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Race-specific Interactions Between Wheat Genotypes and Indian Cultures of Stem Rust

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Summary. Near isogenic/substitution lines of stem rust resistance genes in different backgrounds of 'Marquis', 'Chinese Spring' and W 2691 and certain varieties with known genes for stem rust resistance were tested against each of 19 Indian cultures of stem rust races/biotypes (14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222 and 295). *Sr* 24 ('Sear's 3D/Ag'), *Sr* 24 (TR 380-27 4/3 Ag 14-White seeded recombinant with 'Agent' type resistance), *Sr* 25 ('Sear's 7D/Ag'), *Sr* 26 ('Eagle'), *Sr* 26 (Knott's 6A/Ag translocation), *Sr* 27 (WRT 238-5), Combination line (*Sr* Tt1 + *Sr* 9b) were observed to be completely effective against all the 19 cultures tested. In addition, a number of lines, such as TAF2d (*Sr* Agi), Line W(*Sr* Tt2) and Combination III (*Sr* Tt1 + *Sr* 9e), were found to be effective against at least three of the most prevalent races (21, 40A and 117A-1) and a virulent race 122 in Indian natural population. Lines carrying genes other than *Sr* 2, *Sr* 9a, *Sr* 9f ('Chinese Spring') and *Sr* 15 ('Norka'), and Line E were found to be resistant to one or more cultures of stem rust.

The background effect upon the expression of a gene was observed by comparing the range of infection on single gene host lines in either different backgrounds and/or in cultivars with known genes for stem rust resistance against the 12 cultures of stem rust races found in India.

Key words: Gene expression – Resistance – Local virulence – Stem rust – Wheat

Introduction

Knowledge of genetic variations for virulence and for resistance effective to local flora of the rust pathogen is the basis for the planned utilisation of diverse resistance in the development of wheat cultivars resistant to the pathogen. It is well known that diversity can be introduced into a crop community at a number of levels and in a number of ways. One of the well known methods for extending the field life of varieties, the development of 'multigene' and 'multiline' cultivars, also requires information on the effectiveness of known genes for resistance against local virulences. Further, differential interactions between isogenic host lines and a series of rust cultures serve as a useful step in establishing the genetic constitution for resistance in potential wheat parents having one or two genes for resistance. These interactions also serve as a test of allelism by establishing the identity of the resistance genes in the appropriate strains.

Sawhney et al. 1977 studied for the first time the virulence pattern of Indian leaf rust races on near isogenic lines having individual genes of leaf rust resistance, and some varieties with known specific genes for leaf rust resistance. In a second attempt, the effectiveness of some of the stem rust resistance genes was determined against a number of Indian cultures of stem rust races (Patra et al. 1976). The tests were, however, incomplete with regard to both the variability for resistance genes and the pathogen races currently available in the country. The present communication deals with the interactions produced in near isogenic lines with individual stem rust resistance genes in different backgrounds and a number of cultivars as sources of known genes for stem rust resistance when tested with currently maintained Indian cultures of stem rust races and biotypes.

Material and Methods

Near isogenic/substitution lines of stem rust resistance genes in different backgrounds of 'Marquis', 'Chinese Spring' and W 2691 and certain varieties with known genes for stem rust resistance were inoculated. Seed of the isogenic and substitution lines and the other cultivars used in the study was initially obtained from the University of Sydney, Australia. Some of these lines with

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'Marquis' as background were also obtained from the University of Minnesota (U.S.A.). All the material studied is being maintained at the Division of Genetics, Indian Agricultural Research Institute, New Dehli.

Pathogen Cultures

Nineteen Indian cultures of stem rust races/biotypes (14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222 and 295) were used. The races are being maintained as single spore cultures at the Regional Research Station of the Indian Agricultural Research Institute, Simla.

Seedling Test

Standard procedures (Stakman et al. 1944) for the inoculation of seedlings were followed and the reactions were classified after 15-20 days according to the scale devised by Stakman et al. (1944). The tests were conducted in the greenhouses at the Regional Station of Indian Agricultural Research Institute, Simla, at a temperature not exceeding 22°C. Some of the reactions were confirmed in the temperature controlled Laboratory at the Division of Genetics, I.A.R.I., New Dehli, at temperatures ranging from 12°-22°C where sufficient additional light was provided for the development of healthy infection.

Results and Discussion

The wheat stem rust organism exists as a multiplicity of strains differentiated on a set of differentials. The use of suitable single gene lines and/or varieties with known genes for resistance has been suggested so as to be able to distinguish them relative to virulence pattern (Sawhney and Goel 1980). Furthermore, the detection of new genetic variations in the pathogen, the identification of variability in resistance effective against new virulences, and incorporation of different resistances in the cultivars from time to time, are the other important goals in the study.

Range of Variability in the Indian Population of Stem Rust

Annual surveys are conducted to keep informed of the current status of rust races in nature and also to obtain information regarding evolution shifts or shifts in race flora. Sample analysis conducted mainly on international differentials from the crop season of 1970-71 onwards has revealed that only 12 races/biotypes of stem rust (15, 17, 21, 21A-1, 34, 40, 40A, 42, 42B, 117, 117A-1, and 122) occur naturally in India (Table 1). Races 21, 40A and 117A-1 constitute 90% of the total field isolates whereas the other races have been found in only minor frequencies (Singh et al. 1977, 1978, 1979).

Since the 1970's, race 21 has assumed the top position in order of predominance in the northern parts of the country. This race is reported to have a shorter incubation period and better sporulation (Sharma and Prasada 1975).

Table 1. Summary of Indian cultures of stem rust races identified from 1970-71 to 1979-80

Sampling year	Races identified	Reference
1970-71	15, 21, 21A-1, 34, 40, 42, 42B, 117, 122	Singh et al. (1978)
1971-72	21, 21A-1, 34, 40, 42, 42B, 122	Singh et al. (1978)
1972-73	15, 21, 34, 42B, 117, 122	Singh et al. (1978)
1973-74	21, 34, 117	Singh et al. (1978)
1974-75	21, 34, 40A[a]	Singh et al. (1977)
1975-76	21, 17, 34, 40A	Singh et al. (1977)
1976-77	17, 21, 117A-1[a], 122	Singh et al. (1979)
1977-78	21, 40, 40A, 117, 117A-1	Singh et al. (1979)
1978-79	17, 21, 34, 40A, 117A, 117A-1, 122	(unpublished)
1979-80	15, 17, 21, 40A, 42B, 117A-1, 122	(unpublished)

[a] Picked up for the first time during year indicated

Genes *Sr* 5(*Sr* 5-Ra), *Sr* 8(1*Sr* 8-Ra), *Sr* 9b(*Sr* 9b-Mq), *Sr* 9e('Vernstein'), *Sr* 11 (*ISr* 11-Ra), *Sr* Tt2 (Line W), *Sr* Agi (TAF2d) and a number of other genes that were found resistant to all the races are effective against Indian culture of race 21. *Sr* 5, *Sr* 6, *Sr* 8, *Sr* 9b and *Sr* 11 are the most common stem rust resistance genes observed in cultivars from the Indian breeding programmes (Sawhney unpublished data).

Culture 117A-1 was detected for the first time in 1976-77 in samples from the extensively cultivated varieties 'Bijga Yellow' and NI 5439 from Karnataka (South India). Since then, it has spread considerably, posing a threat to the cultivation of wheat in that area (Sharma et al. 1979). In addition to the genes observed completely resistant to all races, it can be seen from data in Table 2 that culture 117A-1 is avirulent on a number of lines carrying genes (*Sr* 1(*Sr* 1-Mq), *Sr* 5(I *Sr* 5-Ra), *Sr* 6(I *Sr* 6-Ra), *Sr* 7a(CS/KF-4B), *Sr* 9b(*Sr* 9b-Mq), *Sr* 12 (CS/Tha – 3B), *Sr* 13 ('Khapstein-Mq'), *Sr* 14 ('Khapstein-Mq') *Sr* 22 ('Mq-Stewart'-*Monococcum*). *Sr* 23 ('Exchange'), *Sr* 28 ('Kota';), *Sr* 29 ('Etiole de Choisy'), *Sr* Agi (TAF2d), *Sr* Tt2 (Line W) and 'Marquis'.)

Culture 40A was first collected during 1973-74 on a Durum wheat variety, HD 4513, from Wellington (South India), an area considered as the foci of stem rust infection in the country. Wheat cultivars such as HD 2009, 'Choti Lerma', WL 208 and 'Zafrana', considered to be resistant to all the cultures of stem rust races, were found susceptible to this culture (Sharma et al. 1975). In addition to the highly effective genetic resistance against all the races, this culture has been observed to be also avirulent on *Sr* 21 ('Einkorn'), *Sr* 22 ('Mq-Stewart'-*Monococcum*) *Sr* Tt1 (CI 12632 and 'Timvera'), *Sr* Agi (TAF2d) and *Sr* Tt2 (Line W). The Indian culture of race 40 is of particular interest in a search for more resistance in *T.*

Table 2. Summary showing the effectiveness of different *Sr* genes when tested against 19 cultures of Indian stem rust races

Near isogenic line/variety	Races for which effective
Hope/10* Marquis (*Sr* 9d or *Sr* 1)	14, 117A, 117A-1
I *Sr* 5-Ra	14, 17, 21, 21A-1, 24, 42, 42B, 117, 117A, 117A-1, 184, 194, 295
I *Sr* 6-Ra	14, 15, 17, 117A-1, 184
CS *7/Kenya Farmer (*Sr* 7a)	15, 17, 117, 117A, 117A-1
I *Sr* 7b-Ra	14, 117A
I *Sr* 8-Ra	21, 117A, 122
Kenya 117/10 Marquis (*Sr* 9b)	14, 17, 21, 42B, 117, 117A, 117A-1, 122, 184, 194, 295
CS *7/Thatcher 2B (*Sr* 9g)	21A-1, 194, 222, 295
Sr 9e (Vernstein)	14, 17, 21, 21A-1, 24, 34, 42, 42B, 122, 194, 222, 295
Egypt Na 95/4* Marquis (*Sr* 10)	14, 42, 117A, 222
I *Sr* 11-Ra	14. 15, 17, 21, 24, 34, 40, 42, 194, 222
CS *5/Thatcher 3B /*Sr* 12 + *Sr* 16)	17, 117A-1, 194, 222
Khapstein/10* Marquis (*Sr* 13)	14, 15, 117A, 117A-1, 194, 222
Khapstein/10* Marquis (*Sr* 14)	14, 117A, 117A-1
I *Sr* 16-Ra	194
I *Sr* 17-Ra	15, 34
Sr 21 (Einkorn- *T. monococcum*)	21, 21A-1, 34, 40, 40A, 184, 194, 222
Sr 22 Marquis/'Stewart'/*T. monococcum*	14, 24, 34, 40A, 42, 42B, 117A, 117A-1, 184, 194, 222
Sr 23 (Exchange)	42B, 117A-1
Sr 24 – Sear's 3D/Ag	14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222, 295
Sr 24 – TR 380-27* 4/3 Ag 14	14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222, 295
Sr 25 – Sear's 7D/Ag translocation	14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222, 295
Sr 26 (Eagle)	14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222, 295
Sr 26 Knott's/Ag translocation	14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222, 295
Sr 27 (Wheat-Rye translocation-238-5)	14, 15, 17, 21, 21A-1, 24, 34, 40, 40A, 42, 42B, 117, 117A, 117A-1, 122, 184, 194, 222, 295
Sr 28 (Kota;)	14, 24, 42, 42B, 117, 117A, 117A-1, 122, 184, 295
Sr 29 (Etiole de Choisy)	42, 42B, 117A-1, 194
Sr 30 (Festiguay)	14, 15, 21A-1, 24, 42, 42B, 117, 117A, 122, 184, 194, 295
Sr Tt_1 (CI 12632)	14, 34, 40A, 42, 42B, 117, 117A, 122, 184, 194, 222, 295
Sr Tt_2 (Line W)	14, 15, 17, 21, 21A-1, 24, 34, 40A, 42, 42B, 117, 117A-1, 122, 184, 194, 295

Sr 2 ('CS'/'Hope 3B'), *Sr* 9a (I *Sr* 9a-Ra), *Sr* 9f ('Chinese Spring'), *Sr* 15 ('Norka') have been found ineffective against all the cultures tested

timopheevi because it is virulent on both *Sr* Tt1 and *Sr* Tt2, two of the potential genes for resistance designated in *T. timopheevi* (Sawhney and Goel 1979).

Race 122 is an extremely virulent race first isolated during 1952. It infects most of the exotics, indigenous and improved high yielding dwarf cultivars of wheat (Joshi et al. 1974). However, in addition to completely resistance genes, lines carrying *Sr* 9b (*Sr* 9b-Mq), *Sr* 28 ('Kota';), *Sr* 30 ('Webster' and 'Festiguay'), *Sr* Agi (TAF2d), *Sr* Tt1 (CI 12632 and 'Timvera'), *Sr* Tt2 (Line W) were observed resistant when inoculated with Indian culture of race 122.

A logical strategy for breeding resistance to stem rust for the country as a whole would be to incorporate genes for resistance effective at least to the most prevalent and virulent cultures (21, 40A, 117A-1, and 122). Perusal of the data presented in Table 6 indicates that in addition to the genes resistant to all the current Indian stem rust races, TAF2d (*Sr* Agi), Line W (*Sr* Tt2), Combination III (*Sr* Tt1 + *Sr* 9e), and another combination line (*Sr* Tt1 + *Sr* 9b) are of special interest. A number of other genes effective to individual cultures could be useful in providing additional or overlapping resistance, thus ensuring durability for resistance.

Range of Infection on Lines With Stem Rust Resistance Genes Against Indian Cultures of Stem Rust Races

Table 2 presents a series of host lines with known individual resistance genes and the Indian cultures of stem rust races against which these were observed to be effective. Since 'Marquis' was found to be resistant to races 14, 117A and 117A-1, the resistance of isogenic lines with 'Marquis' as genetic background could be due to the carrier variety rather than the effect of specific gene. *Sr* 24 (3D/Ag), *Sr* 24 (TR 380-27 4/3 Ag 14), *Sr* 25 (7D/Ag), *Sr* 26 ('Eagle'), *Sr* 26 (6A/Ag translocation), and *Sr* 27 (WRT 238-5) were observed completely resistant to all 19 cultures used in the study. Lines carrying genes other than *Sr* 2, *Sr* 9a-Ra, *Sr* 9f ('Chinese Spring') and *Sr* 15 ('Norka') were effectively resistant to one or more races.

Table 3. Infection types produced on near isogenic/substitution lines with 'Chinese Spring' background when tested with 12 Indian cultures of stem rust races (*Puccinia graminis tritici*)

Background variety/ isogenic/substitution line	Donor variety	Races											
		15	17	21	21A-1	34	40	40A	42	42B	117	117A-1	122
Chinese Spring (*Sr* 9f)	–	4	4	4	4	4	4	4	4	4	4	4	4
CS/Hope 3B (*Sr* 2)	Hope	4	4	4	4	4	3	4	4	4	4	3	4
I *Sr* 5-Ra	Thatcher	4	0;	0; −1	0; −1	4	3	4	0;	0; −2	0;	0;	4
I *Sr* 6-Ra	Red Egyptian	0; −2	0:	3-4	3	3	3	4	3	3-4	3	0; −1	4
CS/KF-4B (*Sr* 7a)	Kenya Farmer	3$^+$	0;	3	3	4	3	4	3	3	0;	0;	4
CS/Hope 4B (*Sr* 7b)	Hope	3	4	4	3	3	3	4	3	4	3	3	4
I *Sr* 7b-Ra	Hope	3	4	4	3	3	4	4	3	3	3	3	4
I *Sr* 8-Ra (W 3384)	Red Egyptian	4	3	0; −2	3	4	3	4	4	3	3	3	3$^-$
I *Sr* 9-Ra	Red Egyptian	3	4	4	3	3	3	4	4	4	4	4	4
CS/RE-2B (*Sr* 9a)	Red Egyptian	4	4	4	3	4	4	4	4	4	4	4	4
CS/KF-2B (*Sr* 9b)	Kenya Farmer	3	0; −2$^+$	3$^-$	3	4	3	4	4	0; −2	0; −2	3$^-$	3$^-$
CS/Tha-2B (*Sr* 9g)	Thatcher	4	3	3	0; −2	3	4	4	3	3	4	3	3
I *Sr* 11-Ra (W 3015)	Timstein	0;	0;	0; −1	4	0; −1	0;	3	0;	3	4	4	4
CS *5/Tha 3B (*Sr* 12 + *Sr* 16)	Thatcher	3	0;	4	3	3	3	4	3	3	3	0;	4
I *Sr* 16-Ra	Thatcher	4	4	3	3	3	4	4	3	4	3	4	3
CS *6/Hope 7B (*Sr* 17)	Hope	0;	3	4	4	0; −2	4	4	4	4	3	4	4
Sr 24 3D/Ag	*Agropyron elongatum*	0;	0;	0; −1	0;	0; −1	0; −2	0; −1	0;	0;	0; −1	0; −2	0; −1
Sr 24 (TR 380-27 4/3 Ag/14)	*Agropyron elongatum*	0;	0;	0;	0;	0; −1	0; −1	0; −2	0;	0;	0;	0;	0;
Sr 25 (7D/Ag)	*Agropyron elongatum*	0;	0; −2	0; −1	0;	0;	0; −1	0; −1	0;	0;	0;	0; −2	0;−1
Sr 27 (WRT 238-5)	Imperial rye	0;	0; −2	0;	0; −2	0;	0; −1	0;	0;	0;	0;	0;	0;
Sr Agi (TAF2d)	Agropyron	0;	0;	0; −1	0;	4	3	0; −2	0; −1	0;	3;	0;	0; −1

IT 0;, 1, 2, 2$^+$ resistance; IT 2-3, 3$^-$low infection; IT 3, 3$^+$, 3-4, 4 susceptible

Table 4. Infection type produced on near isogenic lines with 'Marquis' background when tested with 12 Indian stem rust races (*Puccinia graminis tritici*).

Background variety/ near isogenic line	Donor variety	Races											
		15	17	21	21A-1	34	40	40A	42	42B	117	117A-1	122
Marquis	–	4	4	4	4	4	4	4	4	4	4	0; −2$^+$	4
Sr 1-Mq	Hope	3	3-4	4	4	4	4	4	3	4	4	0; −2	4
Sr 7a-Mq	Kenya 117A	0; −2$^+$	0;	3	4	4	3	4	3	0; −2$^+$	0;	0;	2-3
Sr 9a-Mq	Red Egyptian	4	4	4	3	3	3	4	4	3	4	–	4
Sr 9b-Mq	Kenya 117A	3	0; −2$^+$	0; −2$^+$	3	4	3	3	3	0; −2	0;	0; −2$^+$	0; −2
Sr 10-Mq	Egypt Na 95	3	4	4	4	4	3	4	0; −2$^+$	3	4	–	4
Sr 13-Mq	Khapstein	0; −2$^+$	3	3	3	3	3	3	3	4	4	0;	4
Sr 14-Mq	Khapstein	4	4	4	3	3	3	4	3	3	4	0;	4
Sr 22-Mq	*T. monococcum*	4	3	3	3	0; −1	3	0; −2	0;	0; −2	2-3	0; −2	3

See Table 3 for explanation of infection types
– = Reactions not available

Table 5. Infection types produced on near isogenic lines with W 2691 background when tested with 12 Indian stem rust races (*Puccinia graminis tritici*)

Background variety/ near isogenic line	Races											
	15	17	21	21A-1	34	40	40A	42	42B	117	117A-1	122
W 2691	3	4	4	4	4	3	4	3	4	4	4	4
Line E	4	4	4	4	4	4	4	4	4	4	4	4
Line F/NHL *Sr* 10	3	4	4	4	4	3	4	0; −2$^+$	3	4	4	4
Bob's *Sr* 14	3	3	4	4	4	3	4	4	4	4	4	4

See Table 3 for explanation of infection types

Table 6. Infection types produced on varieties with known specific genes when tested with 12 Indian stem rust races (*Puccinia graminis tritici*)

Stocks	Races											
	15	17	21	21A-1	34	40	40A	42	42B	117	117A-1	122
Vernstein (*Sr* 9e)	3	0; −2	0; −1	0; −1	0; −1	4	4	0; −1	0; −2	4	4	0; −2
Thew (*Sr* 15 + *Sr* 10)	0; −2	4	4	4	3	4	4	0; −2	4	4	3	4
Norka (*Sr* 15)	3	4	3	4	3	4	3⁻	–	4	–	4	4
Renown (*Sr* 17 + Sr 1 + *Sr* 2 + *Sr* 7b)	0;	4	4	4	0;	4	3	3	4	4	3	4
Spica (*Sr* 17 + *Sr* 7b)	0;	4	4	4	0;	4	3	4	3	3⁻	0; −2⁺	3-4
Einkorn (*Sr* 21)	4	4	0; −2	0; −2	0; −1	0; −1	0; −1	3	4	3	4	4
Exchange (*Sr* 23)	4	3	4	4	4	4	4	3	0;	4	0;	4
Eagle (*Sr* 26)	0; −1	0; −1	0; −1	0; −1	0; −1	0; −2	0; −1	0;	0;	0; −2	0;	0; −2
Kota; (*Sr* 28)	4	3	4	4	3	4	3	0;	0;	0;	0;	0;
Etiole de Choisy (*Sr* 29 + *Sr* 23)	3	3	3	3	–	4	–	0; −2	0; −2	4	0;	4
Webster (*Sr* 30)	0;	3	3	0; −2⁺	4	4	3	0; −2	0;	0;	3	0; −2
Festiguay (*Sr* 30)	0; −1	3	3	0; −1	3	3	3	0; −2	0; −2	0; −2	3	0; −2
CI 12632 (*Sr* Tt_1)	4	4	4	4	0;	4	0; −2	0; −2⁺	0; −2⁺	0;	3	0; −2⁺
Timvera (*Sr* Tt_1)	4	4	4	3	0;	3	0;	0; −1	0; −2	0;	0; −1	0;
Combination III (*Sr* Tt_1 + *Sr* 9e)	0; −2	0; −1	0;	0;	0;	3	0;	0;	0;	0;	0;	0;
Sr Tt_1 + *Sr* 9b	0; −1	0; −1	0;	0;	0;	0; −1	0;	0;	0; −1	0;	0;	0;
Line W (*Sr* Tt_2)	0; −2	0; −1	1-2	0;	0; −2⁺	4	0; −1	0;	0;	0;	0;	1-2
TAF2d (*Sr* Agi)	0;	0;	0; −1	0;	4	3	0; −2	0; −1	0;	3	0;	0; −1

See Table 3 for explanation of infection types
– = Reactions not available

Table 7. Comparison of infection types on group of lines with different backgrounds carrying a common gene for resistance when tested with 12 cultures of Indian stem rust races (*Puccinia graminis tritici*)

	Races											
	15	17	21	21A-1	34	40	40A	42	42B	117	117A-1	122
I *Sr* 6-Ra	0; −2	0;	3-4	3	3	3	4	3	3-4	3	0. −1	4
McMurachy (*Sr* 6)	0; −2	0;	3	4	4	3⁻	4	4	0;	3	0; −1	3
Sr 7a-K 117a/Mq	0; −2⁺	0;	3	4	4	3	4	3	0; −2⁺	0;	0;	2-3
Sr 7a-CS/KF 4B	3⁺	0;	3	3	4	3	4	3	3	0;	0;	4
Sr 8-Ra (W 3384)	4	3	0; −2	3	4	3	4	4	3	3	3	3⁻
Mentana (*Sr* 8)	3	3	0; −2	3	3	3	4	4	2-3	3	3	3⁻
Sr 9b-CS/KF 2B	3	0; −2	3⁻	3	4	3	4	4	0; −2	0; −2	3⁻	3⁻
Sr 9b-Mq	3	0; −2⁺	0; −2⁺	3	4	3	3	3	0; −2	0;	0; −2⁺	0; −2⁺
Sr 10 Mq	3	4	4	4	4	3	4	0; −2⁺	3	4	–	4
Line F NHL (*Sr* 10)	3	4	4	4	4	3	4	0; −2⁺	3	4	4	4
Sr 11-Ra (W 3015)	0;	0;	0; −1	4	0; −1	0;	3	0;	3	4	4	4
Yalta (*Sr* 11 + Yt_1 + Yt_2)	0; −2	0; −2	0; −1	4	0; −1	0; −1	4	0; −1	3-4	4	4	4
Sr 14-Mq	4	4	4	3	3	3	4	3	3	4	0;	4
Bob's *Sr* 14 (W 2691)	3	3	4	4	4	3	4	4	4	4	4	4
CS/Hope 7B (*Sr* 17)	0;	4	4	4	0; −2	4	4	4	4	3	4	4
Renown (*Sr* 17 + *Sr* 1 + *Sr* 2 + *Sr* 7b)	0;	4	4	4	0;	4	3	3	4	4	3	4
Spica (*Sr* 17 + *Sr* 7b)	0;	4	4	4	0;	4	3	4	3	3⁻	0; −2⁺	3-4

reaction not available
See Table 3 for explanation of infection types

The range of infection produced on various host lines with known individual genes for stem rust resistance available in 'Chinese Spring', 'Marquis', or W 2691 backgrounds and certain varieties used as source of resistance against 12 cultures of stem rust sampled during the last 10 years is presented in Table 3-6. Lines carrying *Sr* 2, *Sr* 7b, *Sr* 9a, *Sr* 9f, *Sr* 15, *Sr* 16, and Line E show susceptibility. Effectiveness of Line *Sr* 14-Mq to race 117A-1 is probably again due to the resistance of 'Marquis', its recurrent parent. Lines with other genes have conferred resistance to one or more races. The infection reaction on *Sr* Tt1 and *Sr* 9b when present singly or in combination reveals that only the combination gives resistance to races 15, 21A-1, and 40 (the increased protection of genes when present together could be explained on the basis of complementary or additive gene interaction). Combination III, a line carrying both *Sr* Tt1 and *Sr* 9e has also shown high degree of resistance to the 18 rust cultures except to race 40.

It is also recognized that the expression of a gene could

be dependent on its genetic background either due to additive effect or modifiers. For studying this phenomenon, single gene host lines in different backgrounds and/or cultivars were carefully analysed as their reaction against 12 races (Table 7). Comparing reactions produced on *Sr* 6-Ra in 'Chinese Spring' background and cv. 'McMurachy' (*Sr* 6) shows that the Indian culture of 42B is avirulent on 'McMurachy' to which *Sr* 6-Ra is ineffective. Likewise, cv. 'Mentana' (*Sr* 8) shows low infection to a number of Indian cultures particularly 42B to which *Sr* 8-Ra, with a 'Chinese Spring' background, is ineffective. These results indicate the possibility of both 'McMurachy' and 'Mentana' carrying additional factor(s) effective to Indian cultures of stem rust. However, identical infection types on *Sr* 11-Ra and cv. 'Yalta' (*Sr* 11 + *Sr* Yt1 + *Sr* Yt2) would suggest that two additional genes for resistance in 'Yalta' are not matched by Indian cultures of stem rust. *Sr* 6 is temperature sensitive and completely ineffective at 24°C (Watson 1977) while 'McMurachy' has proved more temperature stable (McIntosh, R.A., personal communication). Cultivars 'McMurachy' and 'Yalta' are used in Australia as supplementary differentials since the genes *Sr* 6 and *Sr* 8 are better recognised when present in cultivars 'McMurachy' and 'Yalta', respectively. Near isogenic line carrying *Sr* 17 and cvs. 'Renown' and 'Spica', both carrying *Sr* 17, have an identical infection pattern except that 'Spica' gives low infection against race 117 and its biotype 117A-1, indicating the possibility of 'Spica' carrying additional factor(s) resistant to Indian culture of race 117 and its biotype.

Sr 7a, with a 'Marquis' background, has a wider resistance, including that against Indian cultures of races 15, 42B and 122 in comparison to *Sr* 7a with a 'Chinese Spring' background. On the other hand a comparison of infection range on *Sr* 9b-Mq and CS/KF-2B (*Sr* 9b, 'Chinese Spring' background) is fairly close except that *Sr* 9b-Mq has a slightly lower infection for a few races. An additional resistance in *Sr* 7a-Mq is probably due to interaction with modifiers in the genetic make-up. The difference in resistance against biotype 117A-1 in *Sr* 14-Mq and Bob's *Sr* 14 in W 2691 background is possibly again due to 'Marquis' itself being resistant.

The information reported here should be of immense use in the planned introduction of diversity for resistance genes and the development of multigene cultivars to provide greater diversity and consequently better durability of resistance for varieties of the future.

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