NILGIRI WHEAT NEWS

VOL:7; Jan. - Apr., 2015 ISSUE:1

ICAR - INDIAN AGRICULTURAL RESEARCH INSTITUTE,
REGIONAL STATION, WELLINGTON - 643 231
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Yield enhancement in wheat through pyramiding of rust resistance genes

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Most alien rust resistance gene(s) confer vertical resistance or they are termed as race specific genes and has some strong linkage drag with either positive or negative. However in the past these has overcome by use of reduced segment or through irradiation to get translocation lines. Some of the examples are *Lr19/Sr25*(linked to yellow pigment in flour), *Lr24/Sr24*(red grain), *Sr22, Lr35* (Yield penalty) and *Sr31/Lr26/Yr9/Pm8/Pm17*(Red grain and sticky dough) etc. The *Secale cereal* - derived linked gene *Sr25/Lr26/Yr9/Pm8/ Pm17* through 1BL-1RS translocation conferred multiple disease resistance initially against most occurring pathotypes of stem, leaf, yellow and powdery mildew across the globe. The gene had strong linkage to slow senescence of leaf, increased yield and its adaptability to varied temperature conditions and this gene complex was much exploited worldwide. Although *Pm8* is effective under winter wheat back-ground its action was suppressed by *Pm3* in spring wheat back-ground. The linkage of this gene complex for sticky dough or poor baking quality and red colour grain was not much preferred in Europe or Australia initially, while the effect of drag was somewhat overcome by getting IAL-1RS and 1D-1RS translocations.

Extensive exploitation of single gene complex lead to breakdown of *Lr26* in Europe, North America, South America, Indian sub-continent and China and subsequently overcome by new pathotypes 12-1, 12-3, 77-3 etc. Since this gene complex was not widely deployed in Australia virulence for *Lr26* is not common. The matching virulence for linked gene *Yr9* occurs in Africa, China, Europe, South America, New Zealand and latter 46S119 reported from Indian sub-continent. The most dreaded rust out break emerged from Africa and the virulent race TTKSK(Ug99). Later emerged several closely related variants of Ug99 viz TTKSK, TTKSF, TTKST, TTTSK, TTKSP, PTKSK, PTKST, and TTKSF+ all fast evolved from common ancestors and occur in Uganda, Kenya, Ethiopia, Sudan, Yemen, Iran and Tanzania and threatening world wheat production. Concerted efforts through national and international supported programmes (ICAR, DBT, DST, DRRW, ACIAR) now an awareness has been created to diversify the genetic basis of resistance so as to effectively checkmate not only Ug99 and other rusts as well

Although wheat related wild species offer better scope in future yield gain and the positive yield traits associated with certain genes like *Sr*31complex, can't be ignored for as of now rather its effectiveness can still be exploited when we pyramid the gene complexes *Sr25/Lr19, Sr36/Pm6* at least in India. The stem rust gene *Sr31* is still effective in India and its effectiveness can be enhanced with pyramiding of more number of genes. The knowledge in understanding the right combination of genes for durable rust resistance without any negative effect on yield and quality often referred as gene stewardship has to effectively taken up to pyramid genes

to achieve near term and long term goals

Through meticulously planned back-cross programme the popular Indian bread wheat cultivars carrying *Sr31* gene complex viz.,. PBW 343, PBW 502,MACS 2496, WH 542, HD 2877, UP 2338, HD 2733, HS 240 and PBN 51 were pyramided with *Thinopyrum ponticum* - derived linked genes *Lr19/Sr25.* Several workers worldwide reported that this gene complex is linked to positive yield traits, slow senescence of leaf, increased with spikelet per spike combines very well with *Sr31.* Initially we used the Australian stock 'Sunstar' (later confirmed to carry only *Lr24/Sr24*) and 'Cook' (Showing variation for presence of *Lr19/Sr25, Sr36/Pm6*)

Hence finally for *Lr19/Sr25* the CIMMYT, Mexico line 'Wheat ear' and our own stock HW 4444 to pyramid *Triticum timopheevii* derived gene *Sr36/Pm6 Lr19/Sr25*) were used to introgress three rust resistance gene complexes. The derived advance lines in the back ground PBW 343, PBW 502,MACS 2496, WH 542, HD 2877, UP 2338, HD 2733, HS 240 and PBN 51 are in BC_2F5 stage (were confirmed molecularly) confers high degree of field resistance against occurring races of leaf, stem, yellow and powdery mildew has at least >10% yield advantage over the recurrent parents needs to further evaluated under larger plot size. More over most of these adapted wheat varieties are popular in North Western Plain zone of India(NWPZ), pyramiding additional effective yellow rust resistance genes like *Yr10* and *Yr15* is paramount important. The work to pyramid these yellow rust genes are in advance stage and the product delivery can be expected during 2016.

Adult plant response to occurring pathotypes of leaf, stem, yellow rusts and Pm races by the wheat rust resistance gene(s) stocks which are maintained, conserved *in situ* under net house conditions at ICAR-I.A.R.I., Regional station Wellington - Current status

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Nearly 321 RIL's carrying different leaf, stem, yellow rust powdery mildew and *Fusarium* head scab resistance genes are constantly maintained in the net house, which are regularly monitored and utilized for developing multiple disease resistant materials at IARI, Regional station for more than one decade. These stocks were obtained from CIMMYT nurseries, USDA, Australia, DWR, Shimla, USA and also inclusive of our own materials. The very purpose of maintaining and monitoring/ phenol-typing for rust is to shortlist the effective genes for prevailing rust races in India and effectively utilizing in our crossing programme to develop resistant wheat varieties. The adult plant response to prevailing rust races of leaf (17, 77A, 77-5, 77-7, 77-8, 77-9, 77-10), stem (40A and 40-1) and Yellow(I), *Fusarium* head scab and powdery mildew races are presented in the table-1. The most effective rust genes which include both race specific (major) and race non-specific(APR) ones are *Lr19, Lr24, Lr32, Lr34+, Lr35* (yield penalty), *Lr39, Lr44, Lr47, Lr48+, Lr52, Lr57, Lr67, Lr68* in leaf rust, *Sr2,*

Sr22, Sr26, Sr27, Sr30, Sr31, Sr32, Sr33, Sr39, Sr44, *Sr47, Sr49* for stem rust and *Yr10, Yr15, Yr17, Yr18, Yr24, Yr27, Yr29, Yr30, Yr35, Yr37, Yr38, Yr40, Yr42, Yr46* and *Yr47* for yellow rust. The major genes can be exploited for near term goal, and for long term goal the combination of APR/Race specific seedling resistance genes or pyramiding of APR genes can be an option for the breeders in India to explore. The same gene sources were obtained from different sources which show varied reactions may be due to presence or absence of additional genes in the given genotype background

NB: For sharing of these materials it is now mandatory to make an absolute MOU between the institutions and however I am more than willing to share (not only the stocks but the materials) NIL:'s developed through our institution supported projects. We are now in the IPR regime and so sharing materials involves my institution and anything misquoted will reflect on my institution. However all the materials are available with NBPGR as EC numbers, since we strictly followed import procedures.

Table-I : Adult plant response to rusts by the resistant gene stocks maintained at I.A.R.I., R.S., Wellington

Pot No.	Gene stock	Black rust	Brown rust	Yellow rust	PM
1	Sunstar (*Lr24*)	20MR	-	5S	3
2	Cook (Sr36/Pm6)	TR	-	-	-
3	Darf Kite (*Lr24+Sr 24, Sr26*)	-	-	20S	-
4	Tr380-4 (*Lr 24+Sr 24*)	10S	-	-	1
5	*Lr26* (WH 542)	-	60S	-	2
6	*Lr28*	10S	20MS	10S	-
7	*Lr32*	10S	30MR-MS	-	-
8	*Lr34*	TR	-	-	2
9	*Lr35*	20MS-S	-	-	-
10	*Lr37*	40MS-S	-	-	-
11	*Lr39*	20MS-S	-	-	-
12	*Lr40@*	20S	-	80S	-
13	*Lr41@*	10S	-	10S	-
14	*Lr42*	-	-	40S	-
15	*Lr44*	-	-	60S	-
16	*Lr48*	40MS-S	40MR-MS	-	2
17	*Yr10*	40MS-S	20S	-	-
18	*Yr*15 (SMST)	20MS	20MR-MS	-	1
19	Thatcher	-	-	40S	-
20	Chinese Spring	-	-	60S	-
21	*T.spelta*.album	-	-	20S	-
22	*Capelle-Desprez*	10MS-S	-	-	-
23	Tc + *Lr32*	-	-	10MS	-
24	CSP 44 (*Lr* 48)	10MS	-	-	-

25	VL 404 (*Lr49*)	20S	-	-	4
26	*T. monococcum* 1	-	-	-	-
27	*T. monococcum* 2	-	-	-	-
28	Moro	-	-	-	-
29	Compair(S) *Yr8, Yr18*	-	-	-	-
30	*T.spelta*.album	-	-	TR	-
31	HW 971(*Sr2+)*	20MS	20MS	TR	-
32	Chiriya -3	-	-	-	4
33	HW 2022(*Lr24/Sr24*)	-	-	-	4
34	*Yr10* + WH 542	10MS-S	-	-	2
35	*Yr15*	10MR-MS	-	-	-
36	*Lr45*	-	-	-	2
37	*Yr15* (PAU)	10S	20S	TR	-
38	*Sr31,Lr26,Yr9,Pm8* (WH 542)	10MS	60S	-	-
39	*Sr2* (McFadden)	20MS-S	40S	40S	-
40	*Lr39*	-	-	40S	-
41	*Lr40*	-	-	60S	-
42	*Lr41*	-	-	60S	-
43	*Lr42*	-	-	-	-
44	*Lr43*	-	80S	-	-
45	*Lr44*	-	-	60S	4
46	*Lr45*	-	-	TR	-
47	*Lr47*	20MS-S	-	-	4
48	*Sr37*	-	-	50S	-
49	*Sr38*	-	-	-	-
50	*Sr39*	30MR-MS	-	-	2
51	*Sr40*	40MS-S	-	-	2
52	*Sr42*	10S	-	10S	-
53	*Sr43*	-	-	-	-
54	*Yr17*	-	40S	-	-
55	*Yr24*	20S	-	10S	-
56	*Yr26*	40S	-	20S	5
57	Wheat ear 1	-	-	-	-
58	Wheat ear 2	10MR-MS	-	-	4
59	Morocco	40MS-S	60S	60S	3
60	Seri 82 (*Sr31*)	TR	20S	-	-
61	Cham 8 (*Sr31*)	-	30S	-	-
62	*Sr*31 (Benno)/6*LMPG (*Sr31*)	10MS	20S	-	-
63	*Lc Sr24* Ag (Sr24)	10S	-	20S	-
64	*Sr24* (Agent)/9*LMPG(*Sr24*)	20S	-	40S	-
65	*Sr36* (CI 12632)/8*LMPG (*Sr36*)		-	40S	-
66	W2691 SrTt-1 (*Sr*36)	TR	-	60S	-
67	Eagle (*Sr*26)	-	-	20S	-
68	*Sr*26/9*LMPG(*Sr*26)	-	-	20S	-
69	Super Seri (*Sr*25)	TR	40S	-	-
70	Lr Sr25 Ar5 (*Sr*25)	10MS	-	20S	-
71	Coroong (*Sr*27)	-	10S	-	-
72	Pollmer(*Sr*27) Triticale	-	-	-	-

73	Cham 6 (Sr27)	10MS	-	-	-
74	Cham 10	10MS-S	-	-	-
75	El- Nielain	10MR-MS	10S	-	5
76	Utique 96 (*Sr*31 absent) Triticale	-	-	-	-
77	Inqualab 91	10MR-MS	20S	-	-
78	Bacanora =Kauz 's'	-	40S	-	-
79	Cook (*Sr*36)	-	-	-	-
80	Debeira	-	-	-	-
81	Altar(Durum)	TR	-	-	-
82	Pavon 76 (*Sr*2 complex)	TR	10MS	-	-
83	Buck Buck (*Sr2+Sr27,Sr23*)	5S	-	-	-
84	Aguilal	-	-	10S	-
85	Imillo(Durum)	10S	-	60S	-
86	Kubsa=Attila (*Sr*31 absent)	10MS-S	-	10S	-
87	Thatcher	40S	-	20S	-
88	Guard	-	-	-	-
89	Kasyon/Genaro-81/Cham4	30MR-R	-	-	-
90	Karim (Durum)	-	-	-	-
91	Rihane	-	-	-	-
92	ER/APM(Barley)	-	-	-	-
93	ISr6 -Ra (*Sr6*)	TR	-	-	-
94	W 2691 *Sr9b(Sr9b*)	40S	TR	40S	-
95	Vernstein (*Sr 9e*)	40S	-	-	-
96	St 464 *Sr13*(*Sr 13*)	-	-	40S	-
97	Combination VII *Sr17*(+13)	20S	-	20S	-
98	*Sr22* TB (*Sr22*)	10S	-	20S	-
99	Bt *Sr30* Wst (*Sr30*)	-	-	40S	-
100	Cns *Sr32* As *Sr32*	-	-	-	-
101	RL 5405 (*Sr33*)	-	-	-	-
102	Mq (2)5* G2919 (*Sr35*)	-	-	40S	-
103	W 2691 Sr Tt-2 (*Sr37*)	10S	-	-	-
104	RL 6081 (*Sr38*)	40S	-	-	-
105	RL 6082 (*Sr39)*	40S	-	-	-
106	RL 6088 (*Sr40*)	-	-	-	-
107	Taf-2 (*Sr44*)	10S	-	-	-
108	Golden Ball dervi *Sr dp-2*	-	-	-	-
109	W 2691 Sr Gt (*Sr Gt*)	-	-	10S	-
110	Cns *Sr Tmp*	-	-	-	-
111	Bt/Wld (*Sr Wld-1*)	-	-	10S	-
112	Chris (*Sr 7a, Sr12, Sr6*)	TR	-	-	-
113	Norm	TR	-	-	-
114	Line A Seln *Sr14*	-	-	10S	-
115	W 2691 *Sr28* Kt	TR	10S	20S	-
116	ISr 890+2 (*Yr 40*) *Lr57*	-	-	-	-
117	*Sr22* 74	-	TR	TR	4
118	VL 404/WL711 (*Lr49*)	-	-	-	2
119	CSP 44/WL711 (*Lr48+Lr34+Lr13*)	10S	-	-	-
120	*Lr53/Yr 35*		-	20S	-

121	*Sr46*-Evan's material 1	10S	-	-	-
122	*Sr46*-Evan's material 2	TR	-	-	-
123	*Sr46*-Evan's material 3	20S	-	-	-
124	*Sr49* (922)(420)	-	-	20S	-
125	*Yr 47/Lr52* (1094)	-	-	-	-
126	Diamond Bird (*Lr34+Yr18+BDV1+ Pm 38+ Sr resistance/Ltn*)	20S		-	-
127	Webster (*Lr34+Yr18+BDV1+ Pm 38+ Sr resistance/Ltn*)	-	-	80S	-
128	Pavon 76(*Lr47*)	-	-	10S	-
129	RL 6077(*Lr67+ Yr46*)	-	-	20S	-
130	RL 6058*(Lr34+Yr18+BDV1+ Pm 38+ Sr resistance/Ltn*)	-	-	10S	-
131	NL 1073	-	-	-	-
132	NL 971	TR	-	-	-
133	Lumle local	20S	40S	20S	-
134	Pica flour	20MR	-	-	-
135	Lerma 52	TR	-	-	-
136	*Yr 10* (WH 542)	10S	-	-	-
137	*Yr 15*	-	-	-	-
138	*Yr 17/Lr37/Sr38*	10S	-	-	-
139	*Yr 18/Lr34*	-	-	-	-
140	*Yr 29/Lr46* (Pavon 76)	-	-	40S	-
141	*Yr 35/Lr53*	-	-	-	-
142	*Yr 40/Lr57*	TR	-	-	-
143	*Yr 46/Lr67*	-	-	-	-
144	*Yr 47/Lr52*	-	-	-	-
145	WL 711	20S	40S	20S	-
146	Vernapolis	TR	-	-	-
147	Roelfs 2007	TR	-	-	-
148	Sumai 3	-	40S	-	-
149	Parula (*Lr34+,Lr46+,Lr68+)*	20MR	10MR	10S	-
150	Kingbird(*Sr2+)*	TR	10S	TR	-
151	Lc *Sr24* Ag	20S	-	40S	-
152	Lc *Sr25* Ars (*Sr25*)	TR	-	30S	-
153	Eagle (*Sr26*)	-	-	30S	-
154	DAS 15 (*Sr47*)	-	-	30S	-
155	AUS 28011 (*Sr49*)	TR	-	-	-
156	Tetra canthatch /Ae. (*Sr35*)	10S	-	-	-
157	Marquis (2)5/G2919 (*Sr35*)	-	-	10S	-
158	Taf-2 (*Sr44*)	10MR-MS	-	-	-
159	W 2691 SrTc.1 (*Sr36*)	20MS-S	-	40S	-
160	Raj 3077/COW(W)1	-	-	-	-
161	Eagle (*Sr26*)	-	-	20S	-
162	HW 4444(*Lr19/Sr25, Sr36/Pm6*)	-	-	-	-

@ both has been designated as same gene(s)

Identification of Resistance Sources to Head Scab (Blight) in Wheat

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Head blight or scab is an important seed borne fungal disease of wheat. Several species of *Fusarium* have been documented worldwide. Reduction in yield and the quality of grains positively related with occurrence of intermittent rain fall during heading and ripening stages of this crop. Severe epidemic due to toxigenic species of *Fusarium* not only contaminate the grains but also elaborate secondary fungal metabolites (mycotoxins), resulting unsafe even to feed animals. Therefore, in addition to rusts, head scab is also economically important for the wheat growers and consumers. Keeping in view of these background, a set of wheat genetic stocks differ in intrinsic factors related with other diseases were evaluated during Rabi season (2014-15) at Wellington, Nilgiri in Tamil Nadu. A total of 140 lines under MDSN (multiple disease screening nursery and HSSN (head scab screening nursery) representing different agro-climatic zones of the country were evaluated for heads scab resistance under field conditions. Out of these, 50% of the lines of MDSN covering the sources ie., EPPSN 2013-14, AVT I (2012-13) and AVT II (2012-13) were completely free from head scab. However, some of the entries viz., HI 8735(d), HPW 381, KRL 348, GW 432, HD 3095, RAJ 4250, HI 1588 Q, RAJ 4015, JAUW 598, RAJ 4324, UP 2872 and WL 711 recorded high incidence ranging between 30-70%. In another set (100 lines) exclusively meant for head scab screening; only 26 lines were free from this disease. Other lines namely PBW 644 (C), PDW 233(C), PDW 291, HD 2864, HI 8737 (D) I (C), MACS 6222 (C), NIAW 1415 (C), UAS 428 d (C), DBW 14 (C), HD 2985 (C), HI 1563 (C), K o307 (C), Kharchia 65 (C), KRL 210, Raj 4083 (C), VL 4001, HD 3159, K 1312, GW 463, PBW 721, DWR-NIL-01 and HPBW 09 recorded an incidence of 15-20%, whereas rest of the lines expressed less than 10% incidence. The association of *Fusarium graminearum* (Schwabe) group 2 was isolated from infected ear heads/grains of wheat. The identity of the organism was confirmed based on taxonomic (phenotypic) characters of the pathogen.

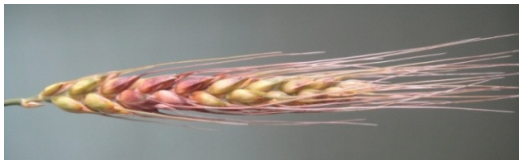

Fig. 1. Wheat ear head with head scab

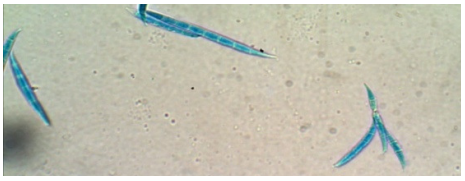

Fig.2. Macroconidia of *F. graminearum* (400X)

Survival and Infection of Leaf and Stem Rust Pathogens of Wheat in Southern hills

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In order to elucidate the role of weather factors and at different altitudes on survival of wheat rusts inoculum, potential and their effect on infection intensity and yield loss, a set of susceptible varieties (Kalyansona, Lal Bahadur, WH147, Agra local, HDW 234, Lok-1, NI 5439 and NP 200) were planted at different locations in Nilgiris and Kodaikanal area at variable altitudes ranging from 386 MSL to 2221 MSL. Seeds were sown at 6 different locations, standard package of practices were carried out and the trails were regularly monitored for the natural infection of all three rusts. Both stem and leaf rusts infection was recorded three susceptible varieties viz., Agra local, Lok-1 and NI 5439 with an intensity ranging from 5MR/MS to 10 MS till last week of March, 2015. Relatively very less or negligible level of rusts infection was recorded at Kodaikanal and other locations. At Kasolai, 10 MS of leaf and 10S of stem rusts were recorded on Agra local and Lok-1 by natural infection. A severe epidemic up to 80S of leaf and 40S of stem rust was recorded in susceptible lines (mixtures) of wheat plated at Ooty at 2218 MSL, Latitude of 11°24'N, Longitude of 76°41'E, maximum mean temperature of 20.2°C and minimum mean temperature of 8.9°C with 9.5 mm rainfall.

Fig.1 Natural infection on Lok-1 and Agra local planted at Kasolai village