FAO-ICARDA Letter of Agreement (PO 319501) on

Training and Surveillance Support for Wheat Rust Diseases in Central Asia and Near East

Activity 2: Field-based assessment of wheat rust pathogenic variability (Trap Nurseries)

Pathogenic variability of cereal rust pathogens is traditionally investigated at the seedling stage using rust differential sets. This needs to be conducted under standard and controlled environmental conditions. In most of the countries in CWANA, there is a paucity of comprehensive understanding of pathogenic variability of cereal rusts because of a lack of standard greenhouse rust facilities, expertise and associated continual financial support.

To facilitate and have a better understanding of the field responses of rust resistance genes and to some extend variation among rust populations, wheat lines carrying specific rust resistance genes can be planted under natural infections in field conditions and their responses to infections can assist in understand if the exposed genes are effective under field conditions or not. It will also help to track the behavior of the rust resistance genes over time and space.

The first evidence of experimental field surveys of pathogenic variation of stripe rust was by Zadoks (1984) who established an ''International Yellow Rust Trials Project'' in the autumn of 1955. The project comprised the sowing and observation of experimental varieties in several locations in and outside of Europe. Over the last 10 years, in collaboration with CIMMYT, the University of Sydney and FAO, three international wheat rust trap nurseries have been distributed annually to more than 32 countries by ICARDA. Rust trap nurseries are valuable tools for early detection of pathogenic changes in rust pathogen populations particularly in wheat growing areas in developing countries where laboratory facilities and/or skilled staff are not available. Although this cannot be claimed to be the best tool in population genetic analysis, in places where race analysis is not possible, the trap nurseries have been considered helpful in assessing pathogenicity and changes. Furthermore, the rust trap nurseries are useful practical open-source training instruments for early career scientists to learn and practice field scoring of rust resistance genes under the field conditions assisting rust resistance screening of breeding germplasms. Sampling from trap nurseries also facilitates postulation of emergence of new rust races through comprehensive race analysis where facilities are available.

Running of the trap nurseries is simple and does not require sophisticated facilities and comprehensive knowledge of host - pathogen genetic interactions. Both race-specific seedling or all-stage resistance genes, adult plant resistance sources and leading varieties can be included in trap nurseries for evaluation under natural conditions over a range of sites. Because of the monogenic nature of most of differential genotypes included in these nurseries, field scoring and assessment of effectiveness of rust resistance gene can be achieved easily in presence of rust infection. In Figure 6, clear differentiation can be observed for *Yr5* with resistance response and *Yr6,* which is fully susceptible to yellow rust.

Figure 1. Field susceptible and resistance responses of Avocet near isogenic lines of *Yr6* (left) and *Yr5* (right) under field conditions to yellow rust.

Through the current LoA project, 132 sets of International Rust Trap Nurseries of yellow, stem, and leaf ruts was distributed to the 10 supported countries (Table 1). During the training workshop, field-note taking of the responses of these genotypes was practiced at the RCRRC in Izmir (Figure 2). The wheat rust trap nurseries comprised of standard differential sets for yellow, stem, and leaf rusts, rust monogenic-single gene lines, commercial and historical cultivars from the region and also source of adult-plant resistance genes which can only be assessed at adult-plant stage (Table 2, 3, and 4). Depending on the appearance of rust infections, national collaborators have collected field response data of the differential genotypes and commercial cultivars. These data show differences or similarities in field responses of rust resistance genes in different locations, which may imply the similarity or difference between the rust populations in different geographical locations. This has been complemented in some of the countries with the support of race typing at national rust laboratories and the support of the current collaboration with the GRRC at the University of Aarhus, Denmark.

Trap Nurseries were evaluated under natural infection and during the growing season. The planted genotypes were scored for rust reaction and disease severities. The rust disease severities were recorded based of Modified Cobb's scale for disease severity (0-100) and for resistance responses (R=Resistant, MR= Moderately Resistant, MS= Moderately Susceptible, S= Susceptible) based on the methods described by Roelfs et al 1992.

Table 1. List of distributed International yellow (10th IYRTN-16), stem (11th ISRTN-16), and leaf (7th ILRTN-16) rust trap nurseries distributed to supported countries through FAO-ICARDA agreement.

Country Name	**Nursery Name**			**Total set**
	10th IYRTN-16 (80)	**11th ISRTN-16 (85)**	**7th ILRTN-16 (85)**	
Azerbaijan	4	4	3	11
Egypt	5	5	5	15
Eritrea	3	4	2	9
Iran	4	4	4	12
Iraq	3	2	2	7
Morocco	5	3	5	13
Pakistan	12	12	12	36
Tajikistan	3	3	3	9
Turkey	3	3	3	9
Uzbekistan	5	3	3	11
Total sets	**47**	**43**	**42**	**132**

Figure 2. Wheat rust training course Izmir 2016. Field note-taking of yellow rust trap nursery.

Table 2. List of genotypes and yellow rust resistance genes (Yr) included in the 10th international yellow rust trap nursery (10th IYRTN-16)

Ent.	Cultivar/ genotype	*Yr-gene*	Ent.	Cultivar/ genotype	*Yr-gene*
1	**Triticale**		41	Spaldings Prolific	(W;*Yr*SP)
2	**Morocco**		42	Avocet 'R'	*Yr*A
3	*Yr* 1/ 6* Avocet S	*Yr*1	43	Inia 66	*Yr*A
4	*Yr* 1/6* AvS	NIL 1	44	Avocet 'S'	-
5	Chinese 166	(W;*Yr*1)	45	Tres/6* AVS	-
6	Chinese 166	*Yr*1	46	*Yr* 18/ 3* Avocet S	*Yr*18
7	Kalyansona (S)	*Yr*2	47	Jupateco 'R'	*Yr*18+
8	Heines VII	(W;*Yr*2+?)	48	Jupateco 'S'	-
9	Vilmorin 23 (W;*Yr*3a, 4a+other)	(W;*Yr*3a, 4a+)	49	Anza	*Yr*A, *Yr*18
10	**Morocco**		50	**Morocco**	
11	Hybrid 46 (W;*Yr*4)	(W;*Yr*4)	51	Cook (S)	APR
12	*Yr* 5/ 6* Avocet S	*Yr*5	52	Lemhi	*Yr*21
13	*Triticum spelta*	*Yr*5	53	TP 981	-
14	*Yr* 6/ 6* Avocet S	*Yr*6	54	TP1295	*Yr*25
15	Heine's Kolben	(S; *Yr*6+1)	55	*YR*27/6*Avocet S	*Yr*27
16	Heine's Peko	(S; *Yr*6+?)	56	Ciano 79	*Yr*27
17	Fielder	*Yr*6, *Yr*20	57	ATTILA CM85836-50Y	*Yr*27+?
18	*Yr* 7/ 6* Avocet S	*Yr*7	58	OPATA 85	*Yr*27+*Yr*18
19	Lee (S;*Yr*7)	(S;*Yr*7)	59	Avocet-*YRA**3/3/ALTAR .	*Yr*28
20	**Morocco**		60	**Morocco**	
21	Reichersberg 42	(W;*Yr*7+?)	61	Lal Bahadur/Pavon 1B L	*Yr*29
22	Thatcher	*Yr*7	62	AVOCET-*YRA**3/PASTOR	*Yr*31
23	*Yr* 8/ 6* Avocet S	*Yr*8	63	PASTOR	*Yr*31+APR
24	Compare	(S;*Yr*8)	64	Pollmer 2.1.1(Triticale)	
25	*Yr* 9/ 6* Avocet S	*Yr*9	65	Cham 1	DW
26	Fed.4/Kavkaz	*Yr*9	66	Cham 4	
27	Clement	(W;*Yr*9+*Yr*2+?)	67	Cham 6	
28	Federation	-	68	Cham 8	*Yr*27
29	*Yr* 10/ 6* Avocet S	*Yr*10	69	Gobustan	
30	**Morocco**		70	**Morocco**	
31	Moro (W; *Yr*10)	(W; *Yr*10)	71	Sardari	
32	*Yr* 15/ 6* Avocet S	*Yr*15	72	Alamout	
33	*YR*17/6*Avocet S	*Yr*17	73	Bohouth 6	

34	Strubes Dickopf	(W;2-more?)	74	Gereck 79	
35	Suwon 92xOmar	(W, YrSu)	75	Hugenoot	
36	Nord Desprez	(W;*Yr*ND)	76	Gun 91	
37	*Yr*32/6*Avocet S	*Yr*32	77	Dustlik	
38	Carstens V	(W, *Yr*32)	78	TATARA CM85836-50Y	
39	*Yr*SP / 6* Avocet S	*Yr*SP	79	**Suwon 92/Omar**	*Yr*Su
40	***Morocco***		80	**Triticale**	

Table 3. List of genotypes and stem rust resistance genes (Sr) included in the 11th international stem rust trap nursery (11th ISRTN-16)

Ent.	Name	*Sr-gene*	Ent.	Name	*Sr-gene*
1	Triticale		44	Trident Sr38	*Sr38*
2	ISr5-Ra CI 14159	*Sr5*	45	Trident	*Sr38*
3	ISr6-Ra CI 14163	*Sr6*	46	RL 5711 Kerber	*Sr39*
4	Na 101/6*Marquis	*Sr7a*	47	RL 6087 Dyck	*Sr40*
5	ISr7b-Ra CI 14165	*Sr7b*	48	TAM 107	*Sr1RS-Am*
6	CI 14167/9*LMPG-6	*Sr8a*	49	Amigo	*Sr24, 1RS-Am*
7	Barleta Benvenuto	*Sr8b*	50	Siouxland	*Sr24, 31*
8	ISr9a-Ra	*Sr9a*	51	Roughrider	*Sr36, 6*
9	Prelude*4/2/Marquis*6/Kenya	*Sr9b*	52	Sisson	*Sr6, 31, 36*
10	ISr9d-Ra	*Sr9d*	53	Fleming	*Sr6, 24, 36, 1RS-Am*
11	Vernstein	*Sr9e*	54	Chris	*Sr7a, Sr12, Sr6*
12	Chinese Spring*7/Marquis	*Sr9g*	55	CsSSrTmp	*SrTmp*
13	W2691Sr10	*Sr10*	56	Bt/Wld	*SrWld-1*
14	Lee/6*LMPG-6	*Sr11*	57	Pavon 76	*Sr2 comp.*
15	Chinese Spring*5/Thatcher	*Sr12*	58	Einkorn	*Sr21*
16	Prelude*4/2/Marquis*6/Khapstein	*Sr13*	59	Seri 82	*Sr31*
17	W2691*2/Khapstein	*Sr14*	60	Morocco	
18	Prelude*2/Norka	*Sr15*	61	PBW343 = Attila with Sr31	*Sr31*
19	Thatcher/CS	*Sr16*	62	Kubsa = Attila	*Sr31 absent*
20	Morocco		63	Chamran = Attila	-

21	Prelude/8*Marquis*2/2/Esp	*Sr17*	64	Cham 6	-
22	Little Club/Sr18Mq Marquis "A"	*Sr18*	65	Cham 8	*Sr31*
23	94A 236-1 Marquis "B"	*Sr19*	66	Cham 10 = Kauz//Kauz/star	*Sr31?*
24	94A 237-1 Marquis "C"	*Sr20*	67	Bacanora = Kauz's'	*Sr31*
25	McNair 701	*SrMcN*	68	Cook	*Sr36*
26	*T. monococcum*/8*LMPG-6	*Sr21*	69	Coorong (Triticale)	*Sr27*
27	Mq*6//Stewart*3/RL 5244	*Sr22*	70	Satu	*SrSatu*
28	Exchange	*Sr23*	71	SrNin	*SrNin*
29	LcSr24Ag	*Sr24*	72	Karim	*Durum*
30	Agatha (CI 14048)/9*LMPG-6	*Sr25*	73	Imillo	*Durum*
31	Eagle Sr26 McIntosh	*Sr26*	74	Altar	*Durum*
32	WRT 238-5 (1984)R.	*Sr27*	75	EL Nielain	
33	Kota RL471	*Sr28*	76	Hidhab	
34	Prelude/8*Marquis/2/Etiole..Choisy	*Sr29*	77	Gemmeiza 9	
35	Selection from Webste	*Sr30*	78	Giza-168	
36	Sr31 (Benno)/6*LMPG-6	*Sr31*	79	Arrehane	
37	ER5155 S-203 (1995)R.	*Sr32*	80	Morocco	
38	RL 5405 (1192) Kerber	*Sr33*	81	Debeira	
39	RL 6098 (1997) Dyck	*Sr34*	82	Aguilal	
40	Morocco		83	Thatcher	
41	RL 6099 (1995) Dyck	*Sr35*	84	Guard	-
42	W2691SrTt-1 CI 17385	*Sr36*	85	Triticale	
43	Prelude*4/Line W	*Sr37*			

Table 4. List of genotypes and leaf resistance genes (*Lr*) included in the 7th international leaf rust trap nursery (7th ILRTN-16)

Ent.	Variety / Line	Pedigree / Origin	Ent.	Variety / Line	*Lr-gene/s*
1	Triticale		44	Morocco	
2	Morocco		45	Thatcher	*Lr22b*
3	Cham 4	Syria	46	TC*6/Centenatrio (RL6003)	*Lr1*
4	Cham-6	Syria	47	TC*6/Webster (RL6016)	*Lr2a*
5	Cham-8	Syria	48	TC*6/Carina (RL6019)	*Lr2b*
6	Cham-10	Syria	49	TC*6/Loros (RL6047)	*Lr2c*

7	Hidhab	Algeria	50	TC*6/Democrat (RL6002)	*Lr3*
8	Aguilal	Morocco	51	TC*6/Aniversario (RL6007)	*Lr3Ka*
9	Arrehane	Morocco	52	Bage/8*TC (RL6042)	*Lr3Bg*
10	Salamoni	Syria	53	Transfer/6*TC (RL6010)	*Lr9*
11	Roomy	West Asia	54	TC*6/Exchange (RL6004)	*Lr10*
12	Florance Aurour	North Africa	55	Kussar (W976)	*Lr11*
13	Potam	North Africa	56	Exchange/6*TC (RL6011)	*Lr12*
14	Nesma	North Africa	57	Manituou	*Lr13*
15	Serie 82	-	58	Selkirk/6*TC (RL6013)	*Lr14a*
16	PBW 343	-	59	TC*6/Maria Escobar (RL6006)	*Lr14b*
17	Bohouth 6	-	60	TC*6/Kenya1483 (RL6052)	*Lr15*
18	Bohouth 8	-	61	TC*6/Exchange (RL6005)	*Lr16*
19	Babaqa	-	62	Klein Lucero/6*TC (RL6008)	*Lr17*
20	Mexipak	-	63	TC*7/Africa 43 (RL6009)	*Lr18*
21	Cham4/CA8055	-	64	TC*7/Tr (RL6040)	*Lr19*
22	Morocco	-	65	Thew (W203)	*Lr20*
23	Cham 1	Syria	66	TC*6/RL5406 (RL6043)	*Lr21*
24	Cham 3	Syria	67	TC*6/RL5404 (RL6044)	*Lr22a*
25	Cham 5	Syria	68	Lee 310/6*TC (RL6012)	*Lr23*
26	Safra maan	-	69	TC*6/Agent (RL6064)	*Lr24*
27	Oued Zenati	Algeria	70	Transec (Awned)	*Lr25*
28	Senatori Cappelli	North Africa	71	TC*6/ST-1-25 (RL6078)	*Lr26*
29	Chili	Tunisia	72	Gatcher (W3201)	*Lr10, Lr27+Lr31*
30	Karim	Tunisia	73	CS2D-2M	*Lr28*
31	Geruftel-1	ICD95-1302	74	TC*6/CS7AG#11 (RL6080)	*Lr29*
32	Tunsyr-2	ICD95-0169..	75	TC*6/Terenz10 (RL6049)	*Lr30*
33	Geromtel-1	ICD95-1174..	76	TCLR32 (RL5497)	*Lr32*
34	Icasyr-1	ICD95-0169..	77	TC*6/PI58548 (RL 6057)	*Lr33*
35	Sebou	-	78	TC*6/PI58548 (RL 6058	*Lr34*
36	Belikh-2	-	79	RL5711	*Lr35*

37	Atlas – 1	-	80	E84018	*Lr36*
38	Ammar – 3	-	81	TC*6/ VPM (RL 6081)	*Lr37*
39	ICA Rasha – 1	-	82	TC*6// CARINA (RL 6051)	*Lr B*
40	Aghram	-	83	WL711	*Lr13*
41	Bohouth 9		84	Morocco	-
42	Bohouth 11	-	85	Triticale	-
43	Otb-6 (DW Check)	-			-

The findings of this activity indicated wide spread occurrence of yellow rust in almost all supported countries at various degrees and disease severities. Collected data from 33 locations for yellow rust indicated that the susceptible checks were infected in almost all locations. This is considered an indication of the wide presence of yellow rust inoculum but due to unfavorable environmental conditions, the disease could not develop due to high severity in most locations. Disease severity of important Yr-genes is used in graphical presentations of effectiveness of Yr-genes at testing sites (Figure 8). In general, and based on obtained data, virulence for *Yr5* and *Yr15* was not observed in any locations and or the disease severity was very low. Virulence for *Yr2*, *Yr6*, *Yr7*, and *Yr9* was fixed in all locations and based on high infection on *Yr27* sources, still the dominant race of yellow rust in this region is the *Yr27* virulent race that is adapted to warm areas and has been responsible for recent epidemics in many countries in CWANA.

Increasing virulence for *Yr1*, *Yr3*, *YrSp*, *Yr32*, and *Yr17* in some of the locations indicates widespread of a Warrior race first found in Europe 2011. This race appeared in northwest Turkey first in 2014, following its wide occurrence and effect in Europe, and is now present almost in all wheat growing areas in Turkey. Seedling race analysis of collected samples from Edirne and Adapazari confirmed the presence of the Warrior race in 2015 but in 2016 yellow rust was at a very low level in these provinces and race analysis did not confirm the presence of Warrior race in this year (Nazari, unpublished data). The same race has been reported in North Africa in the last few years. In 2016 high infection for the key diagnostic genes of Warrior (*Yr1*, *Yr3*, *Yr4*, *Yr32*, *Yr17*) planted as trap nurseries was reported from Egypt indicating possible migration of the Warrior race, perhaps from North African countries to Egypt. Although the pathogenic variability of stripe rust is high for most of *Yr*-genes, still the *Yr27* is considered a dominant race followed by the Warrior race which may replace the *Yr27* race being a major threat for mega wheat cultivars in CWANA.

Obtained data from 28 locations of where ILRTN was planted indicated increasing frequency and severity of leaf rust (Figure 4). High diversity of virulence for most *Lr*-genes was observed within testing sites. In presence of yellow rust epidemics and the fear of devastating epidemics of stem rust, the importance of leaf rust has been almost forgotten in many countries. The trend of widespread, higher disease severity and also increasing virulence factors in leaf rust populations and particularly in warm and humid areas in this region is alarming. Although certain varieties developed recently performed well in terms of yellow rust, stem rust and leaf rust in most of major wheat growing areas, the spread of leaf rust and emergence of its new races has to be monitored and taken into consideration in rust surveys and hence breeding for durable resistance.

Trap nursery data for ISRTN was received from 25 locations (data from 12 locations with stem rust infection are presented), most of them with no stem rust infection (Figure 5). Except for sporadic presence of stem rust in a few countries, stem rust did not cause significant problems for farmers. Dry conditions coupled with planting resistant cultivars and early maturity are major factors in controlling stem rust. Despite the previous report of Ug99 in Iran and Egypt, collected data from sources for *Sr31* did not show high infection rates in Iran and Egypt in 2016. Race analysis of stem rust samples collected from North-west of Iran reported presence of Ug99 but this needs to be further confirmed. Stem rust resistance genes *Sr31* and *Sr24* are still holding their position in CWANA and Near East. Although pathogenic variability can be observed for other stem rust resistance genes in stem rust trap nurseries, the use of race-nonspecific-adult-plant resistance genes with minor effect is the most recommended management strategies. Disease severity on these lines with less than 20% is considered as a source of resistance. However, if the disease severity, even at low infection, is observed with susceptible reaction, then the use of resistance genes has to be carefully revisited since the low severity of susceptible infection may be due to unfavorable environmental conditions and new virulence for that given gene might be on the increase.

The recent spread of local stem rust race TKTTF in Iran, Iraq, and Azerbaijan indicates the importance of local races. In recent years, a number of Ug99 resistant cultivars have become susceptible to this race, which has been known for in Iran, Syria, Turkey and Lebanon. The major difference of this race with Ug99 is the presence of virulence for *SrTmp* and avirulence for *Sr11*, *Sr24*, and *Sr31*. Stem rust trap nursery data shows the presence of virulence for SrTmp in testing sites, which imply the presence of this race. This race was the cause of recent stem rust outbreaks in Ethiopia known as “Digalu” race and is the cause of recent occurrences of stem rust in Europe.

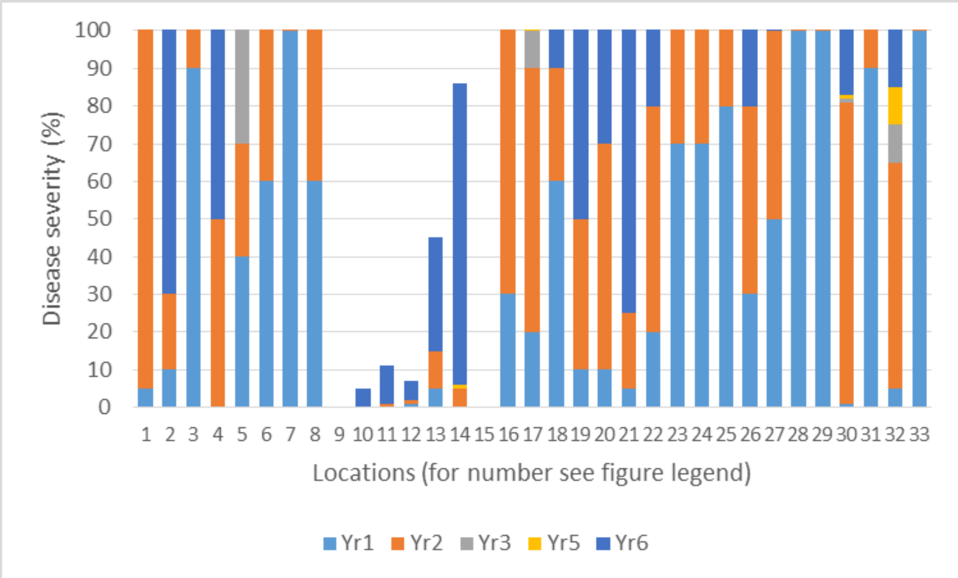
In general, the field data of trap nurseries indicated that despite the dry period, the rusts continue evolving and spreading. There is a shift in yellow rust populations, spread of local stem rust races, and increasing number of virulence in leaf rust populations. It appears that the Warrior race has spread to wider geographies including Egypt. Regarding stem rust, to date there is no indication of further expansion of Ug99 from Iran and Egypt. However, this might need to be further analyzed and followed up over the coming years.

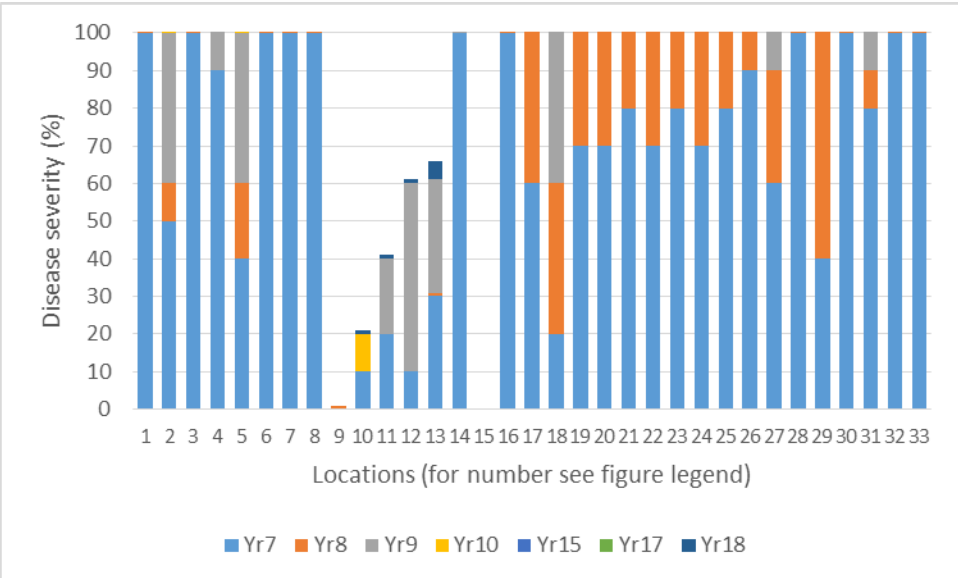
In Figures 3, 4 and 5 diversity of yellow, stem and leaf rust disease severities is presented for most of *Yr*, *Sr* and *Lr* genes in different locations.

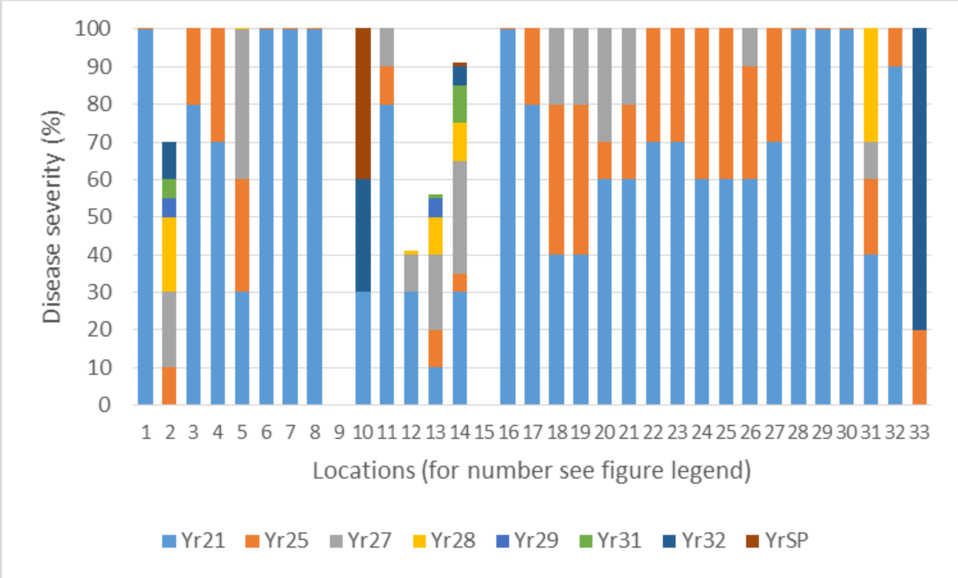
Figure 3. Graphical presentation for pathogenic variability of yellow rust in few countries in CWANA

Figure Legend:

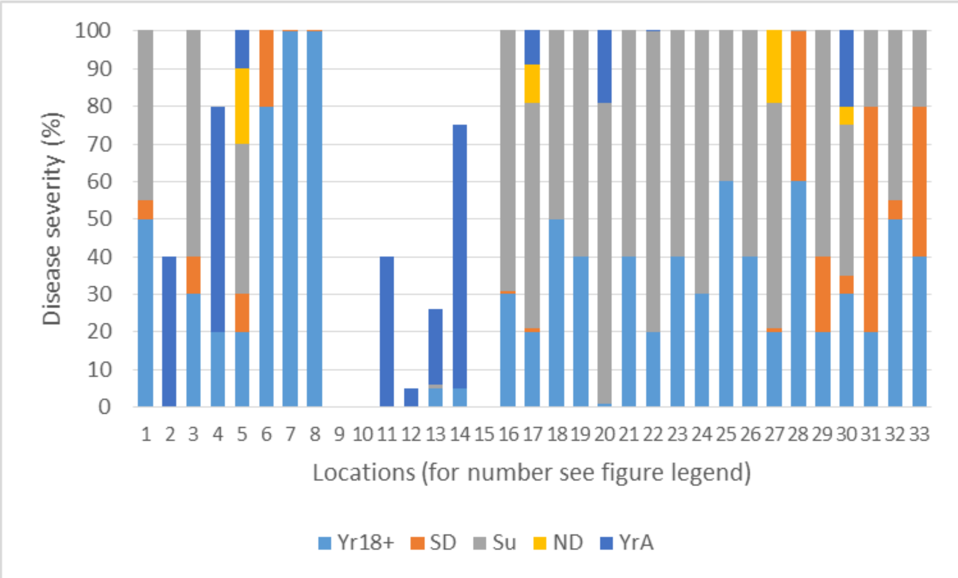
1 - Iran-Karaj, 2 - Iran-Moghan, 3 - Iran-Zargan, 4 - Iran-Sari, 5 - Azerbaijan-Abşeron, 6 - Azerbaijan-Cəlilabad, 7 - Azerbaijan-Qobustan, 8 - Azerbaijan-Tarter, 9 - Egypt-Sids, 10 - Egypt-Gemmeiza, 11 - Egypt-Itay El-Baroud, 12 - Egypt-Kafr Elhmama, 13 - Egypt-Sakha, 14 - Egypt-Nubaria, 15 - Eritrea, 16 - Morocco-Marchus, 17 - Morocco-Taz, 18 - Pakistan-Ghotki, 19 - Pakistan-Rahim Yar Khan, 20 - Pakistan-Bahawalpur, 21 - Pakistan-Faisalabad, 22 - Pakistan-Sailkot, 23 - Pakistan-Islamabad, 24 - Pakistan-Attock, 25 - Pakistan-Nowshera, 26 - Pakistan-Peshawar, 27 - Pakistan-Rawlakot, 28 - Tajikistan, 29 - Uzbekistan-Kashkadadarya, 30 – Turkey-Izmir, 31 – Turkey- Sakarya, 32 – Turkey-Adana, 33 - Turkey-Haymana







Disease severity (%)
Locations (for number see figure legend)
Yr21 Yr25 Yr27 Yr28 Yr29 Yr31 Yr32 YrSP

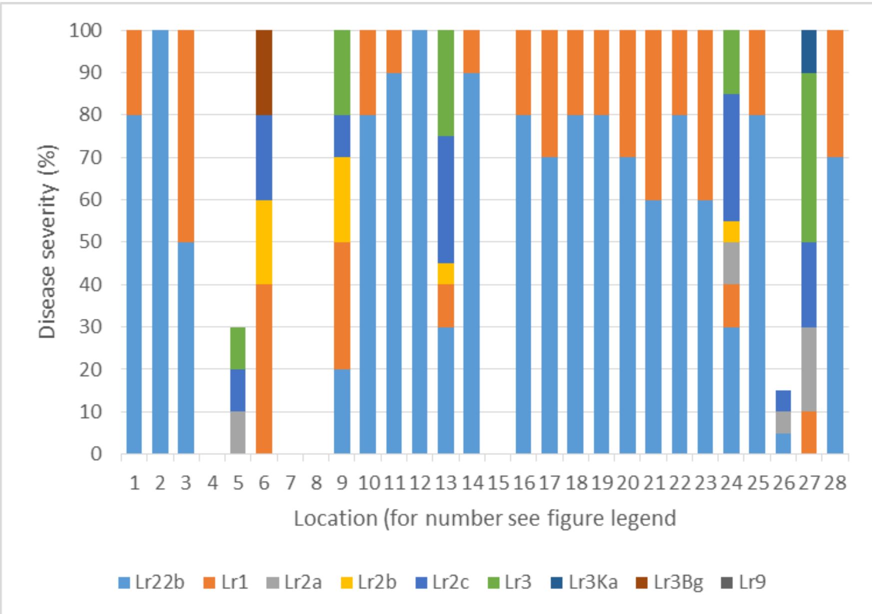


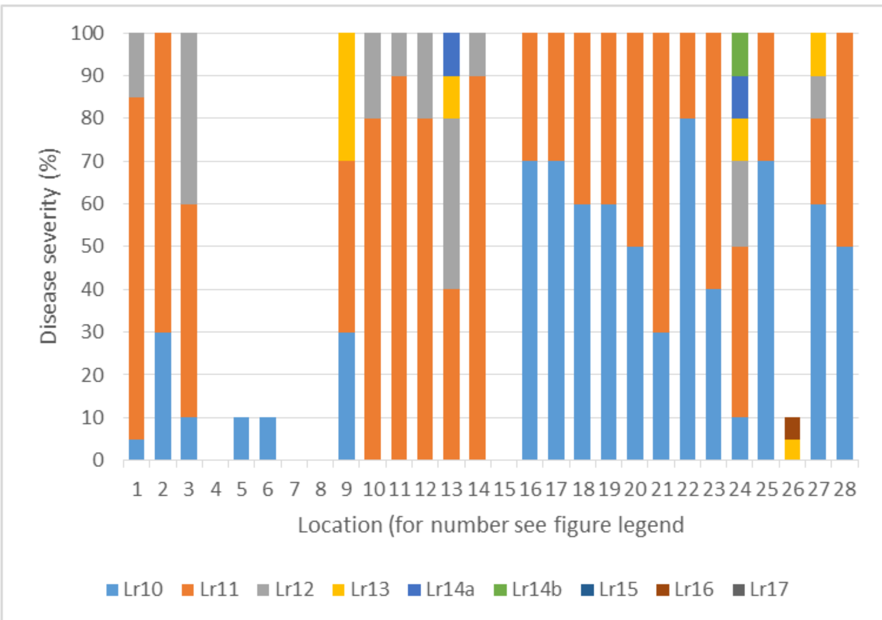
Disease severity (%)
Locations (for number see figure legend)
Yr18+ SD Su ND YrA

Figure 4. Graphical presentation for pathogenic variability of **leaf rust** in few countries in CWANA

Figure Legend:

1- Iran-Ahvaz, 2- Iran-Gorgan, 3- Iran-Sari, 4- IRAN-Kelardasht, 5- Azerbaijan-Absheron, 6- Azerbaijan-Jalilabad, 7- Azerbaijan-Gobustan, 8- Azerbaijan-Tartar, 9- Egypt-Sids, 10- Egypt-Gemmeiza, 11- Egypt-Itay El-Baroud, 12- Egypt-Kafr Elhmama, 13- Egypt-Sakha, 14- Egypt-Nubaria, 15- Eitrea, 16- Pakistan-NIA Tandojam, 17- Pakistan-WRI Sakrand, 18- Pakistan-Kunri, 19- Pakistan-Thatta, 20- Pakistan-Ghotki, 21- Pakistan-RY Khan, 22- Pakistan-Bahawalpur, 23- Pakistan-Faisalabad, 24- Pakistan-Sailkot, 25- Pakistan-Islamabad, 26- Pakistan-Attock, 27 – Turkey-Ankara, 28 – Turkey - Sakarya





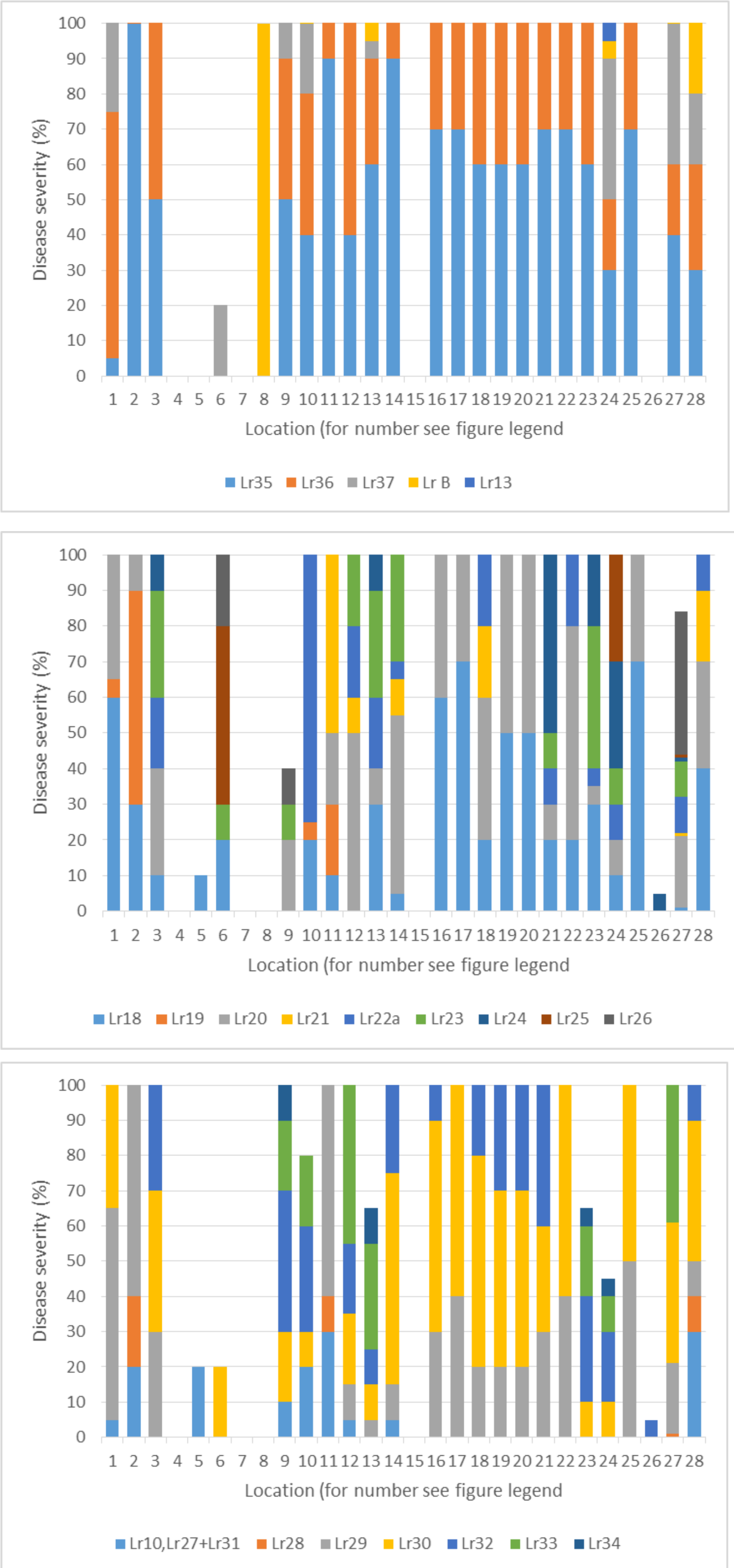
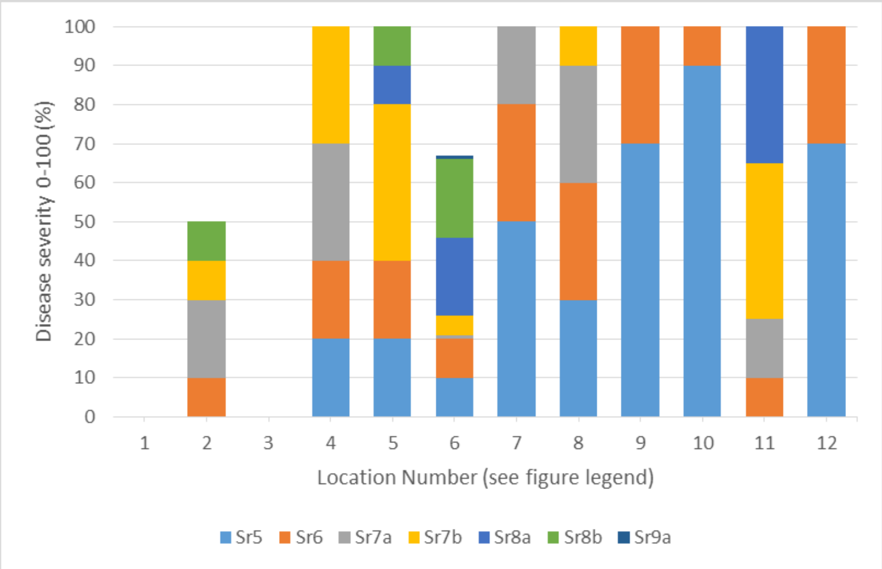
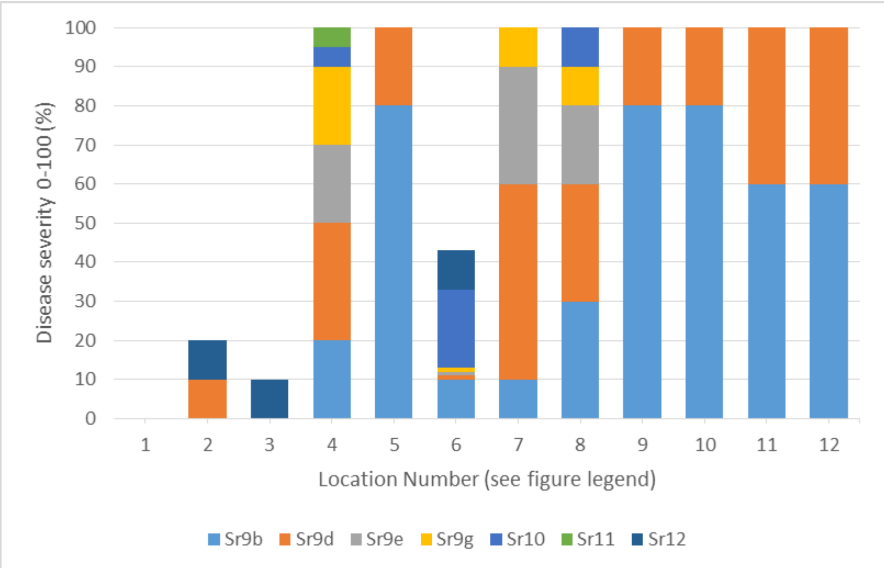


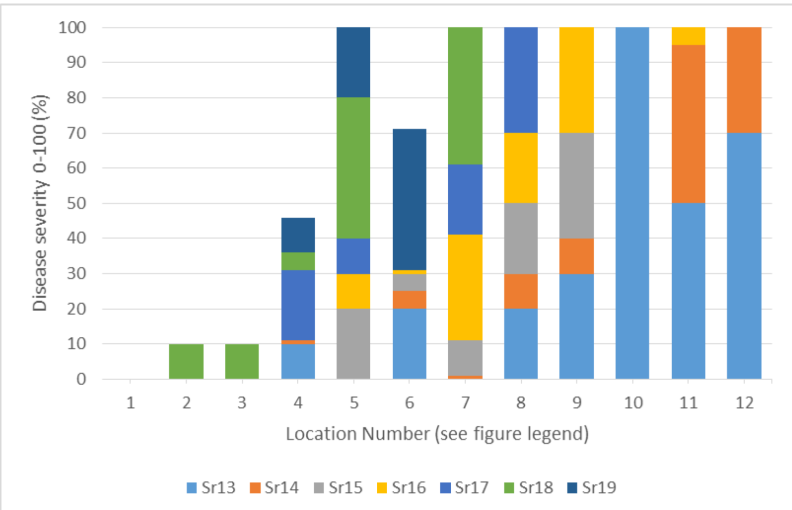
Figure 5. Graphical presentation for pathogenic variability of stem rust in few countries in CWANA

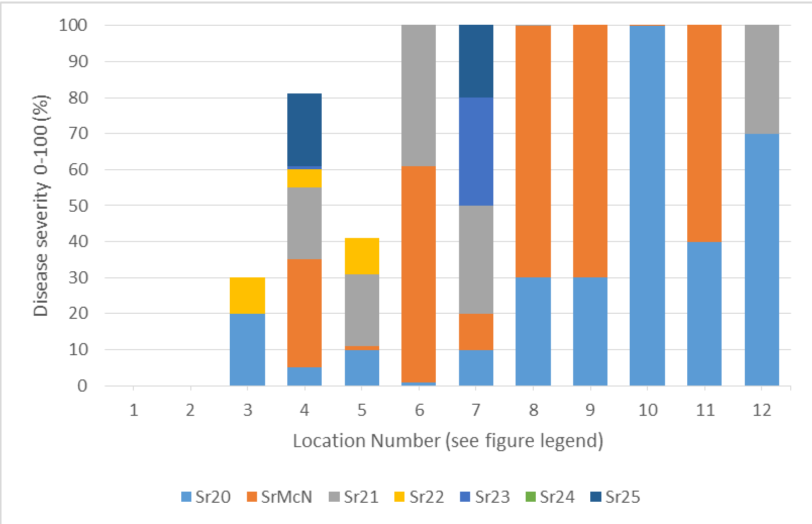
Figure Legend:

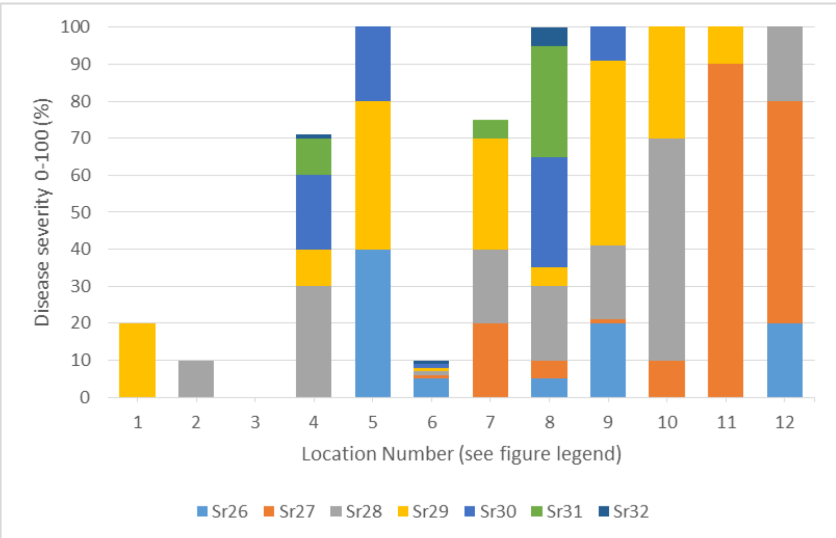
1 - Azerbaijan-Absheron, 2 - Azerbaijan-Jalilabad, 3 - Azerbaijan-Tartar, 4 - Egypt-Sids, 5 - Egypt-Gemmeiza, 6 - Egypt-Itay El-Baroud, 7 - Egypt-Kafr Elhmama, 8 - Egypt-Sakha, 9 - Egypt-Nubaria, 10 - Iran-Kelardasht, 11 - Iran-Hamadan, 12 - Pakistan-Karachi

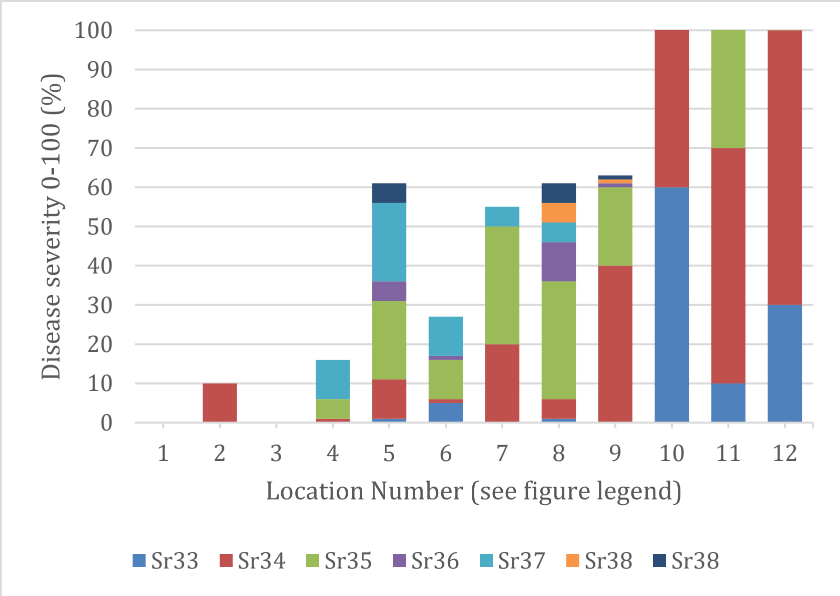


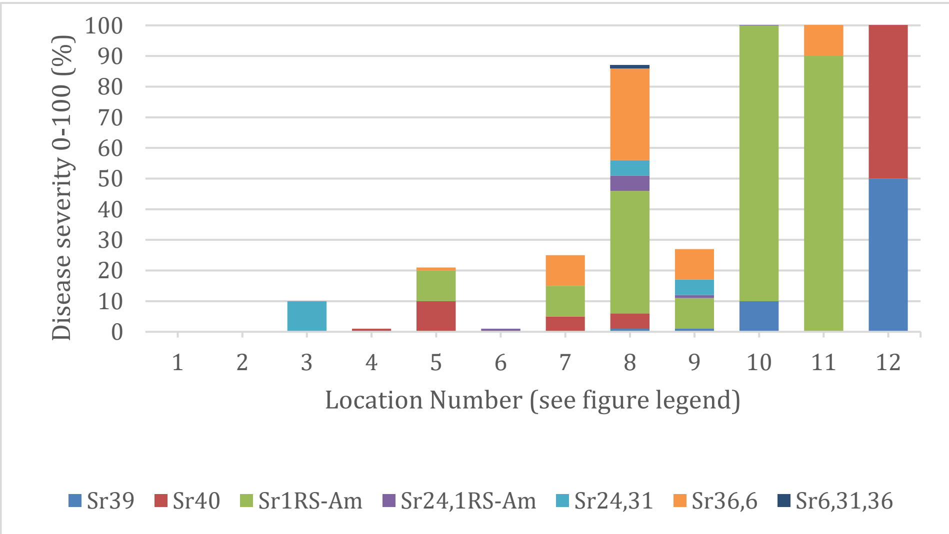


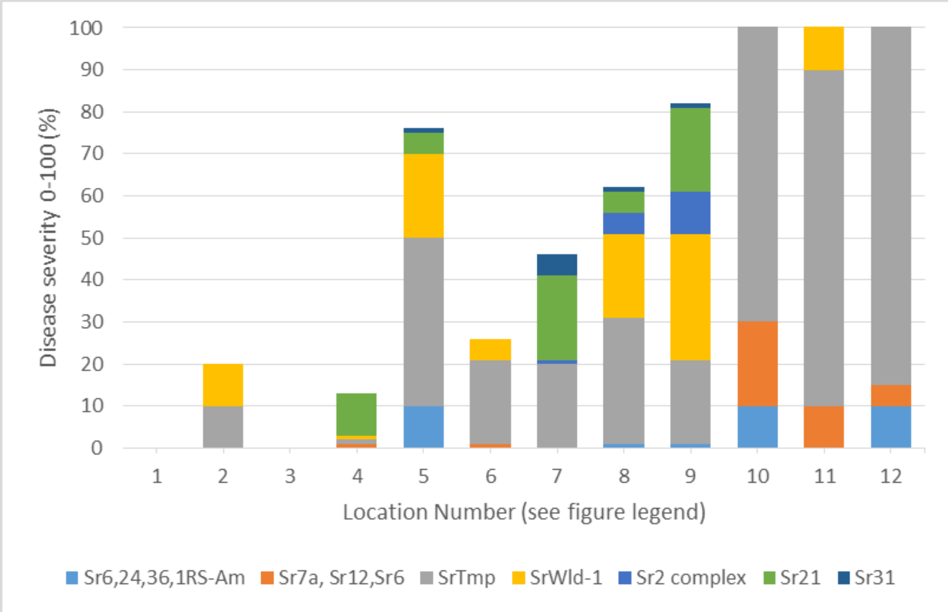


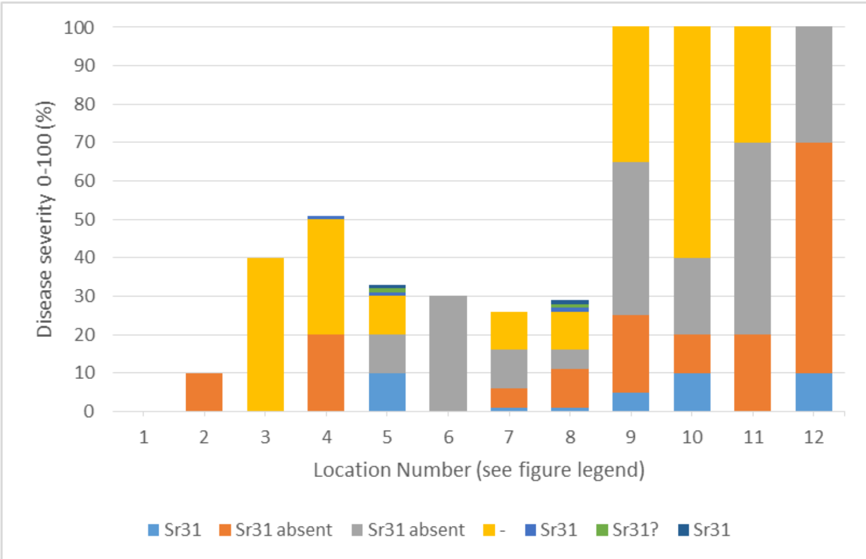

Disease severity 0-100 (%)
Location Number (see figure legend)
Sr20 SrMcN Sr21 Sr22 Sr23 Sr24 Sr25

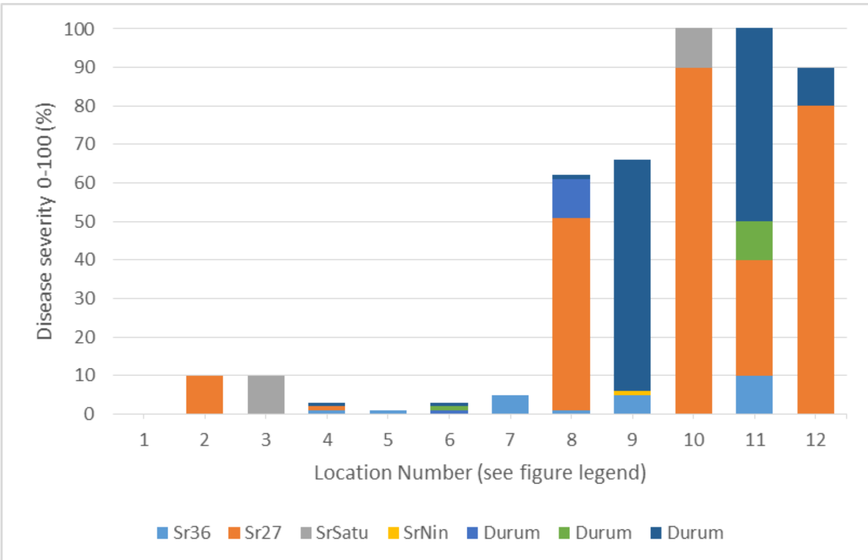

Disease severity 0-100 (%)
Location Number (see figure legend)
Sr26 Sr27 Sr28 Sr29 Sr30 Sr31 Sr32


100
90
80
70
60
50
40
30
20
10
0
Disease severity 0-100 (%)
1 2 3 4 5 6 7 8 9 10 11 12
Location Number (see figure legend)
Sr33 Sr34 Sr35 Sr36 Sr37 Sr38 Sr38


100
90
80
70
60
50
40
30
20
10
0
Disease severity 0-100 (%)
1 2 3 4 5 6 7 8 9 10 11 12
Location Number (see figure legend)
Sr39 Sr40 Sr1RS-Am Sr24,1RS-Am Sr24,31 Sr36,6 Sr6,31,36


Disease severity 0-100 (%)
Location Number (see figure legend)
Sr6,24,36,1RS-Am
Sr7a, Sr12,Sr6
SrTmp
SrWld-1
Sr2 complex
Sr21
Sr31


Disease severity 0-100 (%)
Location Number (see figure legend)
Sr31
Sr31 absent
Sr31 absent
-
Sr31
Sr31?
Sr31


Disease severity 0-100 (%)
Location Number (see figure legend)
Sr36
Sr27
SrSatu
SrNin
Durum
Durum
Durum