INDIAN AGRICULTURAL RESEARCH INSTITUTE
Regional Station, Wellington, Distr. Nilgiris, Tamil Nadu – 643231, India.

The status of host resistance in wheat cultivars of peninsular and central India against the Nilgiri flora of black and brown rusts.

J. Kumar, M. Sivasamy, P. Jayaprakash, V.K. Vikas, P. Nalthambi, Uma Maheshwari, and John Peter (Regional Station, Wellington) and Rajbir Yadav and G.P. Singh (Division of Genetics, New Delhi).

The Nilgiri Hills in southern India enjoy weather that favors wheat cultivation throughout the year. The weather here also is congenial for maintaining the three rust pathogens on the cultivated wheat crop, volunteer self-sown host plants, and naturally growing grasses. Wheat has been grown intensively in the Nilgiri Hills until the middle of 20th century, but now is restricted to isolated locations where local farmers cultivate old indigenous cultivars with a religious family sentiment of a crop of their ancestors that must be essentially consumed as a diet. Most of the of farmers in Nilgiris now have turned on to more remunerative vegetables and tea crops. The Regional Research Station of IARI situated in the Wellington Valley of Nilgiris has been growing wheat during winter and summer seasons since its establishment in the early 1950s. The wheat materials planted here by the scientists of various Indian wheat programs for the purpose of generation advancement in summer season or for natural screening against rust diseases. Therefore, wheat grows in Nilgiris continuously through the year, which harbors three rusts *in vivo*. These southern hills of India are still playing an active role in contributing primary inoculum of rusts for causing infection of wheat crop during autumn in central and peninsular India.

In case of leaf rust, race 77-5 (121R63-1) dominated during the period of 2010–12. The other races monitored were 77-7(121R127) and 77-8 (253R31). Frequencies of 77-7(121R127) and 77-8(253R31) being at par differed significantly from the frequency of race 77-5(121R63-1). Only two races of stem rust, 40A(62G29) and 40-1(62G29-1), occurred with equal frequencies. In fact, the urediospores of all three rusts survive in Nilgiris during summer months on the off-season crop/self sown plants. During late October to the end of November, the cyclonic wind circulations formed in the Bay of Bengal, while crossing the Nilgiris, lift the urediospores and carry to peninsular and central India. The accompanying rain washes down the urediospores on 15 to 20 days old wheat crop in peninsular and central India (Nagarajan, 1973 and Nagarajan and Singh, 1975). Rain also provides the needed leaf wetness for infection. In the following two months the pathogen completes several uredo-cycles reaching a high terminal disease severity. Results of surveillance of stem and leaf rusts conducted during 2010, 2011, and 2012, at the IARI Regional Station, Wellington, also corroborated the fact that the Nilgiri Hills act as source of the initial inoculum to the target areas of central and peninsular India covering states of Karnataka, Maharashtra, and Madhya Pradesh. We found that races (77-5 of brown and 40A/40-1 of black rust) dominating in the states of Karnataka, Maharashtra, and Madhya Pradesh constituted the race flora of Nilgiris also. The Nilgiri Hills seems to be the sole source of initial inoculum for these states in case of both black and brown rusts. Races of both the rusts monitored in Himalayas, the another source of initial inoculum for both the rusts could not be traced in states of Karnataka, Maharashtra and Madhya Pradesh except race 77-5(121R63-1), which exists commonly in the Himalayas as well as the Nilgiris.

Applying the avirulence/virulence formulae of races which prevailed upon in Nilgiris, the effectivity of resistance genes present in wheat cultivars released for central and peninsular Indian states was appraised. We note that it is very alarming that all the wheats released so far for cultivation in these states are susceptible to one or more races of leaf rust surviving in Nilgiris, which acts as source of primary inoculum for these states. The *Lr* genes, *Lr10*, *Lr13*, *Lr23*, and *Lr26*, which are commonly available in cultivars of these states are susceptible to all the races existing in Nilgiris. In the present context, cultivars containing gene *Lr24* being resistant to all the races known so far, hold promise of protection from Nilgiri flora of brown rust. However, the singular presence of this gene in few of the cultivars does not benefit their cultivation, especially at inoculum source areas, because it may fall prey to vertical mutability of pathogen bringing in new virulent races. Therefore, to continue harnessing the agronomic benefits of cultivars having gene *Lr24*, we need to fortify their resistance backgrounds with other genes through pyramid breeding. *Lr24* cultivars also need further attention, because *Sr24* is linked to *Lr24* and is infected by the black rust race 40-1(62G29-1) existing in Nilgiris. Pyramiding additional *Sr* genes in such cultivars is needed if envisaged for cultivation in central and peninsular parts of India. Still, another effective gene, *Lr9*, has been reported with virulence of race 77-7 (121R127; Nayar et al. 2003), which was first traced in Nilgiris only. A population of race 77-7 (121R127) also showed an increasing trend in Nilgiris, therefore releasing cultivars with *Lr9* in central and peninsular India is likely to not serve any useful purpose unless used as a component of gene block with other effective or minor genes pyramided together.

The two races 40A(62G29) and 40-1(62G29-1)of black rust prevailing in Nilgiris with equal frequencies can infect cultivars of central and peninsular India with genes *Sr7b*, *Sr9b*, *Sr9e*, *Sr11*, and *Sr24*. Genotypes possessing these genes, in combination of two or more or in combination with gene *Sr2*, show complete protection from both the races. A majority of the cultivars of central and peninsular zone possess *Sr2*, which is quite desirable for the purpose of preventing black rust epidemics in these zones. The presence of *Sr2* in a majority of cultivars of the Peninsular Zone guarantees aversion of yield losses due to black rust in this zone for the future bacause of the proven durability of this gene. Because of the presence of *Sr2*, rust resistance seems to be stabe in the Central Zone even after 4–5 decades of utilization of cultivars with this gene. *Sr2*, derived from the cultivar Hope, also is responsible for restricting yield losses to only negligible since the late 1960s in southern U.S. This resistance is based on the gene complex *Sr2*, which actually consists of *Sr2* plus 4–5 minor genes pyramided into three to four gene combinations (Rajaram et al. 1988). Because there has been no major black rust epidemics in areas where CIMMYT germ plasm is grown, which may be attributed to *Sr2*, the resistance shows promise to be durable in India also where majority of the cultivars have their origin in CIMMYT germ plasm.

Fortunately, a few cultivars of both central and peninsular India possess gene *Sr31*, which is resistant to both races of black rust monitored in Nilgiris. Therefore, such cultivars show promise of remaining rust free but need to be kept under vigilance, because *Sr31* is susceptible to the stem rust race Ug99 and its variants. Emergence and continued spread of Ug99 races of *P. graminis tritici* now is recognized as a major threat to destabilize wheat production in many countries in its migration path, because most current cultivars are susceptible (Singh et al. 2006). Cultivars such as HI 1531 and DL 788-2, in addition to having *Sr2*, also possess *Lr24*, a gene so far maintaining resistance to all Indian pathotypes of the brown rust pathogen and are capable of providing simultaneous protection from the two rusts. Gene *Lr24* is present in combination with *Lr26* in cultivars such as HW 3094 and HW 5013 of South Hill Zone, which is an inoculum source area, and such a combination may impede the arisal of new races.

A meticulous backcross program is ongoing at the IARI Regional Station, Wellington, which resulted in constitution of black and brown rust resistant genetic stocks. Most of these stocks continuously had adult-plant resistance for five years to black and brown rusts under natural epiphytotics at Wellington (Table 1, pp. 30–31). All these lines have been advanced to the F_9 generation, guaranteeing their genetic stability. Seed can be procured from the IARI Regional

Table 1. Genetic stocks generated through backcrossing for adult-plant resistance to the Nilgiri flora of black and brown rusts (R = resistant, TS = trace susceptibility, MR = moderately resistant, and MS = moderately susceptible) at the Indian Agricultural Research Institute Regional Station, Wellington.

Name	Pedigree	Rust reaction	
		Black	Brown
Lr24 + Sr24 + Sr27			
HW 2091	C 306*3//TR 380-14 *7/3Ag#14/KS [Sr27]	TR	10MS
HW 2093	C 306*3//CS 2A/2M 4/2/KS [Sr27]	TR	10MS
Lr28 + Sr26			
HW 2096	Lok-1*3//CS 2A/2M 4/2/Kite	TS	TR
HW 2099	WH-147*3//CS 2A/2M 4/2/Kite	TS	TR
Lr37 + Sr38 + Yr17			
HW 4022	HD 2285*5/RL 6081	5MR	5MS
HW 4023	HD 2329*5/RL 6081	10MS	5MS
HW 4024	HUW234*5/RL 6081	TR	5MS
HW 4025	Kalyansona*5/RL 6081	5MS	5MS
HW 4026	Lok-1*5/RL 6081	TS	5MS
HW 4028	PBW 226*5/RL 6081	TS	5MS
HW 4029	Sonalika*5/RL 6081	TS	5MS
HW 4030	WH 147*5/RL 6081	R	5MS
HW 4031	WH 542*5/RL 6081	TS	5MS

Table 1. Genetic stocks generated through backcrossing for adult-plant resistance to the Nilgiri flora of black and brown rusts (R = resistant, TS = trace susceptibility, MR = moderately resistant, and MS = moderately susceptible) at the Indian Agricultural Research Institute Regional Station, Wellington.

Name	Pedigree	Rust reaction	
		Black	Brown
***Sr31 + Lr26 + Yr9 + Lr28* (additive effect for yield increase observed)**			
HW 4041	C 306 *2//WH 542/CS 2A/2M 4/2	10MS	10MR
HW 4042	HD 2329*2//WH 542/CS 2A/2M 4/2	10MR	10MR
HW 4043	HUW 234*2//WH 542/CS 2A/2M 4/2	10MR	10MR
***Sr31 + Lr26 + Yr9 + Lr32* (additive effect for yield increase observed)**			
HW 4049	HD2285*2//WH542/C86-8/Kalyansona F4	R	10MR
HW 4050	HD 2329*2//WH 542 /C 86-8/Kalyansona F4	R	10MR
HW 4052	Kalyansona*2//WH 542 /C 86-8/Kalyansona F4	R	10MR
HW 4053	Lok-1*2//WH 542/C 86-8/Kalyansona F4	R	10MR
HW 4055	PBW 226*2//WH 542 /C 86-8/ Kalyan sona F4	R	10MR
HW 4056	Sonalika*2//WH 542 /C 86-8/Kalyansona F4	R	10MR
HW 4057	WH147*2//WH542/C 86-8/Kalyansona F4	R	10MR
***Sr31 + Lr26 + Yr9 + Lr19 + Sr25* (additive effect for yield increase observed)**			
HW 4059	HD 2009*2//WH 542 /Sunstar*6/C 80-1	10MR	TS
HW 4059-1	HD 2009*2//WH 542 /Sunstar*6/C 80-1	10MR	TS
HW 4060	HD 2329*2//WH 542 /Sunstar*6/C 80-1	10MR	TS
HW 4061	HI 1077*2//WH 542/Sunstar*6/C 80-1	10MR	TS
HW 4061-A	HI 1077*2//WH 542/Sunstar*6/C 80-1	10MR	TS
HW 4062	J 24*2//WH 542/Sunstar*6/C 80-1	10MR	TS
HW 4063	Kalyansona*2//WH 542/Sunstar*6/C80-1	10MR	TS
HW 4064	Lok-1*2//WH 542/Sunstar*6/C 80-1	10MR	TS
HW 4065	NI 5439*2//WH 542/Sunstar*6/C 80-1	10MR	TS
HW 4065-A	NI 5439*2//WH 542/Sunstar*6/C 80-1	10MR	TS
HW 4066	WH 147*2//WH 542/Sunstar*6/C 80-1	10MR	TS
Lr19 + Sr25, Sr36 + Pm6			
HW 4202	HD 2009*3//Cook*6/C80-1	TS	10MR
HW 4203	HD 2285*3//Cook*6/C80-1	TS	TS
HW 4204	HD 2329*3//Cook*6/C80-1	TS	TS
HW 4205	HD 2402*3//Cook*6/C80-1	TS	TS
HW 4206	HD 2687*3//Cook*6/C80-1	TS	10MR
HW 4207	HS 240*3//Cook*6/C80-1	TS	10MR
HW 4208	J 24*3//Cook*6/C80-1	TS	TS
HW 4209	Kalyansona*3//Cook*6/C80-1	TS	TS
HW 4210	Lok-1*3//Cook*6/C80-1	TS	TS
HW 4211	MACS 2496*3//Cook*6/C80-1	TS	10MR

Station, Wellington, for use in wheat improvement programs.

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A high-yielding, multiple rust resistant, bread wheat cultivar HW 5216 (Pusa-Navagiri) released for cultivation in the Southern Hill Zone, India.

M. Sivasamy, Jagdish Kumar, P. Jayaprakash, V.K. Vikas, Rebekah Nisha, John Peter, E. Punniakotti, K. Sivan, Arun Kumar, and Satya Prakash (Indian Agricultural Research Institute, Regional Station, Wellington- 643 231); and Vinod, Sanjay Kumar, G.P. Singh, R.K. Sharma, Rajbir Yadav, J.B. Sharma, and Vinod Prabhu (Division of Genetics, Indian Agricultural Research Institute, Pusa, New Delhi).

A high-yielding wheat cultivar, HW 5216, conferring multiple rust resistance was released for cultivation in the Southern Hill Zone of India. The Southern Hills in India are known as the main foci for leaf and stem rust and acts as source for fresh epidemics of rusts to the plains of India when wheat crop raised in winter. Although the Southern Hill Zone is a small but strategically very important zone for India area wise, it is particularly important for the control of rust. Therefore, continuous efforts in diversifying the genetic basis of rust resistance by the release of cultivars that contain the rust inoculum is of national importance in order to arrest the dissemination of uredospores to the plains of India to avoid any rust epidemics (Table 2).

Table 2. Adult-plant response of HW 5216 to wheat rusts under artificial inoculation. The predominant yellow rust race prevalent in the Southern Hills is only I race for which this cultivar confers a high degree of field resistance. Figures in parentheses are ACI.

Disease	Year	HW 5216	HW 2044	COW(W)1
Stem rust	2008–09	10S (3.5)	10S(2.6)	10S (1.0)
	2009–10	10S (3.2)	20S (2.9)	10MR (1.0)
	2010–11	40MR (4.0)	20MR (3.6)	10S (5.6)
	2011–12	10S (3.5)	20S (2.9)	10S (2.3)
Leaf rust	2008–09	TMS (0.1)	20MR (1.1)	40S (7.7)
	2009–10	30S (5.9)	80S (10.8)	5S (0.5)
	2010–11	30S (5.9)	80S (10.8)	5S(0.7)
	2011–12	10MS (1.2)	20MS (4.9)	10MR (1.0)
Postulated genes	2009–10	*Sr31* + *Lr26* + *Yr9*, +		
	2010–11	*Sr31* + *Lr26* + *Yr9*, +		
	2011–12	*Sr31* + *Lr26* + *Yr9*, +		

Salient features of the released wheat cultivar HW 5216.

HW 5216 has yielded significantly superior over checks, HW 2044 and CoW(w)1 over four testing periods and recorded highest zonal mean grain yield of 45.6 q/ha (Fig. 1).

HW 5216 recorded an overall yield advantage of +11.82% over best check CoW(W)1, which occurred 10 out of 11 times in first nonsignificant group as compared to best check CoW(W)1, indicating wider adaptability and stability in performance across zones.

A significant yield advantage for HW 5216 ranging from 2.7% to 51.0% over the checks, indicats a yielding ability in the proposed zone and has the highest yield potential of 62.4 q/ha

The mean yield of 48.7 q/ha in Tamilnadu (hills and lower hills) and 36.4 q/ha in Karnataka (areas adjoining) over the period of three years of testing was significantly higher than the both checks.

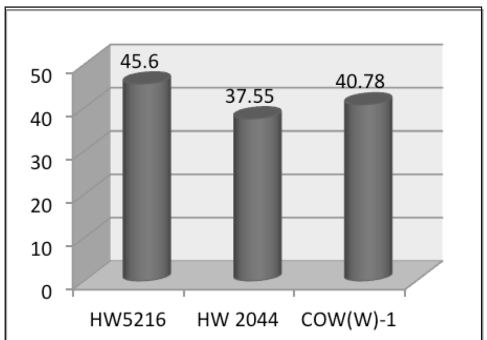

Fig. 1. Comparative mean grain yield of *T. aestivum* cultivar HW 5216 and checks over four years of testing at multiple locations.

When tested for varied irrigation levels, HW 5216 recorded no significant yield loss.

HW 5216 exhibited a high degree of seedling resistance to most stem, leaf, and yellow rust pathotypes under artificial epiphytotic conditions and for all the occurring races in the zone for which it is relased when tested under natural epiphytotic conditions

HW 5216 produced good appearing grains with higher test weight (81.47 kg/hc) and better grain quality (>12% protein and 44.75 sedimentation value).

Marker-assisted selection for the introgression of rust resistance genes (Yr10 and Sr26) in some select Indian wheat cultivars using PCR-based markers.

D. Subhashini, M.Sivasamy, Rebekah Nisha, V.K.Vikas, P. Jayaprakash, and Jagdish Kumar (Indian Agricultural Research Institute, Regional Station, Wellington); K. Kalpana and K. Gajalakshmi (P.S.G.R Krishnammal College for Women, Coimbatore); and N. Senthil (CPMB, TamilNadu Agricultural University, Coimbatore).

Introduction. Wheat, the 'golden grain' or 'king' of the cereal, plays a pivotal role in human nutrition and is a fair source of protein, vitamin B, and minerals around the world. In India, wheat occupies the second slot in production next only to rice, with around 27 x 10^6 ha, yet producing >90 x 10^6 tons and a productivity over 3,000 kg/ha. The consumption of wheat in India has increased over the years, and the demand will continue to grow faster than that of any crop.

There are twelve different wheat diseases in India (Sharma and Mishra 1999) that cause considerable economic loss, but none is more serious than that of the rusts that attack wheat. A combination of cultural and control practices with disease resistance and fungicide applications is the most effective means of control of rust (Singh et al. 1998). Chemical control of rust diseases has been successful, but environmental concerns about chemicals in food grains have limited their use (Rowel 1985). Therefore, the only alternative way of protecting wheat crops is by developing disease-resistant cultivars employing the modern breeding tools such as marker-assisted selection (MAS). Dekkers and Hospital (2002) recently reviewed some of the potential limitations of MAS strategies and concluded that the use of MAS will be determined by the economic benefit relative to conventional selection. This study detected the transfer of two rust resistance genes. *Sr26* and *Yr10*, in different genetic background through molecular markers (AFLP-Sr26#43SSR–XPSP3000).

Materials and methods. All lines were produced employing conventional backcross selection at IARI, Regional Station, Wellington, which is a hot spot for wheat rust, and by taking three crop cycles of wheat in a single year. Simultaneous selection for the targeted genes using MAS is at the TamilNadu Agricultural University, Coimbatore. The entire lot was shuttled between the centers for selection of the best-yielding phenotype with specific genes with wider adaptability. Segregating material was regularly screened at the IARI Regional Station in Wellington for host-pathogen interaction (phenotyping) and confirmation of the resistance offered by each targeted gene(s).

The yellow rust resistance locus *Yr10* is located on short arm of chromosome 1B in Moro and originated from the Turkish line Pl178383. Polymorphism in 12 segregating lines of two different cultivars, 'WH147/*Yr10*' in the BC_1 generation and 'LOK-1/*Yr10*' in the BC_3 generation, confirmed the transfer of *Yr10* resistance gene using a molecular marker (SSR–XPSP 3000). The microsatelite marker *Xpsp3000* is inherited in a codominant manner and linked with the yellow rust resistant gene *Yr10*, with a distance of 1.2 cm, and is useful in MAS.

The *Thinopyrum elongatum*-derived *Sr26* gene is located on the long arm of chromosome 6A. This gene was confirmed at the molecular level by using AFLP marker Sr26#43 in the segregating lines from four cultivars along with five different sources. The plant materials used for molecular confirmation of rust resistance gene *Sr26* included BC_1, BC_2, and F_2 plants from various cross combinations.

Results and discussion. Molecular markers act as DNA signposts for locating gene(s) for a trait of interest on a plant chromosome. In 50 lines of different cross combination screened for the presence of stem rust resistance gene *Sr26*, 46 lines revealed the presence with the primers specific to *Sr26* at 200 bp and 207 bp through PCR analysis.

The dominant gene *Yr10* showed polymorphism for the microsatelite locus *Xpsp3000* in 12 segregating lines of 'WH147/*Yr10*' (BC_1) and 'LOK-1/*Yr10*' (BC_3). Because *Yr10* was located on the short arm of chromosome 1B, only nine SSR markers distributed on the short arm of chromosome 1B were chosen for screening for polymorphism between the resistant and susceptible cultivars. The unique genetic associations of *Yr10*-specific alleles of *Xpsp3000* will be useful in MAS and gene pyramiding. *Yr10* showed a close genetic association with alternate alleles at *Xpsp3000* and/or *Gli-B1* and could be used in MAS for pyramiding *Yr10* with other stripe rust resistance genes (Bariana et al. 2007).

Conclusion. Public breeding programs that have the expertise to utilize successfully MAS technologies have both a challenge and a fantastic opportunity. With the availability of detailed information regarding the location and function of gene(s) encoding for useful traits, scientists are now well equipped for efficiently creating cultivars with the exact combinations of desirable traits. However, genetic transformation will remain a significantly important tool for understanding gene functions and testing the utility of new sequences. In near future, cultivars could be tailor-made to meet both local consumer preferences and the demands of particular environment or niche. The new tools of biotechnology not only have the potential for increasing the effectiveness and efficiency of wheat breeding programs and but also provide insights into the genetic control of key traits to be used for genetic manipulation. The coming years will undoubtedly witness an increasing application of biotechnology for the genetic improvement of wheat trait-specific products and with better genome recovery.

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Imola, Italy.

Response of 31 durum wheat cultivars to cereal soilborne mosaic virus in 2012.

C. Rubies-Autonell (University of Bologna), A. Sarti (ASTRA, Faenza), R. Canestrale (CRPV, Imola), and V. Vallega (CRA–QCE, Rome).

Thirty-one durum wheat cultivars were grown during the 2011–12 season in a field with natural inoculum source of cereal soil-borne mosaic virus (CSBMV) at Cadriano, near Bologna, and evaluated for resistance on the basis of symptom severity, DAS-ELISA value, and agronomic performance. The cultivars, planted on 24 October 2011, were grown in 10-m^2, solid-seeded plots distributed in the field according to a randomized block design with three replicates. Symptom severity was evaluated on four dates (9, 16, 20, and 27 March) using a 0–4 scale. DAS-ELISA was performed on extracts from a bulk of the basal half of the second and third youngest leaves of 10 randomly chosen plants/plot collected on one date only (19 March, 2012). The trial included 10 cultivars THAT had not been tested before.