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Report for *Puccinia striiformis* race analyses 2015, Global Rust Reference Center (GRRC), Aarhus University, Flakkebjerg, DK- 4200 Slagelse, Denmark.

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Key highlights

- Races and new variants of the aggressive strain (likely *PstS2*) were common across many sampling areas in East Africa and Asia
- Aggressive strain *PstS2* was detected frequently in Ethiopia, Kenya, Tanzania and Rwanda, often with additional virulence to *Yr1, Yr10* or *Yr27*
- Warrior and a related race, Warrior(-), were widespread in Europe and also detected in northern Africa. Races of similar virulence phenotypes were observed in South Asia; however, these were different from those in Europe based on SSR genotyping
- New common race names have been assigned to races with significant epidemic impact.
- All race phenotyping results from GRRC (2008-2015) are now available online www.wheatrust.org

This is a report of non-European *Puccinia striiformis* race analyses activities at GRRC in 2015. The activities are based on an agreement between Aarhus University, CIMMYT and ICARDA to facilitate race analyses of *Puccinia striiformis* infecting wheat and other cereals, mainly from Africa and Asia. From 2012-2016, CIMMYT and ICARDA have each agreed to support the research by an annual contribution of USD 20,000 within the frame of the RUSTFIGHT project. Aarhus University is contributing with quarantine lab and green house facilities, consumables and substantial scientific and technical expertise. RUSTFIGHT, which is focusing on more basic research in host-pathogen interactions, is supported by the Danish Strategic Research Council 2012-2016. A summary of the results can be spread within relevant countries and organizations without delay, provided that the author of this report is acknowledged, along with funding institutions, i.e. "Global Rust Reference Center: Research funded by: Aarhus University, Denmark; CIMMYT; ICARDA". Results from previous years are available as Pdf files from the GRRC home page.

All results dating back to 2008 are accessible at http://wheatrust.org/yellow-rust-tools-maps-and-charts/race-mapper/, which was updated with the 2015 results on February 4th, 2016. You will find tick boxes representing specific maps covering specific continents including Europe. The site is being continuously improved by new analytical tools displaying race frequencies, virulence frequencies singly or in combination. We have assigned common names to significant races according to host cultivars or crops where they first caused epidemics (Europe), and in cases where certain races could be assigned to specific epidemic events elsewhere a country/year designation has been used. For instance, ET2010 refers to a significant race from the yellow rust epidemic in Ethiopia in 2010. The new tools allow the user to highlight particular countries, years and/or races, which can be shown by geographical coordinates, if this information has been provided. New initiatives in utilizing molecular data to improve the genetic resolution and interpretation of results are in progress.

Submission and preparation of samples

Prior to submission of rust infected leaf sample, a request must be sent by e-mail to GRRC to obtain an import permit issued. This permit must be enclosed with any sample submission. Information about details of collector (person), host variety, sampling date, location, disease severity in each plot from where samples should be provided. The details of sampling preparation are given at http://wheatrust.org/submission-of-isolates/.

More extensive sampling procedures and explanations are provided in this Y-tube-video, where Dr Sajid Ali, University of Peshawar, Pakistan, demonstrates the ideal sampling procedures at a BGRI training workshop in Nepal, 2015. click here

Focus sampling areas in 2016 will be selected by staff at ICARDA, CIMMYT and NARCs in Africa and Asia, with a focus on high risk epidemic areas. Since 2011, GRRC also accepted samples of stem rust (*Puccinia graminis tritici*) as agreed upon with the Borlaug Global Rust Initiative and the phase II of the Durable Rust Resistance in Wheat Project (DRRW). This report deals only with yellow rust but results for stem rust is also accessible on the web site. A total of 141 yellow rust infected leaf samples from 10 countries entered the recovery process using susceptible seedlings of Cartago and Morocco. A total of 74 isolates were recovered and multiplied. The recovery rates varied greatly from case to case emphasizing the importance of appropriate sample handling and preservation and submission without delay. In 2015 we had acceptable or good recovery rates from Argentina, Azerbaijan, Bhutan, Eritrea, Ethiopia, Rwanda and Tanzania. There may be multiple reasons for lack of viability, e.g., 1) emerging crop senescence, 2) long time between sample collection and arrival at GRRC and 3) non-favorable condition after sampling, i.e., during preparation and postage. Certain couriers may use extensive radiation during the handling of parcels, which may result in poor recovery rates or failure. Additional cycles of multiplication are often needed to obtain sufficient amount of spores for storage and race analyses, which were conducted according to Thach et al. (2015).

2015 results

A subset of 37 isolates from 2015 and 13 additional isolates collected in 2014 were pathotyped using an extended set of wheat differential lines carrying resistance genes to *P. striiformis*. A combination of lines from 'World' and 'European' differential sets and NILs in an Avocet background gave a high resolution in terms of virulence determination despite that additional previously unreported resistance genes were detected in a number of differential lines including some of the Avocet NILs. For commonly used resistance genes like *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17*, *Yr25*, *Yr27*, *Yr32* and *Yr*(Sp), respectively, at least two differential lines were included. Common race names have been proposed based on relatedness to previous published race names or epidemic sites (shown by countries/years) where a race was first recognized. Other refers to races where a common name has not yet been assigned.

Table 1. Number of *P. striiformis* samples submitted to GRRC, January – December 2015. A total of 74 isolates were recovered, and a subset of these were analysed for race phenotype (Table 2).

Collection year	2015					
Antal af Running no. (local)				Status		
Country	Location	Sampled by	Recovery date	failed	recovered	Hovedtotal
Afghanistan	Bamyan	Elias, Raqib Iodin, Ahmad samin samimy	25.08.2015	15		15
	Kabul	(tom)	10.07.2015		2	2
			(tom)	1		1
Argentina	Anguil	Pablo Campos	03.12.2015		1	1
	Bonifacio	Pablo Campos	03.12.2015		1	1
	Bordenave	Pablo Campos	24.11.2015		1	1
	Buenos Aires	Pablo Campos	03.12.2015		1	1
Azerbaijan	Az.research inst.	Konul Aslanova	28.05.2015		1	1
	Baku	Konul Aslanova	28.05.2015		1	1
	Novi Sad	Konul Aslanova	28.05.2015		2	2
	west part	Konul Aslanova	09.06.2015		1	1
	(tom)	Konul Aslanova	09.06.2015		1	1
Bhutan	Bajo station	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015	4		4
	Jangsa	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		1	1
	Khuruthang	Tshewang, Dorji, Legjay, Cisar, Hodson	10.07.2015		1	1
			17.04.2015		2	2
	Limbukha	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		1	1
	Paro Exhibition	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		1	1
	Serigang	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		1	1
	Susuna	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		1	1
	Thangu	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		1	1
	Tsekha, Dzomi	Tshewang, Dorji, Legjay, Cisar, Hodson	17.04.2015		2	2
Eritrea	Adi Abieto	Asmelash Wolday Tecle	11.11.2015		1	1
	ADI GEMBELO	Asmelash Wolday Tecle	11.11.2015		1	1
	Adi-Hawesha	Asmelash Wolday Tecle	11.11.2015		1	1
	Adi-Quala	Asmelash Wolday Tecle	11.11.2015		1	1
	Berakit	Asmelash Wolday Tecle	11.11.2015		1	1
	Degra Merieto	Asmelash Wolday Tecle	11.11.2015		1	1
	Himbrti	Asmelash Wolday Tecle	11.11.2015		1	1
	METERA	Asmelash Wolday Tecle	11.11.2015		1	1
	Wekerti	Asmelash Wolday Tecle	11.11.2015		1	1
	Yehifsi	Asmelash Wolday Tecle	11.11.2015		1	1
Ethiopia	Adigolo RS, EIAR	(tom)	22.10.2014		4	4
	Fala	Netsanet, Tizazu, Dave	22.10.2014	1		1
			22.10.2015		1	1
	Hashenge	Netsanet, Tizazu, Dave	22.10.2015		1	1
	Hugumbera	Netsanet, Tizazu, Dave	22.10.2015		1	1
	Kasowara	D Hodson	08.12.2015		1	1
	Menkara	Netsanet, Tizazu, Dave	22.10.2015		2	2
	Misha	Bekele	24.11.2015		2	2
	Sinana	D Hodson	08.12.2015		1	1
	Sinana RS	D Hodson	08.12.2015		3	3
Kazakhstan	v. Almalybak	Alma Kohkmetova, Gulzat Yessenbekova	02.09.2015	18	2	20
Nepal	Bagdula, Pyuthan	Mr.Basistha Acharya	(tom)	3		3
	Bhaktpur	Dave Hodson	17.04.2015		1	1
	Bhimtar	Dave Hodson	17.04.2015		2	2
	Champi	Dave Hodson	17.04.2015	1		1
			(tom)	2		2
	Chhayachhetra Salyan	Mr.Basistha Acharya	(tom)	4		4
	Dhorchaur, Salyan	Mr.Basistha Acharya	(tom)	1		1
	Kapurkot Salyan	Mr.Basistha Acharya	16.07.2015	3		3
			(tom)	1		1
	Kapurkot, Salyan	Mr.Basistha Acharya	(tom)	4		4
	Khumaltar	Sajid Ali	17.04.2015	4		4
	Luham, Salyan	Mr.Basistha Acharya	(tom)	3		3
Rwanda	Kalima RS	Aloys, Annualite, Jean Marie, Innocent	22.01.2015		1	1
	Kinigi RS	Aloys, Annualite, Jean Marie, Innocent	13.07.2015		1	1
			22.01.2015	1	2	3
		Aloys, Annualite, Jean Marie, Innocent	22.01.2015		2	2
	Kinyababa	Aloys, Annualite, Jean Marie, Innocent	22.01.2015		1	1
	Miyove	Aloys, Annualite, Eliane, Innocent	22.01.2015	1	1	2
	Nyamicucu	Aloys, Annualite, Jean Marie, Innocent	22.01.2015		1	1
	Nyankenke	Aloys, Annualite, Eliane, Innocent	22.01.2015		1	1
	Ruhunde	Aloys, Annualite, Eliane, Innocent	22.01.2015		1	1
		(tom)	04.03.2015		2	2
	Rukingo	Aloys, Annualite, Jean Marie, Innocent	22.01.2015		1	1
Tanzania	Rukwa	Rose Mongi	16.06.2015		6	6
Hovedtotal				67	74	141

Table 2. GRRC race analyses of *Puccinia striiformis* in 2014-2015 shown by number of isolates per race/country/year. Pathotype code corresponds to virulence matching YR resistance genes (thereby considered ineffective for yellow rust control). Common name correspond to well-established race names or epidemic sites/years where the race was common. Other refers to races which have not yet been assigned a common name due to only sporadic occurrence. The testing of 2015 isolates is ongoing.

Priority	1				
Antal af Running no. (loc			Collecti		
Country	Pathotype code short	Common name	2014	2015	Hovedtota
Afghanistan	1,2,-,-,-,6,7,8,9,-,-,17,-,-,27,-,-,Avs,-	Other	3		3
	1,2,3,4,-,6,-,-,9,-,-,-,-,25,27,32,-,AvS,Amb	TJ2010,+V27	1		1
Algeria	1,2,3,4,-,6,7,-,9,-,-,(17),-,25,-,32,Sp,AvS,Amb	Warrior	4		4
	1,2,3,4,-,6,7,-,9,-,-,(17),-,25,-,32,Sp,AvS,-	Warrior(-)	1		1
Azerbaijan	-,-,-,-,-,6,7,8,-,10,-,-,-,-,-,-,-,AvS,-	Other		1	1
	-,2,-,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	PstS2		2	2
	-,2,-,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V27		3	3
Bhutan	-,2,-,-,-,6,7,-,-,-,-,17,-,25,-,-,-,AvS,Amb	Other		1	1
	1,2,-,-,-,6,7,-,-,-,-,-,-,25,-,-,-,AvS,-	Other		1	1
	1,2,-,-,-,6,7,8,-,-,-,-,-,-,-,-,-,AvS,-	Other		4	4
	1,2,-,4,-,6,7,8,-,-,-,-,-,-,-,-,-,AvS,-	Other		2	2
	1,2,-,4,-,6,7,8,-,-,-,-,-,-,27,-,-,AvS,Amb	Other		1	1
	1,2,3,4,-,6,7,-,9,-,-,(17),-,25,-,(32),Sp,AvS,Amb	Warrior-like		1	1
Ethiopia	-,2,-,-,-,6,7,8,-,10,-,-,-,-,-,-,-,-	Triticale2006	1		1
	-,2,-,-,-,6,7,8,-,10,-,-,24,-,27,-,-,AvS,-	ER2002		1	1
	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V27	1		1
	-,2,-,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	PstS2,+V10,+V27	1		1
	-,2,3,-,-,6,7,8,-,-,-,-,-,25,27,-,-,Avs,-	Other	1		1
	-,2,3,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V3,+V27	1		1
	1,2,-,-,-,6,7,-,9,-,-,17,-,-,27,-,-,AvS,-	ET2010	5	1	6
Iran	-,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	PstS2	1		1
	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V27	1		1
Iraq	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V27	3		3
Kenya	-,2,-,-,-,6,7,8,-,-,-,-,-,25,27,-,-,Avs,-	Other	1		1
	-,2,-,-,-,6,7,8,-,-,-,17,-,-,-,-,-,Avs,-	Other	1		1
	1,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V1,+V27	13		13
Mexico	-,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	PstS2	1		1
Nepal	1,2,-,-,-,6,7,8,-,-,-,-,-,-,-,-,-,AvS,-	Other		1	1
	1,2,-,4,-,6,7,8,-,-,-,-,-,-,-,-,-,AvS,-	Other		2	2
	1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,Sp,Avs,Amb	Warrior-like	1		1
Pakistan	-,2,3,-,-,6,7,8,9,-,-,-,-,25,-,-,-,Avs,Amb	Other	1		1
	-,2,3,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V3,+V27	3		3
	1,2,-,-,-,6,7,8,9,-,-,-,-,-,27,-,-,Avs,-	PstS1,+V27	1		1
	1,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V1,+V27	1		1
Rwanda	-,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	PstS2		9	9
	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V27		1	1
	-,2,-,-,-,6,7,8,9,10,-,-,24,25,-,-,-,AvS,-	PstS2,+V10	2		2
	-,2,3,-,-,6,7,8,9,-,-,-,-,25,-,-,-,Avs,-	PstS2,+V3	8		8
	-,2,3,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V3,+V27	4		4
	-,2,3,4,-,6,7,8,9,-,-,-,-,25,27,-,Sd,Avs,-	Other		1	1
	1,2,-,-,-,6,7,-,9,-,-,17,-,-,27,-,-,AvS,-	ET2010	2		2
	1,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V1,+V27	1	1	2
	1,2,3,4,-,6,-,-,9,-,-,-,-,25,27,32,-,AvS,Amb	TJ2010,+V27	1		1
Tanzania	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	PstS2,+V27		3	3
	-,2,3,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,Amb	Other		1	1
Hovedtotal			65	37	102

2015 results (continued)

Races of the aggressive strain (*Pst*S1/2) were also in 2014-2015 common across many sampling areas in East Africa. So far isolates of *Pst*S1/2 always share virulence to *Yr2, Yr6, Yr7, Yr8* and *Yr9*, often being combined with virulence to *Yr27* and/or other specific virulences (illustrated by their common names). *Pst*S2 was detected frequently in Ethiopia, Kenya, Tanzania and Rwanda, often with additional virulence to *Yr1* or *Yr10*. Another group of *Yr27*-virulent races were observed in East Africa, e.g., ET2010 which was often detected during the big epidemics in Ethiopia in 2010. Thus, the combination of virulence for *Yr27* and aggressiveness has proven to increase the epidemic risks in many areas.

The races in Central and South Asia often combined multiple virulences and many isolates produced huge amounts of telia suggesting at least occasional sexual reproduction. The same applied for the 'Warrior' race, which was detected in Northern Africa. This race has been widespread in Europe since 2011, which was published online in Plant Pathology (click here). Recent research has shown that isolates of the Warrior race are aggressive on fully susceptible wheat at the same level as *Pst*S1 and *Pst*S2 reported earlier. In Europe, the Warrior race has caused significant changes in yellow rust susceptibility of a high number of varieties of both wheat and triticale, i.e., previously resistant or partly resistant varieties became susceptible, and a number of previous susceptible or highly susceptible varieties became less susceptible (Sørensen *et al*., 2014). Very similar races were observed in Bhutan (2012 and 2015) and in Nepal in 2014. However, these Warrior-like races from South Asia differed from the Warrior race in Europe by several DNA markers.

The latter example represents a case with minor, quantitative differences in infection type on particular differentials. Such differences may be ignored in typical race analyses unless additional molecular markers or assessments of quantitative differences are applied. We are currently researching in developing rapid and reproducible methods for the assessment of aggressiveness of isolates. In collaboration with other European and international research groups we are also developing robust DNA-based markers which will facilitate a more rigorous analysis of genetic variability among *Pst* isolates, including quantitative differences.

Literature cited

Hovmøller MS, Walter S, Bayles R, et al. (2015). Replacement of the European wheat yellow rust population by new races from the centre of diversity in the near-Himalayan region. Plant Pathology DOI: 0.1111/ppa.12433

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Sørensen, C. K., Thach T., and Hovmøller, M. S 2016. Evaluation of spray and point inoculation methods for the phenotyping of *Puccinia striiformis* on wheat. Plant Disease (first look) http://apsjournals.apsnet.org/doi/pdfplus/10.1094/PDIS-12-15-1477-RE

Thach T, Ali S, Rodriguez-Algaba J, Justesen AF, Hovmøller MS (2015) Recovery and virulence phenotyping of the historic 'Stubbs collection' of the yellow rust fungus Puccinia striiformis from wheat. Annals of Applied Biology http://onlinelibrary.wiley.com/doi/10.1111/aab.12227/abstract

Examples of figures from www.wheatrust.org

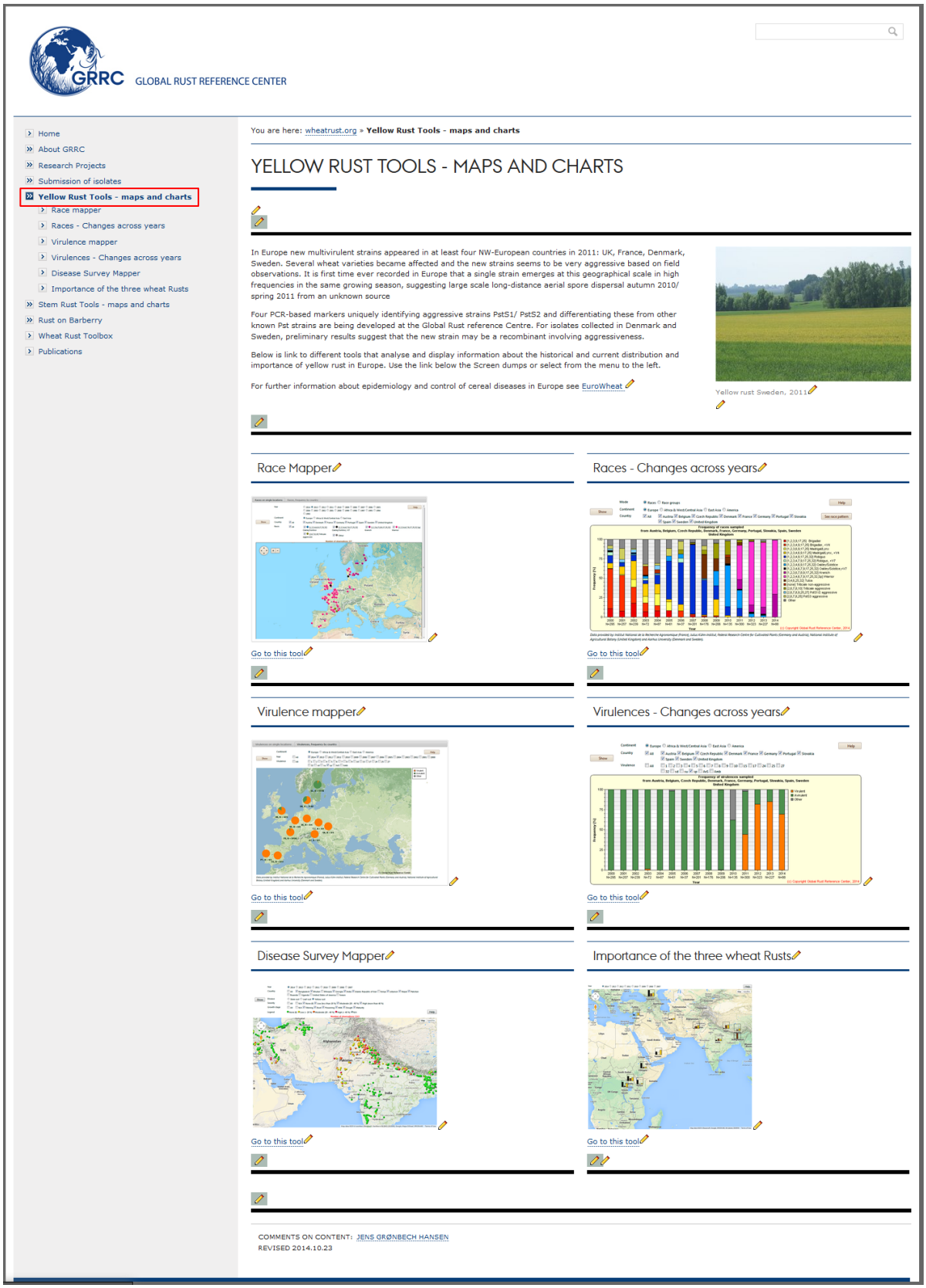

Figure1. From the main page select the menu item "Yellow rust tools – maps and charts"

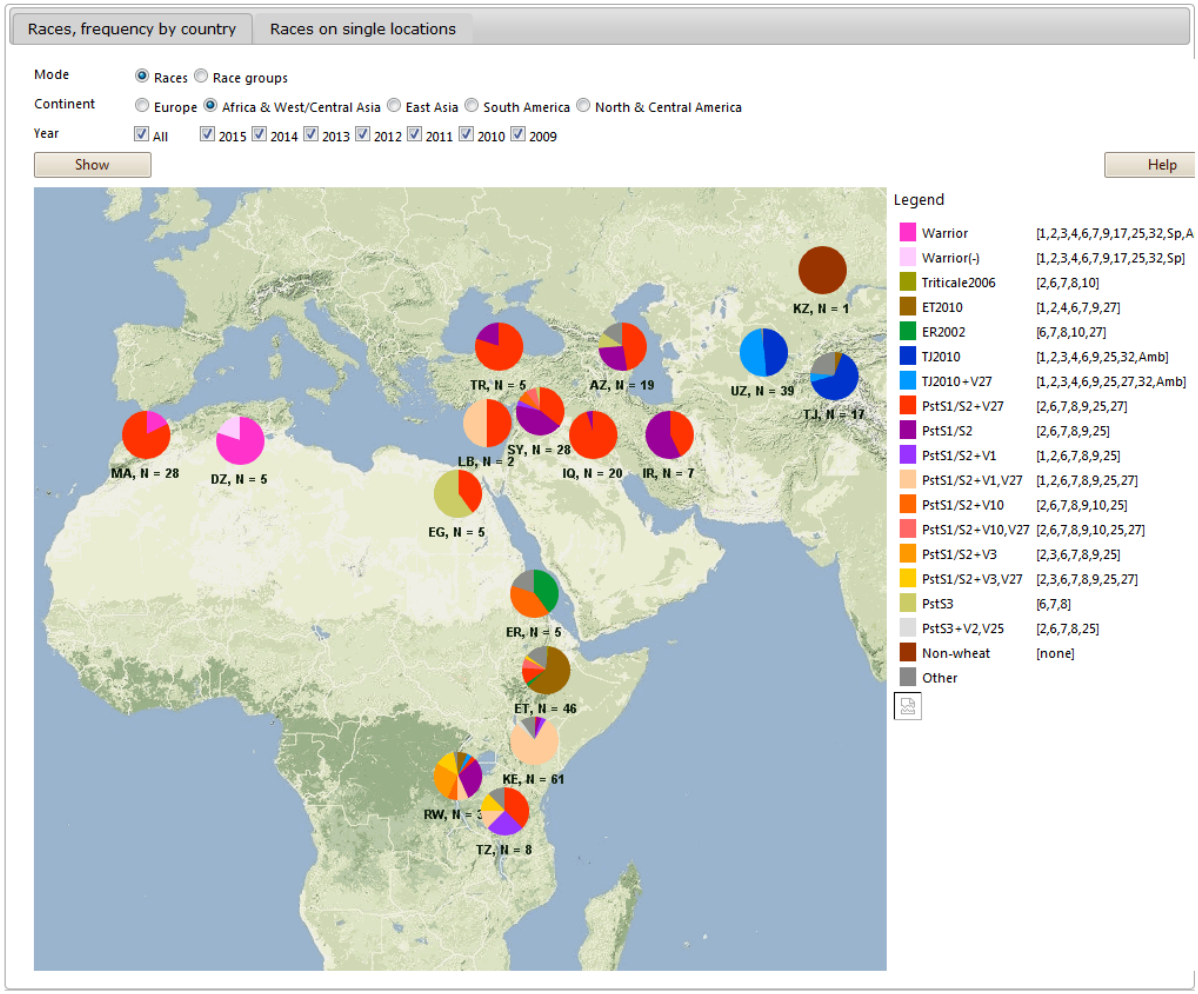

Figure 2. Races shown as frequencies by country (2009-2015), Africa & West/Central Asia.

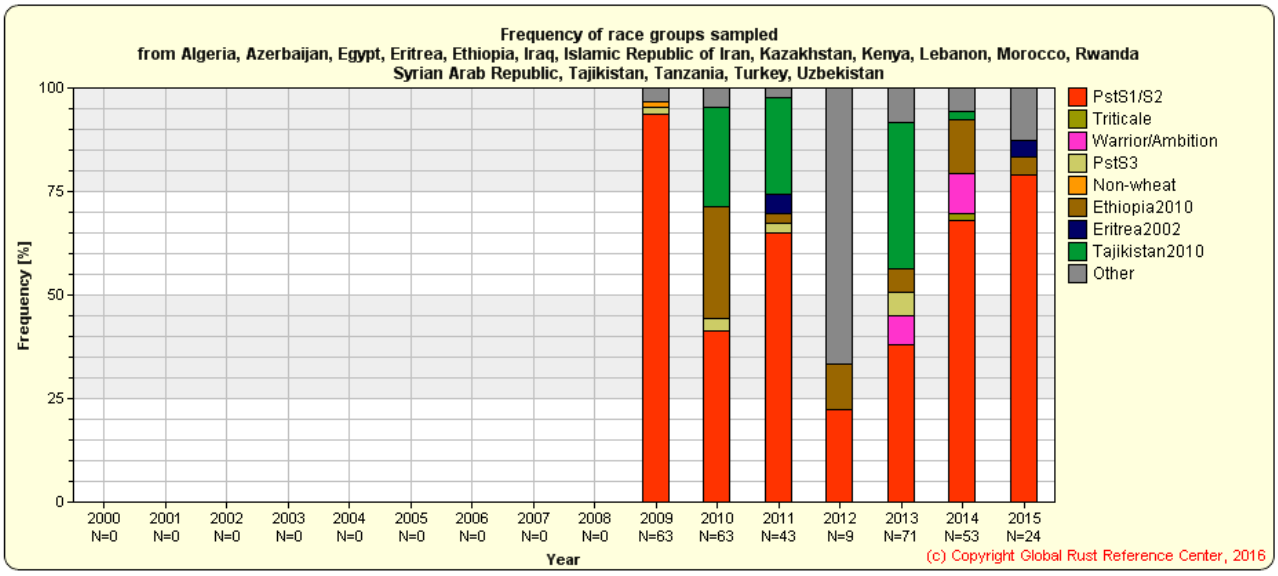

Figure 3. Race groups showing changes across years (2009-2015), Africa & West/Central Asia. A race group consists of two or more related races.

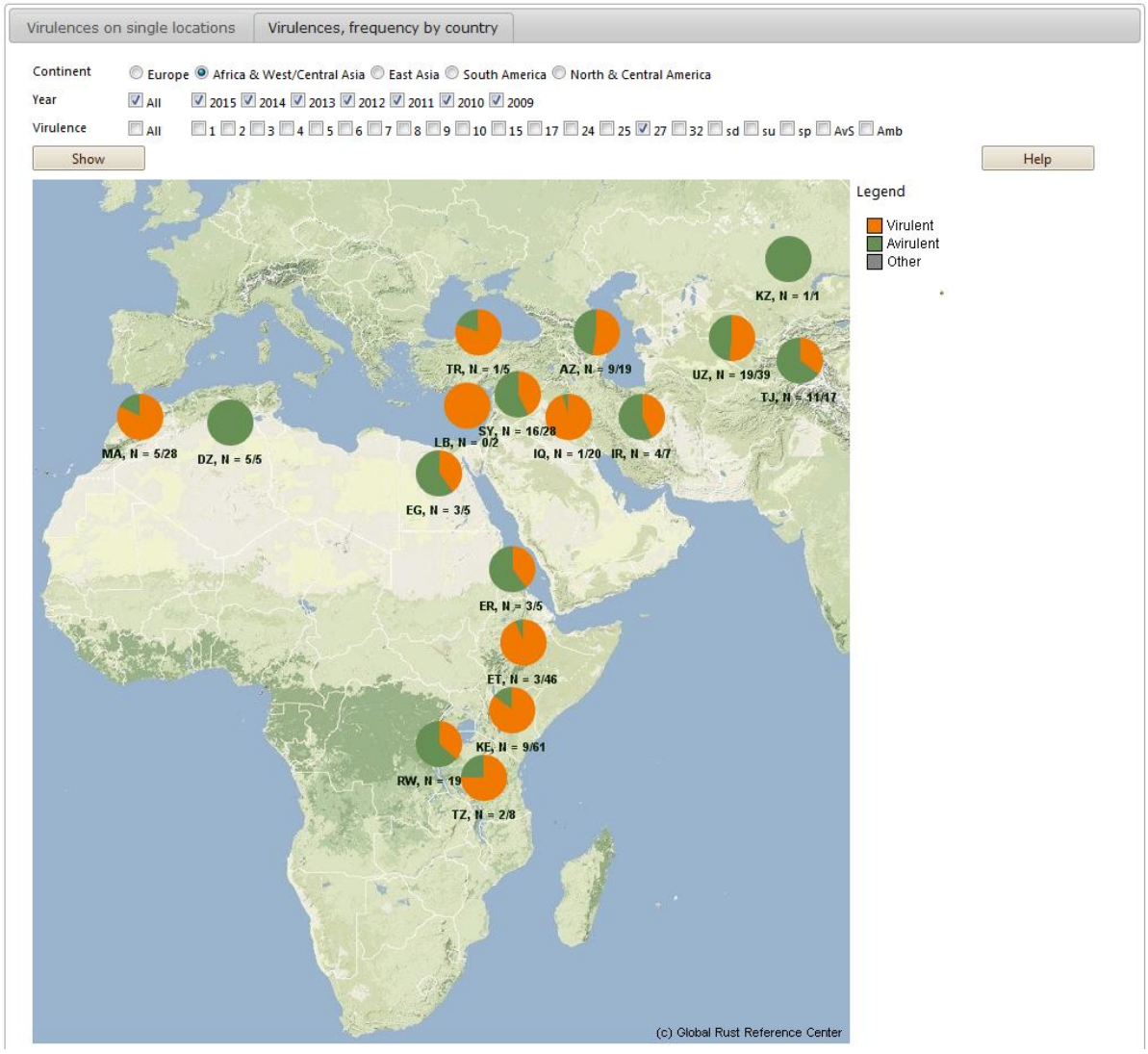

Figure 4. Frequency virulence corresponding *toYr27* shown by country (2009-2015) for Africa & West/Central Asia

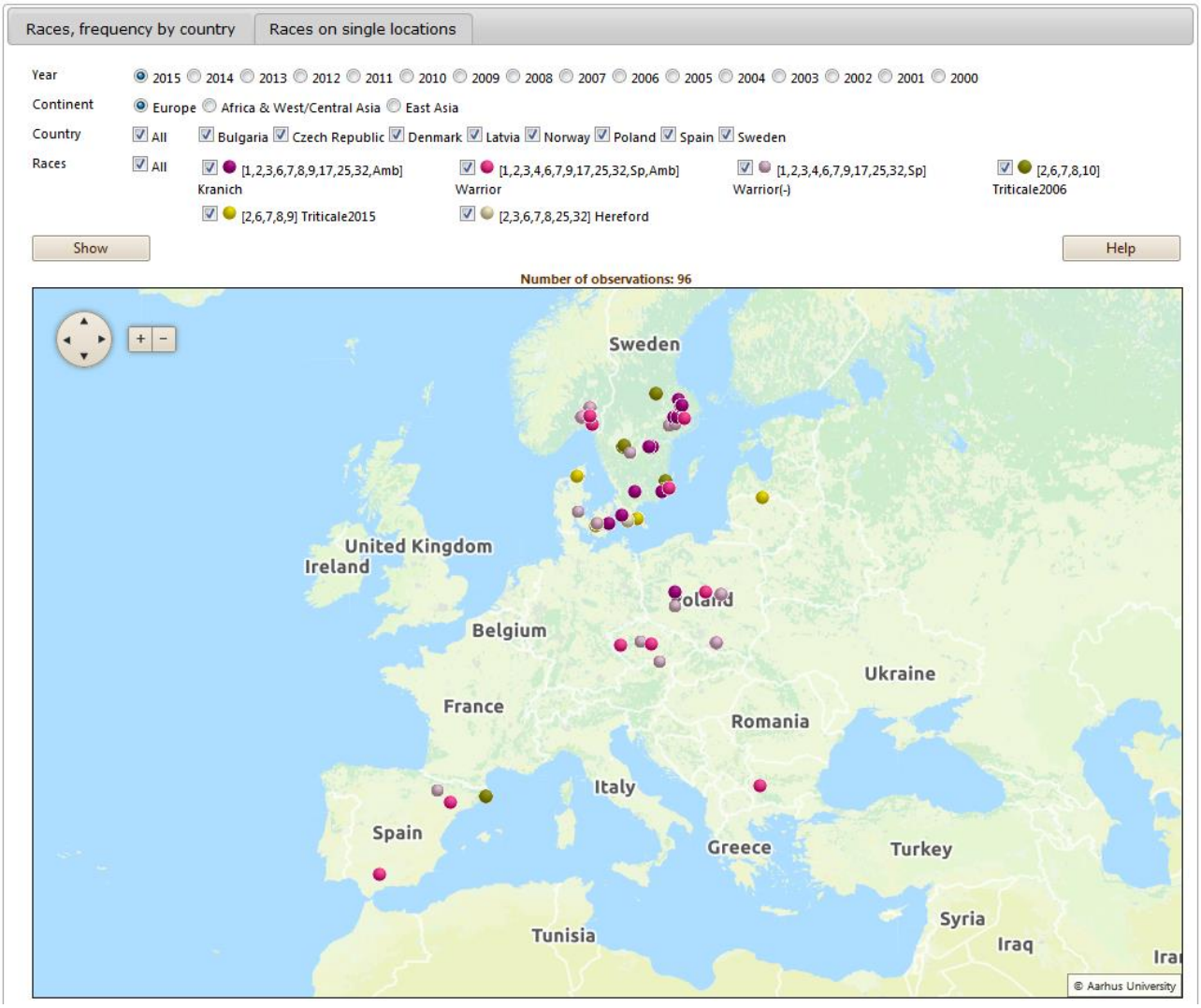

Figure 5. Location of specific races in Europe in 2015 based on GPS coordinates (incomplete).