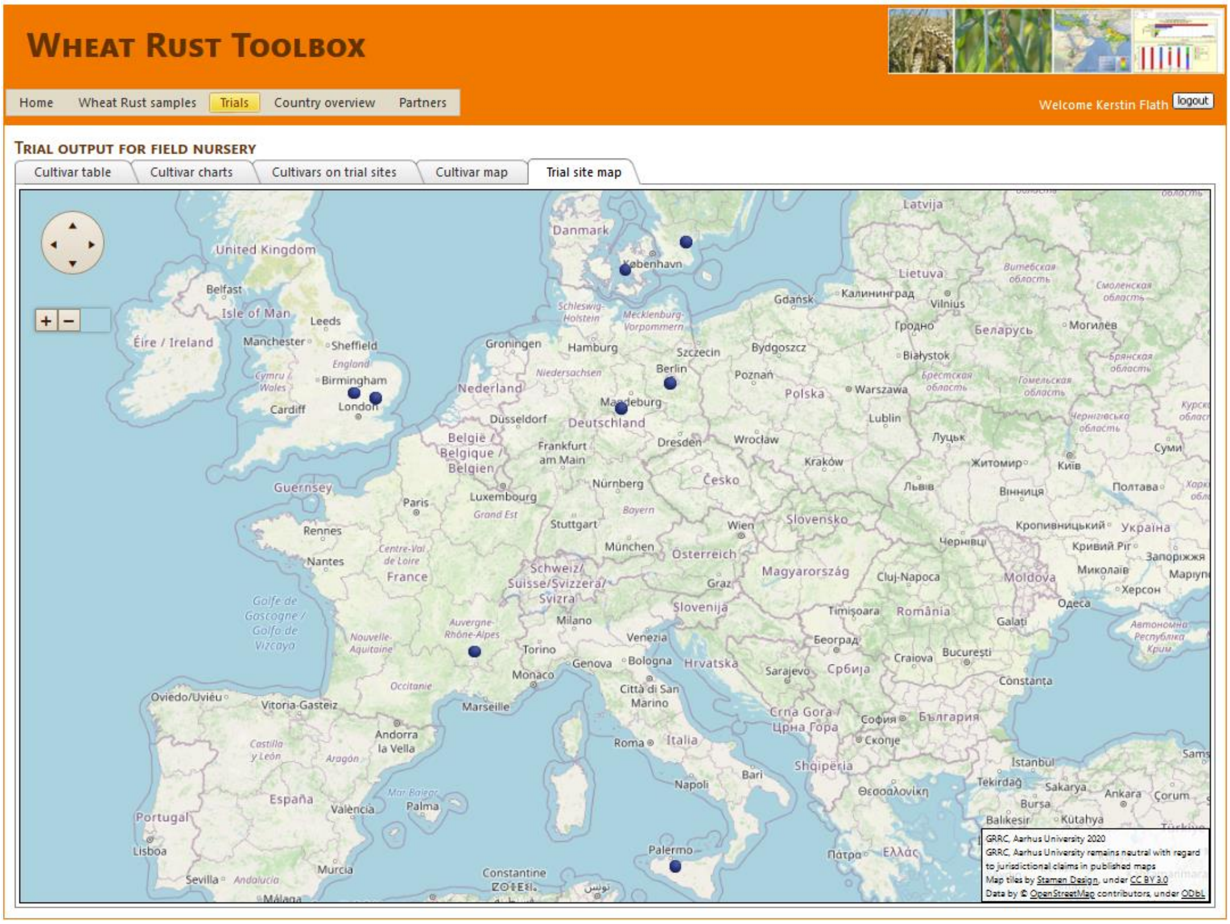


Figure 1: Trial site map as displayed in the Wheat Rust Toolbox

Table 1: Trial hosts and overall design of the 2019/20 field nurseries

Trait	DK AU	UK NIAB	DE JKI	IT AS.A.R.	FR ARVALIS	DE BREUN	SW Lantm.	UK RAGT
Number of replications	2	2	3	2	2	1	1	2
Artificial inoculations	yes	yes	yes	no	no	no	no	no
Number of scoring dates	3	3	6	10	2	2	2	2
Diseases (YR, LR, SR)	YR	YR	YR, SR	YR, LR, SR	YR, LR	YR, LR	YR	YR
No. of varieties tested	142	205	180	247	206	216	200	223

Table 2: Seed providers and contact persons of the 2019/20 field nurseries

Country of origin	Institution	Seed provision	E-Mail address
Latvia	LLU	Liga Feodorova-Fedotova	liga.feodorova-fedotova@llu.lv; janis.jasko@llu.lv
Czech Republic	VURV	A. Hanzalová	hanzalova@vurv.cz
Italy	AS.A.R	Biagio Randazzo	biaran@yahoo.it
Germany	BREUN	Anja Hanemann	hanemann@breun.de; weyen@haploplant.com;
Switzerland	AGROSCOPE	Fabio Mascher	fabio.mascher@agroscope.admin.ch; jessica.joaquim@agroscope.admin.ch
Spain	INTIA	Nerea Arias Fariñas	narias@intiasa.es
Denmark	NORDIC SEED	Jihad Orabi	jior@nordicseed.com; ahja@nordicseed.com
Germany	JKI	Kerstin Flath	kerstin.fath@julius-kuehn.de; philipp.schulz@julius-kuehn.de
Denmark	SEGES	Lars Egelund Olsen	leo@seges.dk; stba@seges.dk
Sweden	LANTMÄNNEN	Tina Henriksson	tina.henriksson@lantmannen.com
UK	NIAB	Sarah Wilderspin	sarah.wilderspin@niab.com; amelia.hubbard@niab.com
Slovak Republic	NPPC	Svetlana Slikova	slikova@vurv.sk
France	ARVALIS	Philippe du Cheyron	p.ducheron@arvalis.fr

A Field Nursery Data Management System (FNDMS) has been developed as a collaborative effort between WP3 and WP4 to support the analyses and presentation of results. This system enables us to store the data, ensure quality control, to improve analyses and visualisation of results and makes data more accessible in a user-friendly form for the stakeholders and data providers. The system is implemented as part of the Wheat Rust Toolbox (see Annex 1 to this deliverable).
Access rights is decided by JKI and partners in task 3.6. AU administers the user database. Login to the Wheat Rust Toolbox: https://web05.agro.au.dk/WheatRustToolbox/Menu/01_Home/Home.aspx. After login, the Field Nursery Data Management system is available under a top menu called Trials.

Results

The mean disease scorings (1-9 scale) averaged over all tested varieties and locations were roughly at the same level as in the previous season for YR (2.8 in 2019 and 2.9 in 2020). In contrast, the 2020 scores were lower for LR (5.6 in 2019 and 2.9 in 2020) and SR (7.1 in 2019 and 5.2 in 2020).
We analysed and visualised the 2019/20 data with the help of the FNDMS. The pie chart tool shows the frequency of the mean disease scorings across all locations. This classification is based on the 1-9 scale, where the scores 1-2 (green) and 2-3 (yellow) indicate low susceptibility (effective resistances), score 5 (orange) moderate susceptibility, scores 6-7 (red) high susceptibility and scores 8-9 (dark red) extreme susceptibility, i.e. no effective resistance.
As shown in Figure 2, 88 % of the varieties reacted with low susceptibility to YR (42 % green and 46 % yellow), 97 % to LR (26 % green and 71 % yellow) and 26 % to SR (11 % green and 15 % yellow).

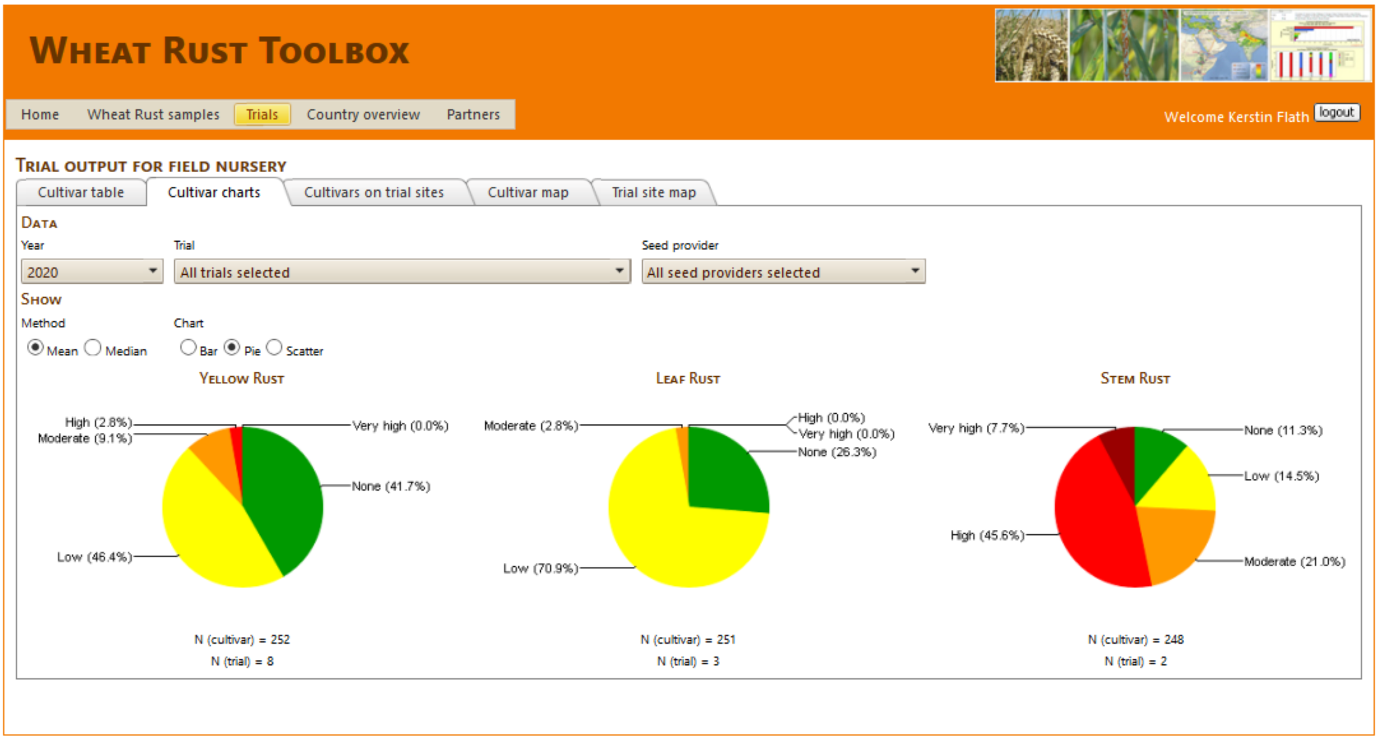


Figure 2: Pie charts of all tested varieties indicating the frequency of mean disease scorings (1-9 scale) for YR, LR and SR (from left to right) across two to eight locations.

Susceptibility to yellow rust was tested at three locations using artificial inoculations of individual races (AU, JKI, NIAB) and under spontaneous infections emerging from natural rust populations (AS.A.R., ARVALIS, BREUN, Lantmännen, RAGT). As expected, the average disease level was lower under non-inoculated conditions, reflected by different proportions of susceptible varieties. However, there were major differences between the individual locations. In the YR-inoculated trials of NIAB and JKI, the proportion of varieties without attack of YR (16 % each) was significantly lower than at the AU site in Flakkebjerg with 34% (Figure 3).
The differences were even higher in non-inoculated trials. While 40-57% of varieties without attack of YR were found at the Lantmännen (SE), ARVALIS (FR) and RAGT (UK) locations (Figure 4), their proportion at BREUN and AS.A.R. was even higher (92-94 %), showing that the natural pressure of infection is not always sufficient to select varieties with effective YR resistance.

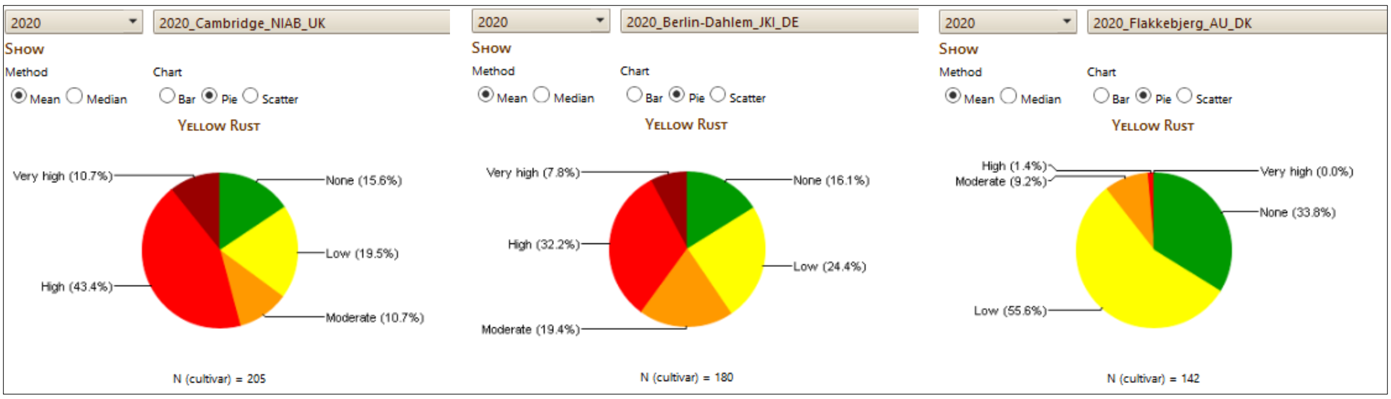


Figure 3: Pie charts of all tested varieties indicating the proportion of varieties with low susceptibility to YR (green and yellow), moderately susceptibility (orange) and high susceptibility (red and dark red) at three locations (NIAB, JKI and AU from left to right) with artificial inoculations of individual YR races.

Figure 4: Pie charts of all tested varieties indicating the proportion of varieties with low susceptibility (green and yellow), moderate susceptibility (orange) and high susceptibility (red and dark red) to YR across three non-inoculated trials with higher infection pressure (top: Lantmännen, ARVALIS and RAGT from left to right) compared to two locations with lower infection pressure (bottom: BREUN left side and AS.A.R. right side).

These differences are most likely due to the inoculum level at certain locations, but also depends on the weather conditions, which can favor or reduce the occurrence of rust diseases. However, unusual YR races could also appear that can infect previously resistant varieties at individual locations. This could e.g. be the case for the wheat varieties shown in Figure 5. The Italian wheat variety Bologna showed only low susceptibility at five locations, but was highly susceptible at the Lantmännen location in Sweden. The same applies to the French variety Rebelde, which only reacted susceptibly at the JKI site in Berlin-Dahlem, and to the UK variety Malacca, which showed low susceptibility at four locations but was highly susceptible at the NIAB site in Cambridge.

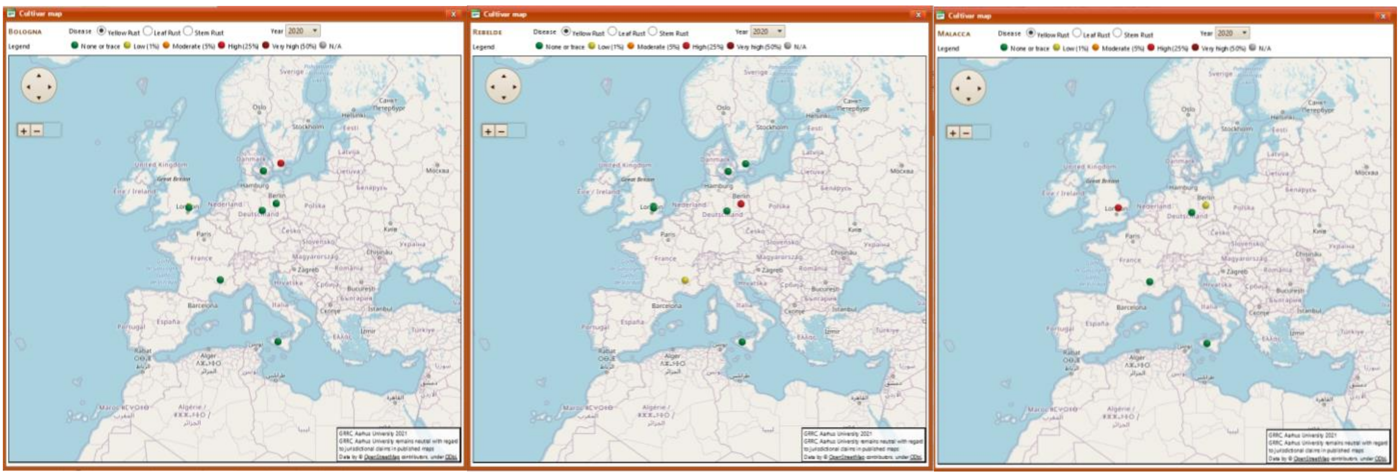


Figure 5: Trial site maps of the Wheat Rust Toolbox showing unusually high scores for the variety Bologna at the Lantmännen site, for Rebelde at the JKI site and for Malacca at the NIAB site (from left to right).

Susceptibility to leaf rust was tested across three locations (ARVALIS, BREUN, AS.A.R) with infections from natural rust populations. The disease scorings (1-9 scale) averaged over all tested varieties were significantly higher at the ARVALIS location in Etoile sur Rhone in France than at the BREUN location in Herzogenaurach in Germany (Figure 6). This can also be related to the prevailing weather conditions and the infection potential of the naturally occurring LR population, which allowed a much more effective selection of LR resistant varieties at the ARVALIS site than at the BREUN site.

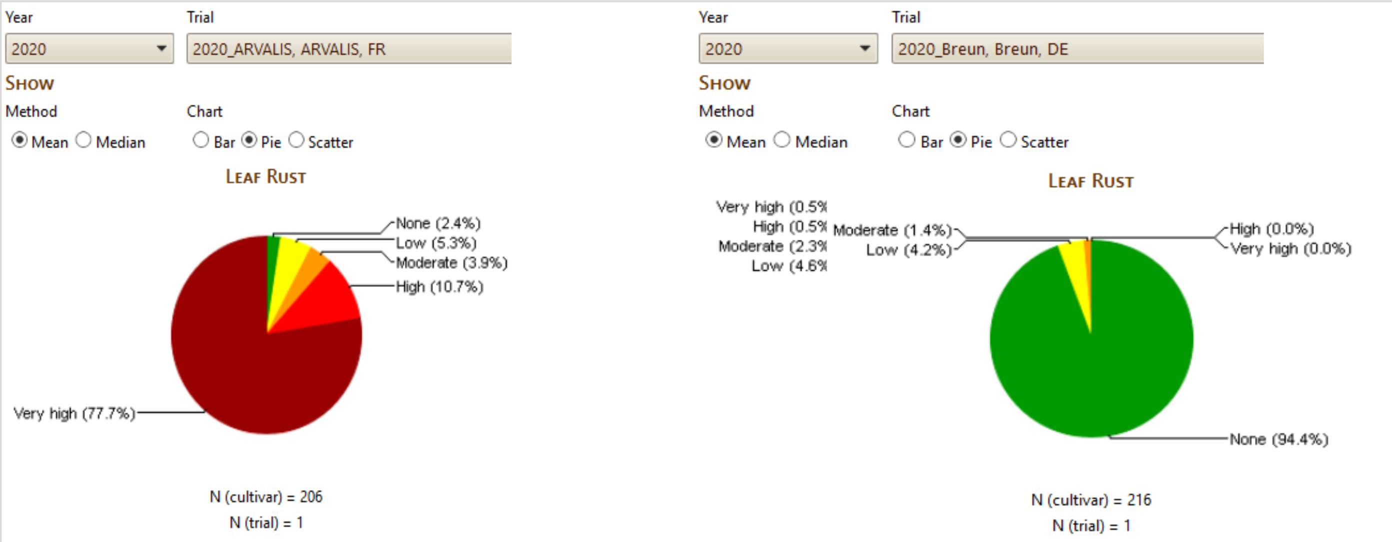


Figure 6: Pie charts of all tested varieties indicating the frequency of mean disease scorings (1-9 scale) for LR across two locations (ARVALIS left side and BREUN right side) with infections from natural rust populations.

Susceptibility to stem rust was tested both, with artificial inoculations of a SR mixture of races at the JKI site in Berlin-Dahlem in Germany and under natural infection conditions at the AS.A.R site in Ciminna, Sicily. With both methods, a proportion of 26 % of varieties with low susceptibility to SR could be determined indicating that efficient selection of resistant varieties is even possible under optimal conditions of natural infections (Figure 7).

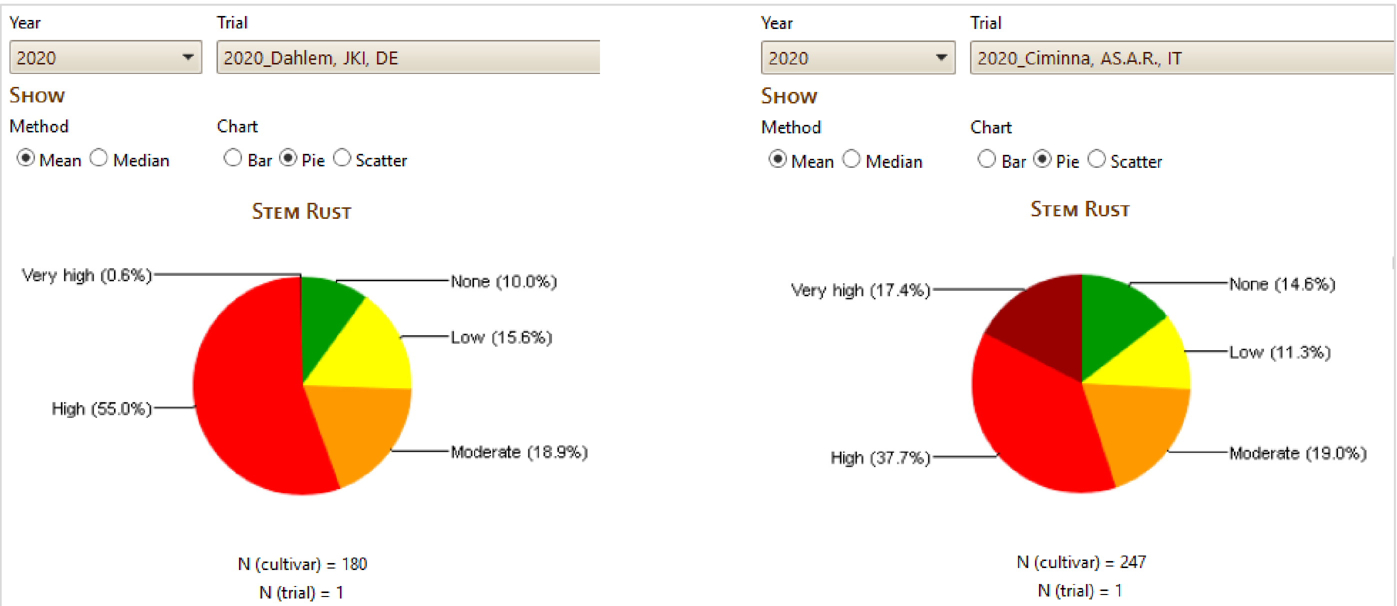


Figure 7: Pie charts of all tested varieties indicating the frequency of mean disease scorings (1-9 scale) for SR across two locations with artificial inoculations (JKI, left side) and infections from natural rust populations (AS.A.R, right side).

Table 3 shows that only a few varieties are characterised by low susceptibility to all three rust diseases. Calculating the mean over all three rusts, the variety Stigg shows the lowest level averaged over all locations.

Table 3: Varieties with low susceptibility to all three rust diseases. Indicated are mean (average disease level on a 1-9 scale), SD (standard deviation of mean), N (number of environments) and the mean over all three rust diseases.

Cultivar	Seed provider	YR Mean	YR SD	YR N	LR Mean	LR SD	LR N	SR Mean	SR SD	SR N	YR+LR+SR Mean
Stigg	NIAB	1,40	0,55	5	1,00	0,00	3	1,75	1,06	2	1,38
Momentum	SEGES	0,87	0,30	5	1,83	1,04	3	1,50		1	1,40
LG Armstrong	ARVALIS	2,10	1,07	8	1,00	0,00	3	1,50	0,71	2	1,53
Aureo	AS.A.R.	2,31	1,62	6	1,00	0,00	2	1,67	0,94	2	1,66
Acorazado	INTIA	1,83	1,18	5	2,17	2,02	3	1,00		1	1,67
Claudio	AS.A.R.	2,24	1,47	7	1,33	0,58	3	1,67	0,94	2	1,75
Forcali	ARVALIS	2,00	1,15	4	2,33	2,31	3	1,00		1	1,78
Iride	AS.A.R.	2,42	2,10	6	1,25	0,35	2	1,67	0,94	2	1,78
RGT Cesario	ARVALIS	1,46	0,56	8	2,33	2,31	3	1,67	0,94	2	1,82

Conclusions

Field assessment of up to 250 winter wheat varieties and breeding lines for susceptibility to unusual rust races was carried out at eight locations in Europe.

Field nurseries under natural conditions of infection are often used for initial selection of rust-resistant wheat varieties, but are heavily dependent on the weather conditions and the infection potential of prevalent rust populations.

Additional artificial inoculations with individual races or mixtures of races can significantly increase the disease load and accelerate the development of rust-resistant varieties.

The high proportion of varieties with low susceptibility (effective resistance) to YR illustrates the successful work of European wheat breeders. However, little is known about the genetic background of YR resistance in European wheat varieties. All varieties with the same R-genes (specificities) are vulnerable to the same changes in pathogen population, and therefore at risk to become rust susceptible at the same time. This aspect will be examined in more detail in WP3: Postulation of R-genes for leaf, yellow and stem rust using differential isolates and SNP tagging R-genes (D2.3).

A few of the winter wheat varieties tested showed low susceptibility to all three rust diseases. In further investigations, the sources of these resistances should be characterised in more detail and the corresponding genes should be localised in order to use them for a targeted breeding of varieties with broad rust resistance.

The results in this report will be analysed and discussed in relation to results from field trials in Pakistan, which were exposed to very different rust populations (D3.5) as well as in relation to results from off-season testing for early detection of susceptibility of wheat lines to new races of yellow rust and leaf rust (D2.2).

The Field Nursery Data Management System (FNDMS), developed as a collaborative effort between WP3 and WP4, was applied for the first time. The system, which proved useful for comparing results across locations and disease, will be further developed according to wishes from stakeholder groups, including plant breeders and seed suppliers. The documentation for the system is enclosed as Annex 1 to this report.

RUSTWATCH
WHEAT RUST EARLY WARNING

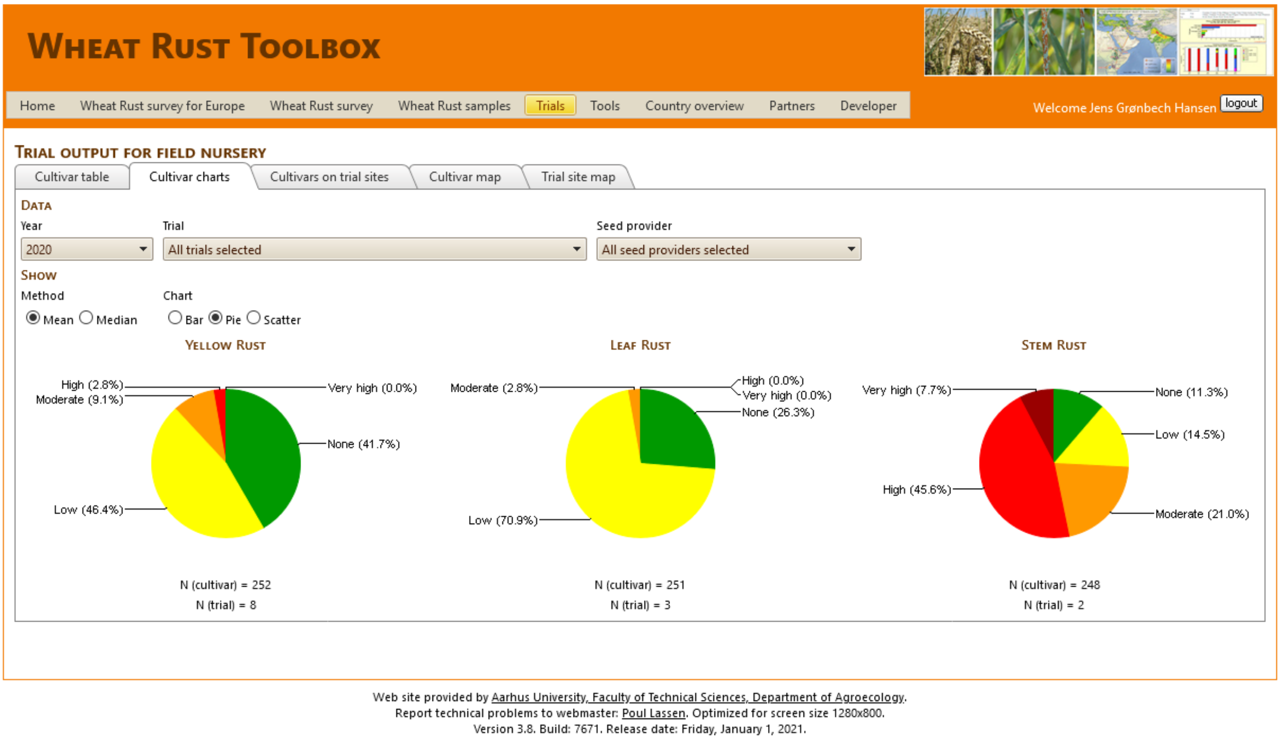
Field Nursery Data Management System

User guide and documentation

WP4

Annex 1 of RustWatch, Deliverable.3.6

Field assessment of wheat varieties and breeding lines for susceptibility to unusual rust races 2020



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Date: 13 January 2021

Contents

Introduction

To support the Field Nursery System organised by RustWatch WP3, Task 3.6, we developed the Field Nursery Data Management System (FNDMS) as a collaborative effort between WP3 and WP4. This activity is part of Task 4.3. The FNDMS stores the data, does quality control of the data, analyses the data and visualises the data. Finally, is makes quality controlled data accessible in a user-friendly form for the stakeholders and data providers. The system was implemented as part of the Wheat Rust Toolbox and this first draft system is only accessible after login.

Access rights is decided by JKI and partners in Task 3.6. AU administers the user database.

Login to the Wheat Rust Toolbox:

https://web05.agro.au.dk/WheatRustToolbox/Menu/01_Home/Home.aspx

After login, the Field Nursery Data Management system is available under a top menu called Trials.

System overview

The system is organised in a management part and an output part as described in Fig. 1. Those two components are separate main menus with associated sub menus and sub-sub menus. Based on Login IDs the Toolbox controls access right of all menus, i.e. the management part is only available for the managers of the Field Nursery system, but the output part is available for a wider audience i.e. the hosts of the field nurseries and the seed providers and selected people from breeding companies.

The management part organises the definitions of trial sites, trials, which cultivars are tested, features for import of the raw results and export of basic and calculated variables. This part is described briefly later in the document.

The output part organises all basic and summary results, statistics in tables as well as on maps and charts. The output part is the main focus of this document, serving as a user guide and a documentation for the proper use and understanding. The statistical methods applied are described late in the document.

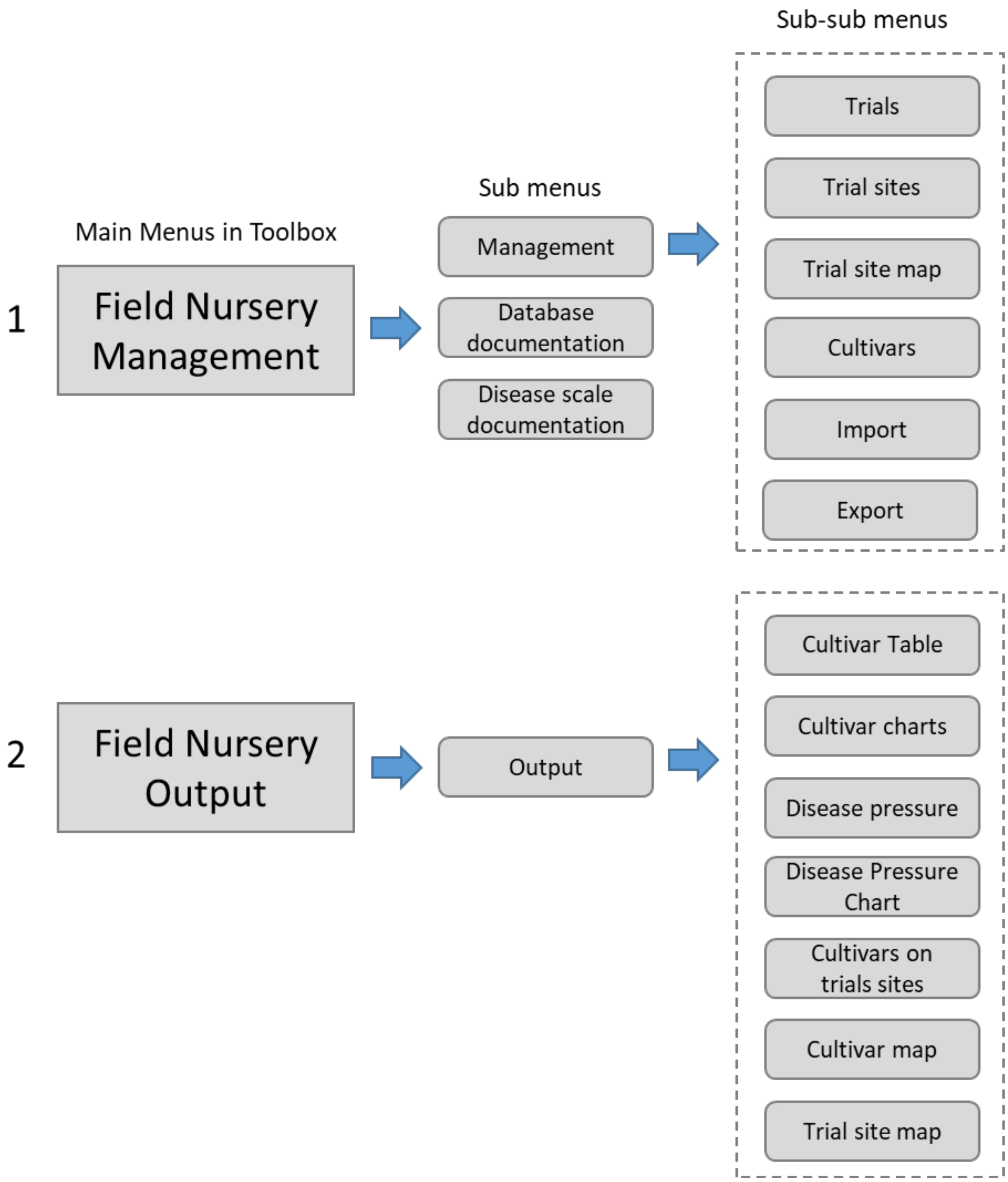


Figure 1. System overview of the Field Nursery data management System as indicated by menus and sub-menus in the Wheat Rust Toolbox.

About the data collected

Trial site names, responsible institutions and trial reps, number of disease scorings and number of varieties tested, 2020 is provided in table 1.

Table 1. Trial sites, responsible institutions and trial reps, number of disease scorings and number of varieties tested, 2020.

Country	Institution	Trial site name	Replicates	Dates scored	Cultivars tested
Denmark	AU	Flakkebjerg	3	3	144
France	ARVALIS	Etoille sur Rhone	2	2	208
Germany	Breun	Herzogenaurach	1	2	218
Germany	JKI	Berlin-Dahlem	3	6	182
Italy	AS.A.R.	Ciminna	2	10	250
Sweden	Lantmännen	Svalöv	1	2	202
UK	NIAB	Cambridge	2	3	217
UK	RAGT	Ickleton	2	2	226

As indicated in Table 1, the number of replicates, number of disease scorings and number of varieties tested is not the same and this is a challenge for the interpretation of the results. The statistics applied reflect this situation and we chose relatively simple methods enabling robust calculated variables as explained in the section about statistics below. The differences on management of the trials is explained in M3.14: Sharing protocols for evaluating adult plant resistance of varieties and breeding lines to rust diseases under field conditions.

Trial output for Field Nursery

Cultivar table

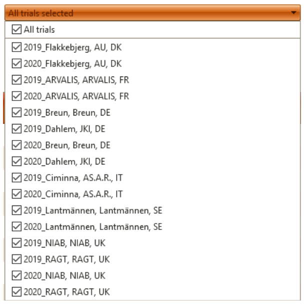
Login to the Toolbox and select the menu Trials / Field Nurseries /Field Nursery output. Now a page opens with six tab pages (Fig. 2). This tool is database driven and interactive. This means you can change the selected data and what you select will be analysed and displayed in the table. What can I select or change?

Year

- The default setting is All years selected. Deselect all years selected by mouse click in the All years check box. Now you can select 2019 and / or 2020.

Trial

- The default setting is All trials selected. Deselect all trials selected by mouse click in the All trials selected check box. The number of trials will depend on the selection of years you did previously. In the example below both 2019 and 2020 was selected for Year. You can select data for one or more trials to be displayed in the table.



Seed provider

- The default setting is All seed providers selected. Deselect all seed providers by mouse click in the All seed providers selected check box. This feature makes it possible to restrict the data to be displayed for one or more seed providers. If you are a seed provider it would be relevant to analyse (only) your own material in single trials or more trials and across one or more years. Results can be very different between years depending on the weather conditions conducive for rust development and the races present in the trial.

Method

- The default setting is Mean. This method refer to the method used to calculate the Mean or Median across environments after calculating the MeanMax by cultivar, location and year. In next version, you will be able to select both methods and results to be displayed at the same time in the table.

Disease

- The default setting is Yellow Rust. You can select one or more of the three rust diseases to be analysed and displayed in the table.

Statistics

- The default setting is Mean, Upp, SD and N. You can select one or more of the statistical variables to be analysed and displayed in the table. See the section Statistical methods applied to know more about how this is calculated and what it means.

Cultivar info

- The default setting is none of those options selected. You can select seed provider name and / or the breeder of the cultivar to be displayed in the table.

Sorting

- The default setting is Cultivar name. You can select Mean of Yr, Lr or Sr disease scorings. We will add the remaining statistical values to this list in the next version.

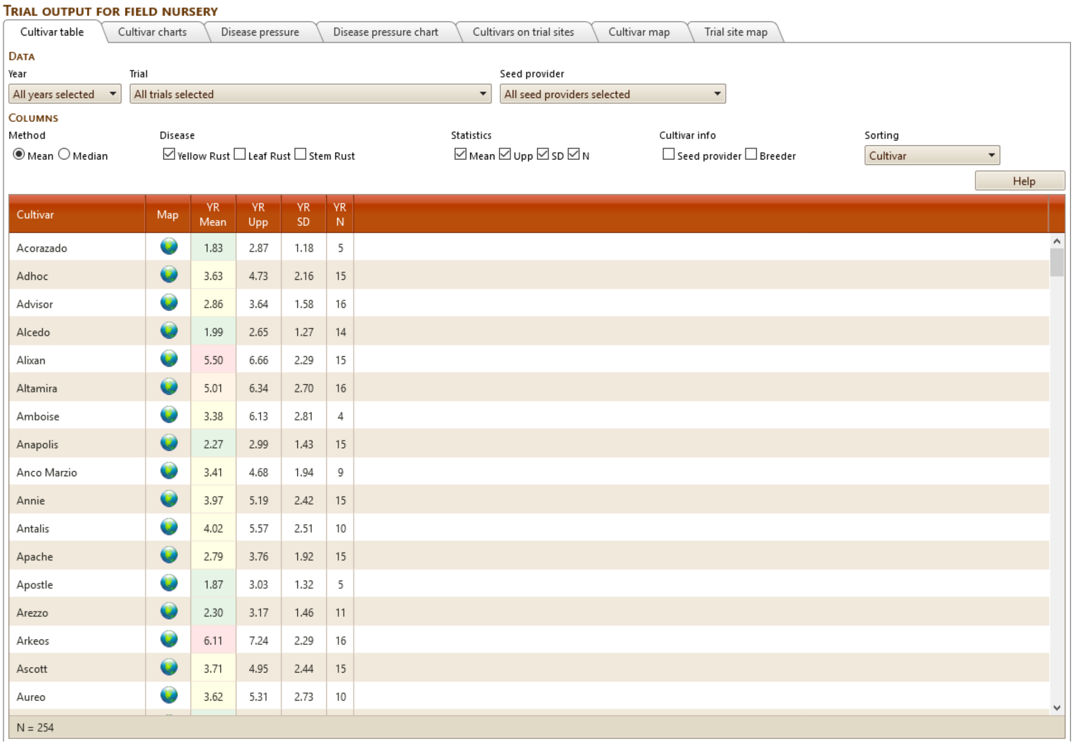


Figure 2. Cultivar table tab page, default setting.

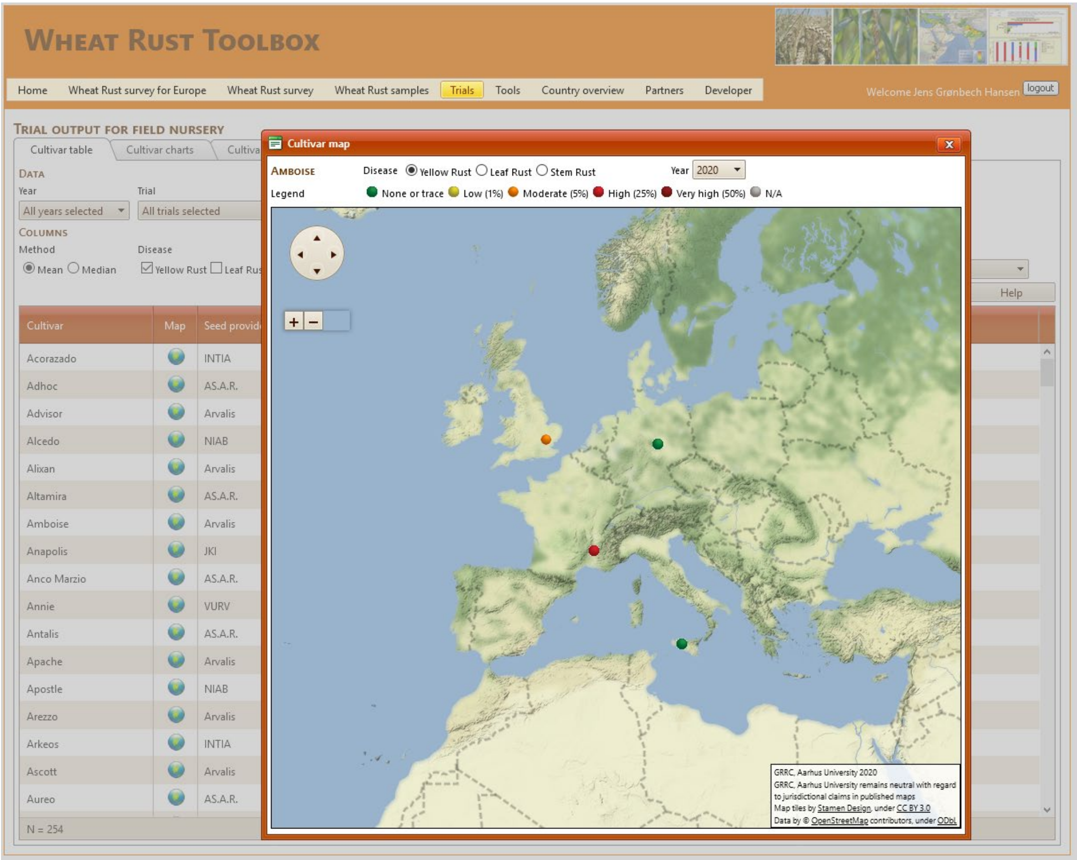


Figure 3. Popup window with map, available in the cultivar table for any cultivar.

Map link

- You can select the Map icon for any cultivar in the table generated. This will open a popup window including a map with the MeanMax disease scoring by location and year for the cultivar selected (Fig. 3). You can zoom on the map and you can select another rust disease scored on the same cultivar, in the same year. Finally, you can change year of observations.

This tool indicates the regional pattern in the susceptibility of varieties tested. You can go to other tools in the toolbox and find what rust races or genotypes were found regionally in the same year. Only after a few more years, we will display the evolution of susceptibility across years on single and regional locations.

Cultivar charts

On the cultivar charts tab page data are summarised on three different chart types:

Bar chart with Mean or Median across environments (green bar), Standard deviation as needle and Upp as a red vertical line:

- Mean: This the average disease level, on a 1 – 9 scale, of a cultivar. It may be regarded inversely indicative for the average resistance level of a cultivar
- SD: This is the environmental standard deviation of cultivar mean: a measure of variability of a cultivar's disease level under the diverse conditions of the environments in which it was exposed. The variability is inversely related to stability. Minimum variability and maximum stability = 0
- Upp: This the upper limit of the 95% confidence interval of the cultivar mean. It may be understood as a plausible upper, somewhat "pessimistic", estimate of the "true" cultivar mean.

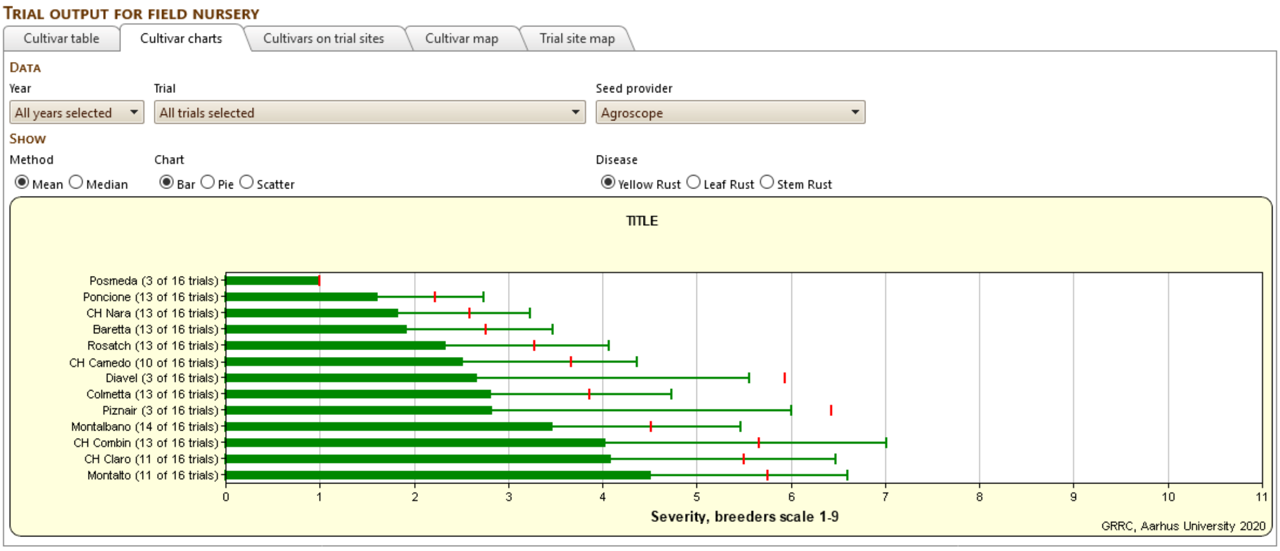
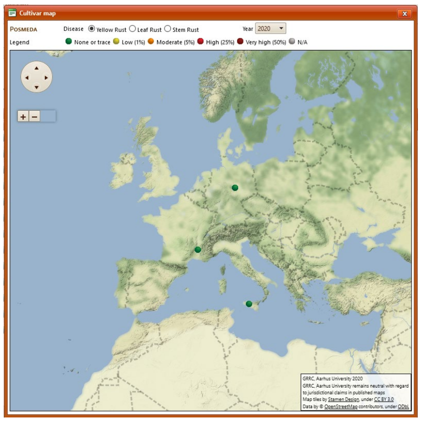


Figure 4. Bar chart of statistics results for All years selected (2019 and 2020) all trials selected (2*8) and for the seed provider Agroscope (13 cultivars). Posmeda obtained a very low Mean of 1, SD=0 and a low upper limit of the 95% confidence interval. However, on the X-axis is indicated that this cultivar was only tested in 3 of 16 trials (Fig 4 and 5).

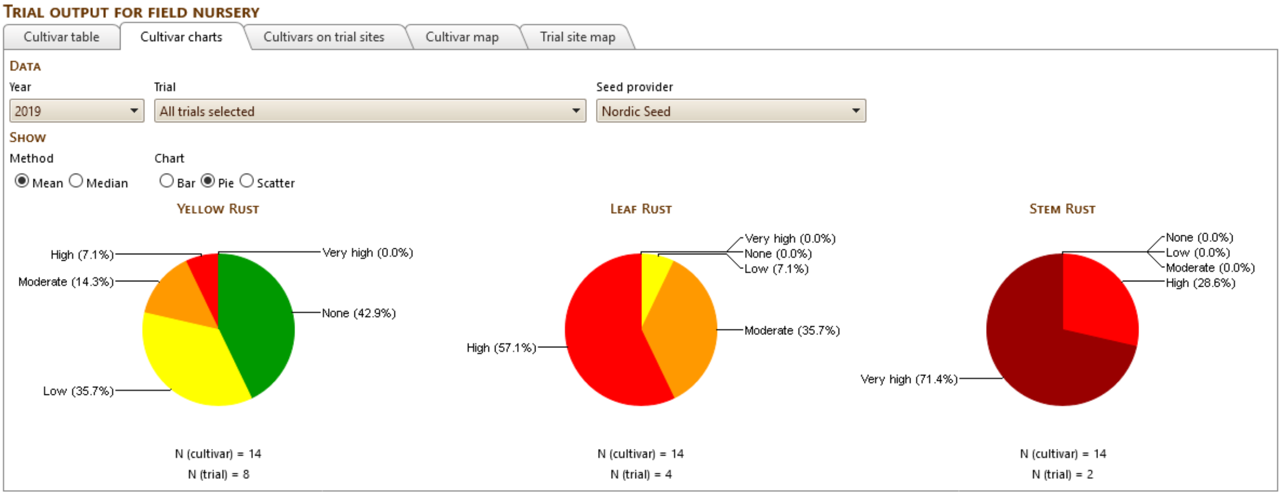
Figure 5. Map indicating that the cultivar Posmeda was tested at three sites in 2020, by Arvalis in the south of France, by Breun in Germany and AS.A.R in Sicily. On all sites the score was 1 on the breeders scale indicating 0 or trace disease.



Similar data can be displayed via the Pie chart tool. In the example below, the user selected the year 2019 (A) and 2020 (B) separately for all trials but only for data provided by the seed provider Nordic Seed (head in DK). The piecharts indicate the frequency of mean disease scorings (1-5 scale) across selected locations.

Green is 0 to 0,3 % severity; Yellow is 0,3 to 3 % severity; orange is 3-7,5%; Red is 7,5 to 37,5% and dark red is ≥ 75% (see the Scale documentation section for further information). This indicates that green and yellow is good, orange is acceptable and red and dark red is not acceptable seen from a breeding perspective. The results in Fig 6 indicate that most material from Nordic seed is susceptible to stem rust in both years, but very god on yellow rust. For leaf rust the results for 2020 obtained considerably lower disease scores compared to the 2019 growing season, which was generally more conducive for development of the wheat rust diseases than 2020.

A



B

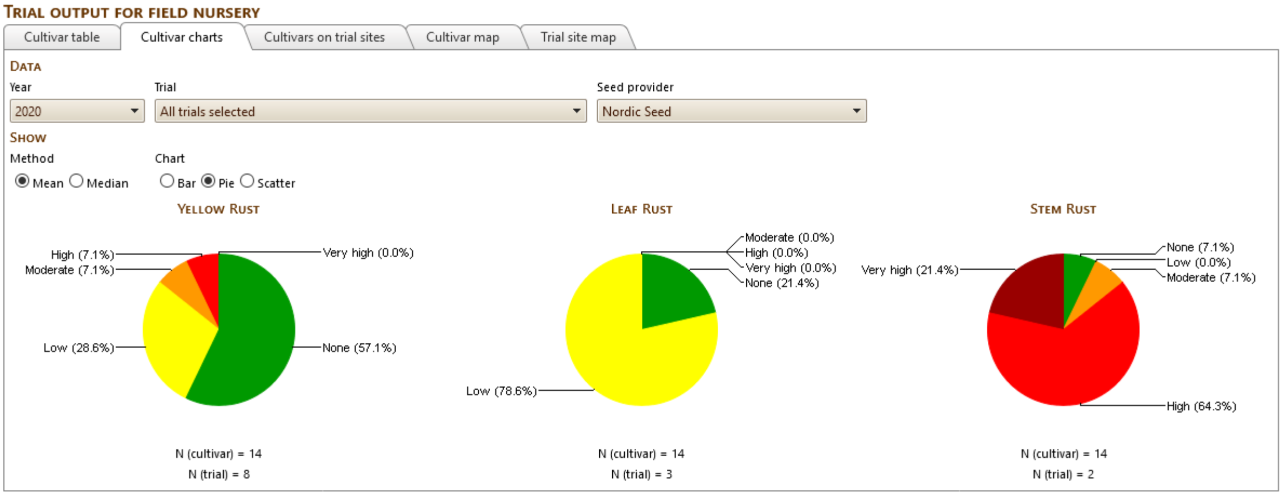
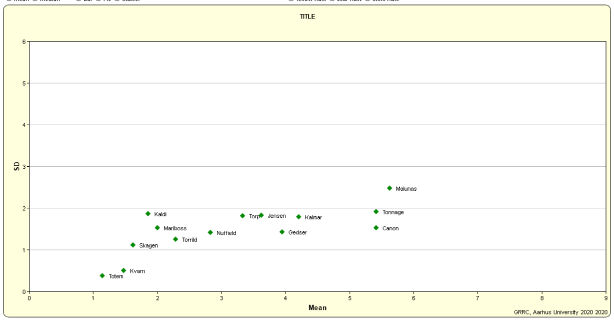


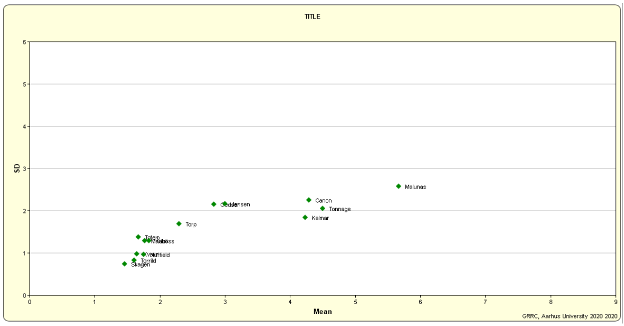
Figure 6. A is covering data from 2019 and B is covering data from 2020.

The performance of cultivars can also by visualised by a scatter plot with the Environmental Standard deviation on the Y-axis and the Mean of the disease scorings on the X-axis. Each marker results are indicated with the name of the cultivar behind. The best result would be a low disease score and at the same time a Low SD. That is the lower left corner of the graph. An Example is provided below using data from Nordic Seed, 2019 and 2020 for all three rust types (Fig. 7). From Figure 6 we know that 14 cultivars were tested across 8 trials in each years 2019 and 2020.

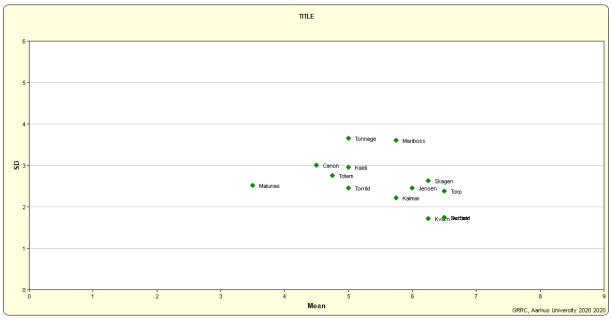
Year 2019
Yellow rust



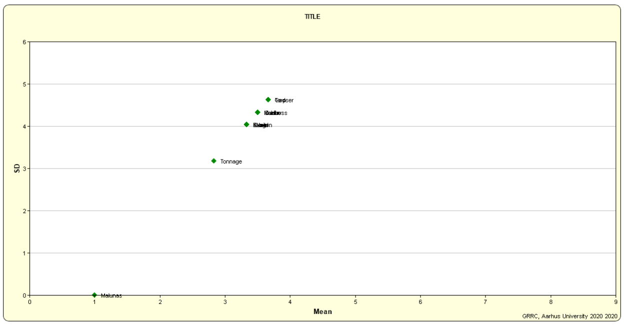
Year 2020
Yellow rust



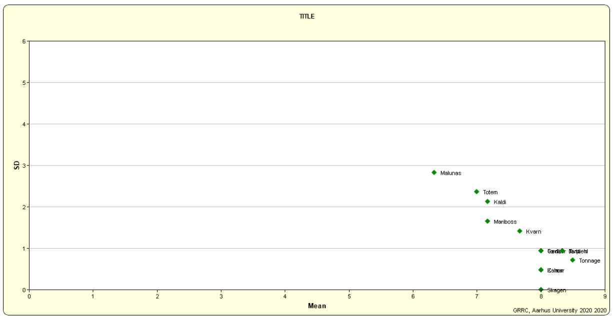
Leaf rust



Leaf rust



Stem rust



Stem rust

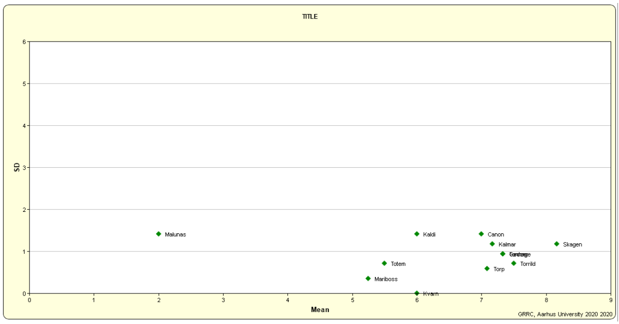


Figure 7. Mean disease levels vs Standard Deviations (SD) for cultivars from Nordic Seed, tested for Yr, Lr and Sr in 2019 and 2020 at 8 locations each year.

Disease pressure

To provide a robust indication of the disease pressure by location and year we calculated the mean of the MeanMax values across all cultivars that were tested in all environments (Fig 8). The table provides results as “Mean severity across (common) tested cultivars in a 1-9 scale (see Disease Scale Documentation on page 21). N(Trial) is the number of trials by disease and year. N(Cultivar) indicates how many cultivars were common across all environments by disease and year. Stem rust was only tested at two locations, Ciminna in Sicily and Berlin-Dahlem in Germany. Leaf Rust was tested at four locations in 2019 and three locations in 2020. Yellow rust was tested at all sites in both years.

Trial output for field nursery

Cultivar table | Cultivar charts | Disease pressure | Disease pressure chart | Cultivars on trial sites | Cultivar map | Trial site map

Disease	Year	N (trial)	N (cultivar)	Ciminna	Etoille sur Rhone	Herzogenaurach	Ickleton	Cambridge	Berlin-Dahlem	Flakkebjerg	Svalöv
Yellow Rust	2020	8	106	1.24	2.73	1.42	2.62	4.90	4.85	2.81	3.60
Yellow Rust	2019	8	65	2.22	4.55	4.32	3.08	3.65	5.36	4.91	4.22
Leaf Rust	2020	3	203	1.08	7.48	1.13					
Leaf Rust	2019	4	186		7.32	5.20	2.97				5.67
Stem Rust	2020	2	181	5.16					5.26		
Stem Rust	2019	2	198	8.32					6.36		

Figure 8. Disease pressure table results based on wheat cultivars tested at up to eight locations in Europe 2019 and 2020. See text for explanation.

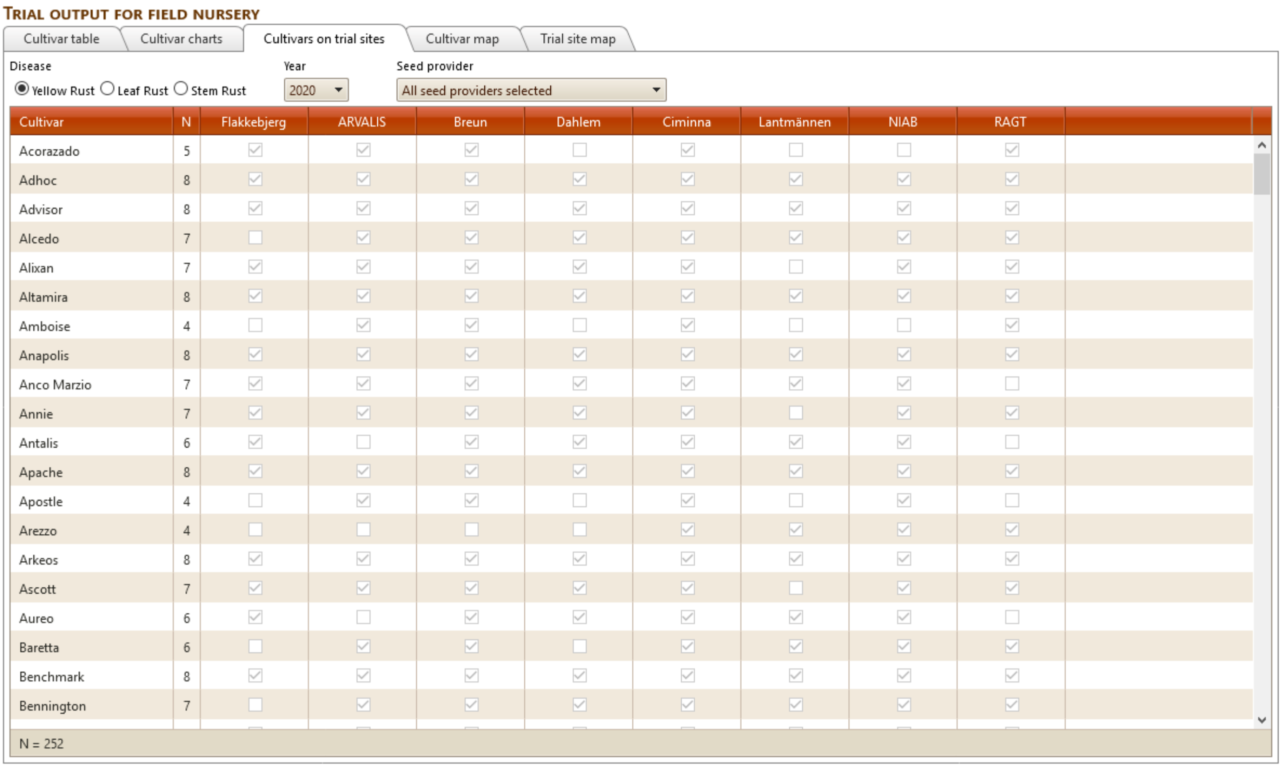
Disease pressure chart

The same data are displayed as disease pressure charts with locations and grouped bars on the x-axis and mean severity across tested cultivars [1-9] on the Y-axis. Via the radio buttons the users can select to show results for Yellow rust, Leaf rust or Stem rust

Figure 9. Disease pressure chart, displaying the same data as presented in the table in Fig. 8.

Cultivars on trial sites

You can see which cultivars were tested against which diseases on which locations in 2019 and 2020 respectively. This table can also be modified by selecting one or more Seed providers to be included in the table (Fig 10).



Cultivar	N	Flakkebjerg	ARVALIS	Breun	Dahlem	Ciminna	Lantmännen	NIAB	RAGT
Acorazado	5	☑	☑	☑	☐	☑	☐	☐	☑
Adhoc	8	☑	☑	☑	☑	☑	☑	☑	☑
Advisor	8	☑	☑	☑	☑	☑	☑	☑	☑
Alcedo	7	☐	☑	☑	☑	☑	☑	☑	☑
Alixan	7	☑	☑	☑	☑	☑	☐	☑	☑
Altamira	8	☑	☑	☑	☑	☑	☑	☑	☑
Amboise	4	☐	☑	☑	☐	☑	☐	☐	☑
Anapolis	8	☑	☑	☑	☑	☑	☑	☑	☑
Anco Marzio	7	☑	☑	☑	☑	☑	☑	☑	☐
Annie	7	☑	☑	☑	☑	☑	☐	☑	☑
Antalis	6	☑	☐	☑	☑	☑	☑	☑	☐
Apache	8	☑	☑	☑	☑	☑	☑	☑	☑
Apostle	4	☐	☑	☑	☐	☑	☐	☑	☐
Arezzo	4	☐	☐	☐	☐	☑	☑	☑	☑
Arkeos	8	☑	☑	☑	☑	☑	☑	☑	☑
Ascott	7	☑	☑	☑	☑	☑	☐	☑	☑
Aureo	6	☑	☐	☑	☑	☑	☑	☑	☐
Baretta	6	☐	☑	☑	☐	☑	☑	☑	☑
Benchmark	8	☑	☑	☑	☑	☑	☑	☑	☑
Bennington	7	☐	☑	☑	☑	☑	☑	☑	☑
N = 252									

Figure 10. Cultivars on trial sites tab page.

Cultivar map

The regional pattern of disease severity results on a 1-5 scale is available on the Cultivar map page (Fig. 11).

You can:

- Select to show results for Yellow rust, Leaf Rust or Stem rust
- Select the year 2019 or 2020
- Select to show data from one or more seed providers
- Select results for a specific cultivar to be displayed on the map
- Zoom the map in and out

Figure 11. Cultivar map tab page indicating the regional pattern of obtained results.

Trial site map

In 2020, more than 200 varieties were tested at eight locations in Europe (Table 1).

Table 2. Trial sites and responsible institutions, 2020.

Country	Institution	Trial site name
Denmark	AU	Flakkebjerg
France	ARVALIS	Etoille sur Rhone
Germany	Breun	Herzogenaurach
Germany	JKI	Berlin-Dahlem
Italy	AS.A.R.	Ciminna
Sweden	Lantmännen	Svalöv
United Kingdom	NIAB	Cambridge
United Kingdom	RAGT	Ickleton

The two UK trials were so close that it was decided to move the locations on the maps, that the data were immediately visible on the map

Location data for NIAB was from 52.2000, 0.12000 to 52.2000, -0.30000. Location data for RAGT was changed from 52.06000, 0.15000 to 52.06000, 0.60000 (Fig. 12).

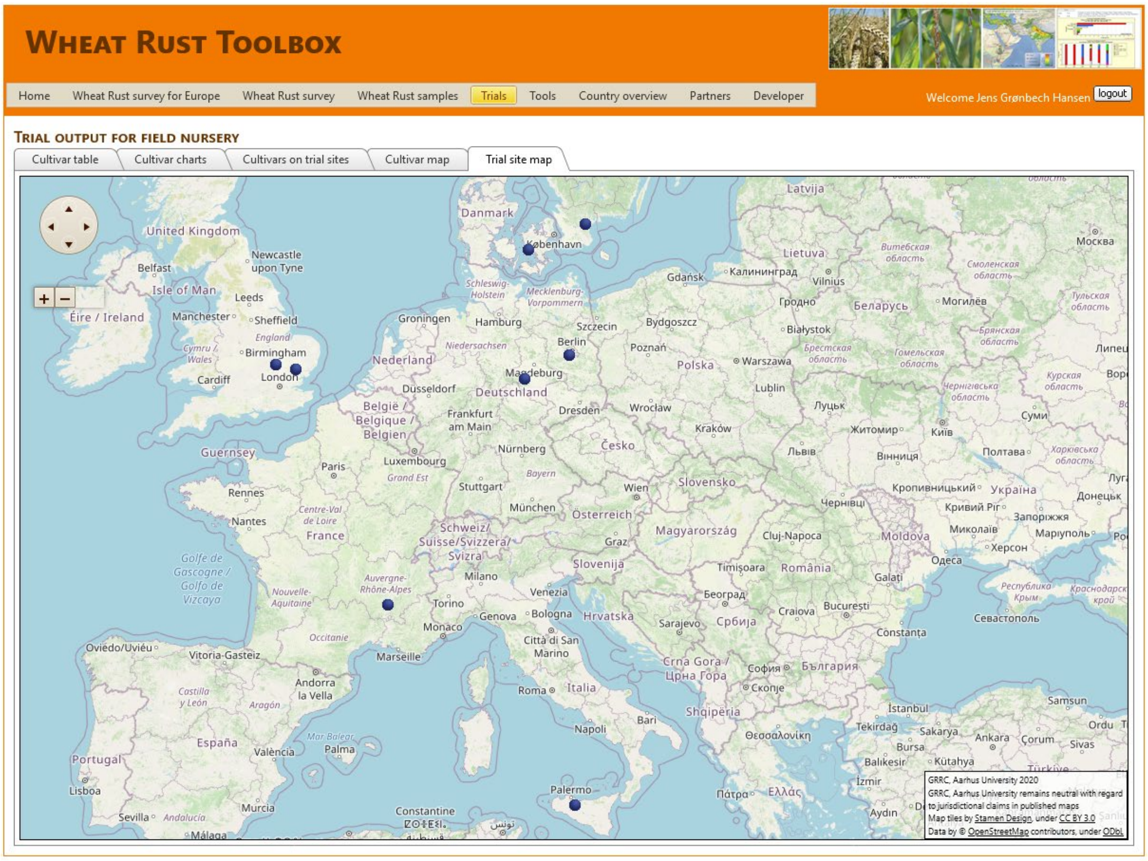


Figure 12. Trial site map as displayed in the Wheat Rust Toolbox.

Statistical methods applied

Main responsible for this part is Hans O. Pinnschmidt, UKE.

Rationale, aim & scope

About two-dozen different measures for characterising cultivar performance under variable environmental conditions have been described in the literature. Many of these are difficult to understand and require sophisticated statistical methods. We decided to suggest a few simple, pragmatic and easy-to-understand key figures for summarising and characterising wheat cultivar susceptibility to rust diseases as observed under the range of environmental field conditions to which these cultivars were exposed in the RUSTWATCH field nurseries. Such figures can be important elements of rust risk management tools to be developed in WP4.

Preparing disease data for characterisation of cultivar resistance resp. susceptibility

Since the field nursery disease scoring methodology varies for different working groups, particularly with respect to no. replicates per cultivar & site-by-year and no. scoring dates per plot, a compromise solution is needed for deriving the basic data to be used for characterising the resistance resp. susceptibility properties of individual cultivars. The following procedure is therefore suggested:

a) Firstly, the maximum disease score value (on a 9-step scale) per cultivar, site-by-year and replicate is determined,
b) secondly, the mean of these maximum-values is computed per cultivar and site-by-year.

We thus obtain a "meanmax"-value for each cultivar in each site-by-year environment where it was tested. Based on these cultivar- and environment-specific meanmax-values, parametric and non-parametric measures of rust performance of individual cultivars are determined as described below.

Measures for characterising cultivar resistance resp. susceptibility

A) Parametric measures

1) **Overall susceptibility**: Cultivar mean.
   Short name:
   - CMean.

   Computation:
   - $CMean = \sum(x_i)/n$ where x_i = *meanmax* disease score of a given cultivar measured in different environments i, n = no. environments.

   Meaning:
   - Cultivar mean: the average disease level, on a 1 – 9 scale, of a cultivar. It may be regarded inversely indicative for the average resistance level of a cultivar.

2) **High risk estimate**: Upper 95% confidence interval limit of CMean.
   Short name:
   - CMupp.

   Computation:

- $CMupp = Max\{1,Min[9,CMean + 1.96 \cdot SE(CMean)]\}$; where $SE(CMean)$ =standard error of $CMean$ = *environmental standard deviation* $/(no.\ environments^{1/2})$ → see A4) for environmental standard deviation.

Meaning:

- Upper limit of the 95% confidence interval of the cultivar mean. It may be understood as a plausible upper, somewhat "pessimistic", estimate of the "true" cultivar mean.

3) **Measure of spread**: C mean upp. 95% ci – C mean.

Short name:

- CMspread.

Computation:

- $CMspread = CMupp - CMean$.

Meaning:

- CMspread estimates how much worse, compared to its CMean, a cultivar might perform under severe rust conditions.

4) **Stability measure**: Environmental standard deviation of the average disease level of a cultivar (instead of environmental variance, because standard deviation has the same scale as the underlying data).

Short name:

- CSD.

Computation:

- $CSD = \{[\sum(x_i - CMean)^2] / (n-1)\}^{1/2}$ where where x_i = *meanmax* disease score of a given cultivar measured in different environments i, n = no. environments.

Meaning:

- Environmental standard deviation of cultivar mean: a measure of variability of a cultivar's disease level under the diverse conditions of the environments in which it was exposed. Variability is inversely related to stability. Minimum variability and maximum stability = 0.

B) Non-parametric measures

1) **Overall susceptibility**: Cultivar median.

Short name:

- CMedian.

Computation:

- When the *meanmax*-values of a cultivar are sorted, *CMedian* = value in the middle if the no. environments is uneven; if the no. environments is even, *CMedian* = average of the two neighboring *meanmax* values in the middle.

Meaning:

- Cultivar median: the median disease level, on a 1 – 9 scale, of a cultivar. It may be regarded inversely indicative for the median resistance level of a cultivar.

2) **High risk estimate**: Cultivar maximum (if many more environments tested per cultivar are available than currently (data from 2019 & 2020), the cultivar maximum could be replaced, e. g., with the 95 percentile or some other percentile).

Short name:

- CMax.

Computation:

- *CMax* = maximum *meanmax* value of a cultivar observed in the range of environments to which it had been exposed.

Meaning:

- Maximum severity score observed for a cultivar in the environments in which it was exposed, representing the worst observed case. The difference between the highest observed severity score and 9 may be regarded as some measure of a cultivar's "basic resistance level" which, however, is sensitive to outliers.

3) **Measure of spread**: Cultivar maximum – Cultivar median.
   Short name:
   - CMedspread.

   Computation:
   - *CMax – Cmedian.*

   Meaning:
   - This is a somewhat "pessimistic" measure indicating how much worse a cultivar might perform under severe rust conditions, compared to its median.

4) **Stability measure**: Cultivar median absolute deviation.
   Short name:
   - CMAD.

   Computation:
   - $CMAD = median(\mid x_i - CMedian \mid)$ where x_i = *meanmax* disease score of a given cultivar measured in different environments *i.*

   Meaning:

   - Median absolute deviation of a cultivar's environment-specific disease scores from its median score. It is a robust measure of the variability (inversely related to stability) of a cultivar's rust performance under the varying environmental conditions it was exposed to.

C) Study size: No. environments
Short name:
- N.

Meaning:
- Number of site-by-year environments in which a cultivar was tested.

Implementation

It is suggested that the RUSTWATCH partners agree on as few as possible summary measures described above that capture the most important rust resistance features to be employed for rust risk management. Ideally, only one or two measures per cultivar and rust disease (leaf, stem and yellow rust) would suffice, e. g., one describing

(a) the overall level of susceptibility of a cultivar (example: CMean as described in A1) and another one indicating

(b) its susceptibility under a high risk (pessimistic) scenario (example: CMupp described in A2) or

(c) instability/variability of cultivar susceptibility under variable environmental conditions (example: CSD described in A4).

Additionally, the number of environments in which a cultivar has been tested should be indicated (see C).

Parametric measures (see A) might be preferable but any measure can eventually be converted into a 0-1 risk score and coupled with other risk scores (to be obtained elsewhere), e. g. those characterising the rust proneness of a given environment or cropping situation and measures or scores describing the edapho-climatic and agronomic suitability of individual cultivars for specific sites or climatic/geographical regions.

Database Documentation

TRIAL

Field	Type	Size	Obligatory	Options
TrialAppID	Integer		Yes	-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 7: Blight Trial | 8: Field nursery
TrialID	Integer		Yes	
TrialName	String	200		
TrialTypeID	Integer			
PublishedLevel	Integer			0: Unpubl. | 1: Country | 2: Project | 3: Expert | 4: Supplier | 9: All
PublishedAllDate	Date			
PublishedAllUserInit	String	3		
TrialDescription	String	1073741823		
TrialSiteID	Integer			
HostGenusID	Integer			
HostSpeciesID	Integer			
HostFormaID	Integer			
HostCultivarName	String	50		
PotatoTypeID	Integer			
PotatoResistanceGroupID	Integer			
PotatoMaturityClassID	Integer			
CropEmergence50Pct	Date			
StartPhase2	Date			
StartPhase3	Date			
StartPhase4	Date			
UserInit	String	3		
TrialYear	Integer			
Replicate	Integer			
ReferenceTreatmentID	Integer			
DifferentialSetID	Integer			
ColorStr	String	10		
Color	Integer			
MapPositionX	Integer			
MapPositionY	Integer			
Published	Boolean			True | False
ModelFirstDateID	Integer			
ModelLastDateID	Integer			
PlantingDate	Date			
InoculumDate	Date			
SoilType	Integer			
NFertilization	Integer			
IrrigationFrequency	Integer			
IrrigationAmount	Integer			
LateBlightRegionDate	Date			
LateBlightRegionNo	Boolean			True | False
LateBlightTrialDate	Date			
LateBlightTrialNo	Boolean			True | False
EmergenceDate	Date			
EmergenceDateEarly	Date			
EmergenceDateMidEarly	Date			
EmergenceDateLate	Date			
PlantsPerPlot	Integer			
PreviousCrop	String	50		
InoculumSource	Integer			
InoculumTrialPart	Integer			
InoculumDensity	Integer			
InoculumComposition	Integer			
LeafSource	Integer			
IsolateType	Integer			
PlantWeekAge	Integer			
Droplet	Integer			
PlantingDateEarly	Date			
PlantingDateMidEarly	Date			
PlantingDateLate	Date			
Organic	Integer			
HarvestDate	Date			
ContainsData	Boolean			True | False
Comment	String	1073741823		

Trial site

Field	Type	Size	Obligatory	Options
TrialSiteID	Integer		Yes	
TrialSiteName	String	50		
InstitutionName	String	100		
TrialAppID	Integer			-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 7: Blight Trial | 8: Field nursery
CountryID	String	2		
RegionID	Integer			
RegionName	String	100		
Latitude	Decimal			
Longitude	Decimal			
Altitude	Decimal			
MapPositionX	Integer			
MapPositionY	Integer			
Selected	Boolean			True | False

Trial date

Field	Type	Size	Obligatory	Options
TrialAppID	Integer		Yes	-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 7: Blight Trial | 8: Field nursery
TrialID	Integer		Yes	
TrialDateID	Integer		Yes	
ObservationDate	Date			
Comment	String	1073741823		

Cultivar

Field	Type	Size	Obligatory	Options
CultivarID	Integer		Yes	
AlternativeID	Integer			
TrialAppID	Integer			-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 7: Blight Trial | 8: Field nursery
CultivarName	String	50		
HostGenusID	Integer			
HostSpeciesID	Integer			
HostFormalID	Integer			
PathogenGenusID	Integer			
PathogenSpeciesID	Integer			
CultivarTypeID	Integer		Yes	-9: N/A | 1: Differential | 2: Mega | 3: Local | 4: Check cultivar
StatusID	Integer		Yes	
CultivarSeedProviderID	Integer			
Gene	String	25		
GeneList	String	50		
Origin	String	100		
Source	String	50		
SourceCountryID	String	2		
SourceReleaseYear	Integer			
ColorID	Integer		Yes	
SortOrder	Integer		Yes	
Active	Boolean			True | False

Cultivar observation

Field	Type	Size	Obligatory	Options
TrialAppID	Integer		Yes	-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 8: Field nursery
TrialID	Integer		Yes	
TrialDateID	Integer		Yes	
CultivarID	Integer		Yes	
ReplicateID	Integer		Yes	
DiseaseID	Integer		Yes	1: Stem Rust | 2: Leaf Rust | 3: Yellow Rust
SeverityPercentID	Integer			
Severity	Decimal			
SampleCollected	Boolean		Yes	True | False
SampleCode	String	100		
SampleTypeID	Integer			
CollectorName	String	100		
InstitutionName	String	100		
GrowthStageID	Integer			

Local cultivar

Field	Type	Size	Obligatory	Options
TrialAppID	Integer		Yes	-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 7: Blight Trial | 8: Field nursery
TrialID	Integer		Yes	
LocalCultivarID	Integer		Yes	
LocalCultivarName	String	50		
StandardCultivarID	Integer			
ColorID	Integer			
DiseaseID	Integer		Yes	1: Stem Rust | 2: Leaf Rust | 3: Yellow Rust
SortOrder	Integer			

Local cultivar observation

Field	Type	Size	Obligatory	Options
TrialAppID	Integer		Yes	-9: N/A | 1: Trap Nursery | 2: Skimmelstyring | 3: EuroWheat | 4: EucaBlight | 5: IPM Blight 2.0 | 6: Trap nursery | 7: Blight Trial | 8: Field nursery
TrialID	Integer		Yes	
TrialDateID	Integer		Yes	
LocalCultivarID	Integer		Yes	
ReplicateID	Integer		Yes	
DiseaseID	Integer		Yes	1: Stem Rust | 2: Leaf Rust | 3: Yellow Rust
SeverityPercentID	Integer			
Severity	Decimal			
SampleCollected	Boolean		Yes	True | False
SampleCode	String	100		
SampleTypeID	Integer			
CollectorName	String	100		
InstitutionName	String	100		
GrowthStageID	Integer			

Disease Scale Documentation

Scale documentation

Simple scale for assessment of foliar disease in wheat, translating to typical assessment scale used in breeding. Midpoint in the scale is 5.
In case more detailed assessments are required, mid-point values can be used, e.g., '3' as midpoint between 1 and 5 and 7,5 as midpoint between 5 and 10.

Disease severity (in %)	Interval of OBS	Breeder's scale	Color gradient	Symptoms on WHEAT crop/plot level (indicative)			
				Leaf Rust	Yellow Rust	Powdery Mildew	Septoria/Tan spot..
0	0	1		No attack			
0,1 (trace)	0<x<0,3	2		Few postules per plant - may be uneven	Few stripes per plant - may be uneven (foci)	Few colonies per plant - may be uneven	Max one spot per plant
0,5	0,3<=x<0,75	3		Few postules per tiller - may be uneven	Few stripes per tiller	Few colonies per tiller - may be uneven	Max one spot per tiller
1	0,75<=x<3	4		Several postules per tiller on lower leaves	Several lesions/stripes per tiller on lower leaves	Several colonies per tiller on lowewr leaves	Few spots per plant on lower leaves
5	3<=x<7,5	5		Lower leaves up to 10-25% coverage	Leaves with overlapping lesions	Lower leaves up to 10-25% coverage	Lower leaves up to 10-25% coverage
10	7,5<=x<17,5	6		Lower leaves typically 25% coverage or more			
25	17,5<=x<37,5	7		Lower leaves 50% coverage or more			
50	37,5<=x<75	8		Half of leaves senescent, lower leaves 75-100% coverage			
>75	x>=75	9		Almost no green leaf area left			