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## *Pathogenic evolution of wheat rust pathogens in relation to resistance genes in Indian wheat cultivars – some suggestions for strengthening wheat rust resistance in India.*

Wheat (*T. aestivum*, *T. turgidum* subsps. *durum* and *dicoccum*) is one of the prime cereal crops of India and is attacked by the three rusts, stem or black, leaf or brown rust, and stripe or yellow rust. Stem rust survives throughout the year only in the Nilgiri Hills of southern India. The Himalayas in northern India are too cold for the pathogen to survive during winter. Therefore, after the wheat harvest in the Nilgiris Hills of southern India, stem rust drastically disappears from India because of low inoculum build up in absence of the host. A *P. striiformis* that needs low temperature survives for the whole year in the Himalayas is of epidemic consequences to the wheat crop in Himachal Pradesh, Uttranchal, Punjab, Haryana, West Uttar Pradesh, and north Rajasthan. Leaf rust needs an intermediate temperature, and, thus, survives and spreads from both southern and northern foci and is important throughout India (Nagarajan and Joshi 1985). Systematic work on wheat rusts in India began in 1931 by Dr. K.C. Mehta. We haver made an effort to update the list of rust races that have prevailed in different parts of India since 1975 by consulting ICAR monographs (Mehta 1940, 1952) and Annual Wheat Workshop Reports regularly released by the All India Coordinated Wheat and Barley Project, previously from the IARI, New Delhi, but now from the Directorate of Wheat Research (ICAR), Karnal (Table 1).

**Table 1.** New pathotypes in Indian rust flora over the years. New race names are based upon the binomial system of nomenclature of Nayar et al. (1997, 2003).

| Period | Stem/black rust | Leaf/brown rust | Stripe/yellow rust |
|---|---|---|---|
| Up to 1975 | 11, 11A, 14, 15, 17, 21, 24, 24A, 34, 34-1, 40, 42 | 10, 11, 12, 12a, 17, 20, 63, 77, 106, 107, 108, 162 | 13, 14, 19, 20, 31, 38 |
| 1975–80 | 21-1, 40A, 21A-2 | 77A, 104 | 14A, 20A, 38A, I |
| 1980–85 | 117A-1 | 114A, 104B, 12-2 | K |
| 1985–90 | 40-1,117-1 | 77-1, 77-2, 77-3, 12-1, 12-3, 12-4, 107-1, 108-1 | L, N, P |
| 1990–95 | 117-2, 117-3, 117-4, 117-5, 117-6 | 77-4, 77-5, 104-2, 104-3 | T, U, CI, CII, CIII |
| 1995–2011 | 40-2 | 77-6, 77-7, 77-8, 77-9, 77-10 | *Yr9* virulence (46S119 and 78S84) |

## *Changes in the distribution patterns of wheat rust pathotypes in India – an historical account.*

Vast areas under high-yielding wheat cultivars resulted in changes in the frequency and spectrum of stem, leaf, and stripe rust pathogens. Race 12 (5R5) of *P. triticina* was the most predominant between 1972 and 1977 in the north and east zones with an overall frequency of 46%. During this period in the Nilgiris Hills in southern India, race 77 (45R31) was predominant with a frequency as high as 56%. Race 12 (5R5), although it virulence for very few genes, remained most predominant in the country during these five years, except in the Nilgiris Hills. Race 104 (17R23), which was first detected in samples from Nepal in 1972, was the second most prevalent race and predominated between 1972–77. However, the frequency of these races declined during 1982–87 and were replaced by 104B (29R23). Although the frequency of race 77 (45R31) declined in the Nilgiris Hills to 5% in 1982–87, it became most predominant race in the Northern Hills, Northern Plains, and Eastern and Far Eastern zones replacing the virulent race 12 (5R5). The increase in the frequency of race 77 (45R31) in rest of India appears primarily due to the increase in area of cultivars specifically susceptible to race 77. A second reason may be the presence of a greater number of virulence genes. In the Nilgiri Hills, other biotypes of race 77, possessing additional pathogenicity for *Lr10* and *Lr10*+*Lr26*, replaced race 77 (45R31). This group of biotypes is well distributed all over India and was found in over 46% of the samples analyzed. The shift in virulence pattern from races 12 (5R5), 104 (17R23), and 77 (45R31) in 1972–77 to 77A (109R31), 77A-1 (109R23), 77-1 (109R63), and 104B (29R23) in 1982–87 is the result of a shift in varietal pattern over different parts of India (Table 2, p. 29). *Puccinia striiformis* races 14(66S0), 20 (70S0) and 38 (66S0-1) prevailed in India before the cultivation of dwarf wheats. After widespread cultivation of Mexican wheats, three variants 14A (66S64), 20A (70S64), and 38A (66S64-1) predominated during 1975–80 in northwest India. Race I (38S102), which matches Sonalika, predominates in the Nilgiri Hills. Since 1982, race K (47S102) had the highest frequency in northwest India until the emergence of new races N (46S102), P (47S103), and *Yr9* (46S119 and 78S84) (Table 3).

**Table 2.** Population shift in *Puccinia triticina* over the years and consequential breakdown of erstwhile cultivars/genes.

| Period | Prevalent population (>60% frequency) | Important new races emerged/ built up | Susceptible genes/genotypes |
|---|---|---|---|
| 1961–65 | 20, 77, 162 | 107A, 162A, 17, 131 | NP770 and NP824, NP710 and NP809, *T. turgidum* subsp. *dicoccum* |
| 1966–70 | 12, 77, 162, 162A | 104, 104A, 77A | *Lr3*: Democrat, Bowie, Texas<br>*Lr10*: Federation, Gabo, Ridley |
| 1971–75 | 12, 77, 104A, 162 | 104B | Sujata, C306, Sonora 64<br>*Lr13*: Sonalika, Kalayansona, Lerma Rojo |
| 1976–80 | 12, 77, 104B | 77A-1 | *Lr13*: HD2009, WL711 |
| 1981–90 | 104B, 77A-1 | 12-3, 77-3, 77-4, 107-1, 108-1 | *Lr23*: HD2285, HI977, DL153-2, GW173, HD2278, K8804<br>*Lr10+Lr13*: HD2329 |
| 1991–97 | 77-3, 77A-1 | 77-5, 104-2, 104-3 | *Lr26*: WH3004, UP2338, CPAN3004, DWR162, HP42, HS277 |
| 1997–2011 | 77-5 | 77-7, 77-8, 77-10 | *Lr9* by 77-7, *Lr19* by 77-8 and *Lr28* by 77-10 |

**Table 3.** Population shift in *Puccinia striiformis tritici* over the years and consequential breakdown of erstwhile cultivars/genes.

| Period | Prevalent population (>60% frequency) | Important new races emerged/ built up | Susceptible genes/genotypes |
|---|---|---|---|
| 1961–65 | 14, 19, 20, 31, A | 38 | NP770, 792, 809, 824, 710, NP200, 201, 202, K65, C591 |
| 1966–75 | 14, 19, 20, 38, A | 14A, 20A, 38A | *Yr2*: Kalyansona, Sonalika, Lerma Rojo, Sonora 64 |
| 1976–85 | 20, 38, 14A | I, K | *Yr2* (KS): WL711, Kalyansona, HD2009 |
| 1986–90 | 12, 77, 104B | 77A-1 | *Lr13*: HD2009, WL711 |
| 1991–96 | N, K | P, race *Yr9* | *Yr9*: WH542, CPAN3004, UP2338 |
| 1997–2011 | *Yr9* virulences | — | *Yr9*: PBW 343, DBW 17 |

***New variability in rust pathogens renders genes ineffective from time to time.***

The wide-spread cultivation of high-yielding cultivars over a large area with a high level of disease resistance since 1970 exerted directional selection pressure on the rust pathogen population. In response, new rust pathogens evolved to match the resistance genes incorporated into the new wheat cultivars. In *P. triticia*, 17 new races emerged after 1970 from different regions of the country. The additional virulence was observed in race 12 (5R5) for *Lr20+Lr23*, *Lr23*, *Lr26*, *Lr15+Lr26*, *Lr9*, *Lr19*, and *Lr28*. The race 104 (17R23), isolated from Nepalese samples in 1972, has now arisen with biotypes having virulence for *Lr20*, *Lr23*, and race 77 (45R31) has acquired virulence to *Lr10*, *Lr10+Lr23*, and *Lr10+Lr26*.

For *P. striiformis*, eight new races or biotypes were encountered over the last 20 years; 14A (66S64), 20A (70S64), and 38A(66S64-1), all virulent on Kalyansona; I (38S102), which matched Sonalika and Strubes Dickopf; and *Yr1*, L (70S69), N (46S102), L (70S69), and P (47S103) had additional virulence for hybrid 46 (*Yr3b*, *Yr4b*), Chinese 166 (*Yr1*) and *Yr3a+Yr4a*. *Yr9* races have now emerged and spread into the northwest plains, where a major portion of the area is under cultivation with wheats having the *Yr9* gene.

For *P. graminis tritici*, the evolution of new races has been comparatively less, because wheat cultivation is not that intensive in the Nilgiri Hills of southern India (inoculum source for stem rust target areas). The most remarkable emergence of a new race has been that of 40-1, which is virulent on gene *Sr24* and present in very few cultivars released for cultivation in southern, central, and peninsular India.

### *Rust-resistant stocks used in Indian wheat breeding programs for protection from leaf and stripe rusts.*

The 'boom and bust' cycle, which occured particularly after the introduction of Mexican semidwarf wheats in the Indian subcontinent, was eliminated by incorporating effective rust resistance genes (*Lr* and *Yr*) using specific resistant donor lines in Indian wheat breeding programs (Tables 4 and 5).

**Table 4.** *Lr* genes used to date in Indian wheat breeding programs for leaf or brown rust resistance.

| Gene | Source | # of cultivars/lines | Cultivar/line name |
|---|---|---|---|
| *Lr1* | Malakoff, Sharbati, Sonora | 4 | Khushal 69, Moti, UP301, MP846 |
| *Lr3* | Democrat (CI 3384) | 1 | CPAN1235 |
| *Lr10* | Lee, Timstein | 6 | BW11, NI747-19, I5439, HD2009, HD2329, HS86 |
| Lr11 | Hussar (CI 4843) | 1 | HS86 |
| *Lr13* APR | Thatcher, Frontana | 7 | UP115, WL2265, PBW65, HS86, IWP72, Sonalika |
| *Lr14* | Hope, H44 | 2 | Sonalika, WL711 |
| *Lr17* | RL6041, 6008 | 1 | NP846 |
| *Lr23* | Gaza durum | 13 | HI977, HYB65, HD2135, HD2270, HD2278, HD2204, HD2258, HD2281, HD2285, HUW213, UP262, DL153-2, Girija |
| *Lr26* | *Secale cereale* | 22 | HUW206, AKW1071, CPAN1874, DL802-3, DL803-2, CPAN1922, CPAN3004, DWR162, DWR195, GW190, HD2610, HPW42, HS207, HS240, HS277, HUW318, K8804, MACS2496, PBW299, 343, UP2338, WH542 |
| *Lr34* | Chinese Spring | 23 | C306, DWR39, GW173, HD2189, HD2329, HD2501, 2610, HI977, 1077, HP1209, HPW42, HS207, 240, 295, K9006, Kalyansona, NI5439, PBW175, PBW299, UP262, UP2338, WH147, WH54 |

**Table 5.** *Yr* genes used to date in Indian wheat breeding programs for resistance to stripe or yellow rust.

| Gene | Source | Documented line |
|---|---|---|
| *Yr2* | Heines VII type | HD2009, 2189, 2278, 2285, 2329, 2380, HI977, 1077, HP1209, 1633, HS86, HUW234, HW741, HW971, IWP72, J405, K8020, NI5439, PBW175, PBW222, RAJ2184, RAJ3077, Sonalika, Swati, UP262, VL421, VL616, WH283 |
| *Yr2* (KS) | Heines VII type B | W11, GW173, HD2402, HD2428, HDR77, HI1123, HP1102, HUW234, K7410, K8027, LOK-1, PBW65, WL711 |
| *Yr3* | Vilmorin type | HS295 |
| *Yr9* | *Secale cereale* | CPAN1922, 3004, DL803-3. WR162, 95, GW190, HD2610, PW42, HS207, 240, 277, HUW206, 318, K8804, MACS2496, PBW299, 343, UP2338, WH533, 542 |
| *Yr18* | *Lr34* sources | C306, DWR39, GW173, HD21892, HD2329, HD2610, HI1077, HP1209, HPW42, HS207, 295, K8962, K9006, NI5439, PBW175, 299, UP2338, WH147, 542 |

### *In search of additional/new genes.*

Unfortunately, the genetic base of rust resistance in India wheat cultivars languishes in front of the array of new pathotypes that have emerged or built up during the last 2 to 3 decades. To sustain wheat yields in India, the search for new genetic sources of resistance becomes imperative. A number of genes are available and need to be exploited to alleviate resistance base of Indian wheat germ plasm (Tables 6 and 7).

**Table 6.** Unutilized genes for resistance to leaf or brown rust useful for Indian wheat breeding programs.

| Gene | Source | Remarks |
|---|---|---|
| *Lr2a* | Webster (CI 3780) | Useful component of multiple gene resistance. |
| *Lr4–Lr8* | Waban (CI 12992) | Difficult to characterize, not of much use. |
| *Lr9* | *Ae. umbellulata* | Present in very limited Indian cultivars, widespread effectiveness. |
| *Lr11* | Hussar (CI 4843) | Temperature insensitive, slow ruster. |
| *Lr12* | Spring | Adult-plant resistance. |
| *Lr15* | Kenya W1483 | Temperature sensitive, effective at 15–18°C. |
| *Lr16* | Selkirk | Frequency of virulence remains low. |
| *Lr17* | Timson | Useful in multiple gene resistance. |
| *Lr18* | *T. timopheevii* | Temperature adability. |
| *Lr20* | Thew, Chinese Spring | Durable resistance |
| *Lr21* | *Ae. tauschii* var. *meyeri* | Adult-plant resistance. |
| *Lr22* | *Ae. tauschii* | No known virulence. |
| *Lr24* | *Thinopyrum ponticum* | Undesirable red grains. |
| *Lr25* | *Secale cereale* cv. Rosen | No known virulence. |
| *Lr27+Lr31* | CS*6/Hope 3B | Complementary genes. |
| *Lr28* | *Ae. speltoides* | No virulence in India. |
| *Lr29* | *Th. ponticum* | Virulence in Pakistan and Turkey. |
| *Lr30* | Terenzio | Slow ruster. |
| *Lr32* | *Ae. tauschii* (RL 5497-1) | Wider stability. |
| *Lr33* | Thatcher*6/PI 58548 | Effective in combination. |
| *Lr35* | *Ae. speltoides* | Adult-plant resistance. |
| *Lr36* | *Ae. speltoides* | Not studied much. |
| *Lr37* | *Ae. ventricosa* | Effective field resistance. |
| *Lr38* | *Th. intermedium* | Virulence unknown. |
| *Lr39–Lr44* | *Ae. tauschii* | Not studied much. |

**Table 7.** Unutilized genes for resistance to stripe or yellow rust useful for Indian wheat breeding programs.

| Gene | Source | Remarks |
|---|---|---|
| *Yr1* | Chinese 166 | Becomes susceptible to barley races, world wide. |
| *Yr4* | Hybrid 46 | Low level of virulence in India. |
| *Yr5* | *T. aestivum* subsp. *spelta album* | Rare virulence. |
| *Yr6* | Heines Kolben | Higher resistance at low temperature. |
| *Yr7* | Iumillo durum | High frequency of virulence worldwide. |
| *Yr8* | Ae. comosa | Resistance is not durable. |
| *Yr10* | Moro (PI 178383) | No known virulence in India. |
| *Yr11* | Joss cambier | Adult-plant resistance (presumed). |
| *Yr12* | Mega | Adult-plant resistance (presumed). |
| *Yr13* | Maris Huntsman | Adult-plant resistance (presumed). |
| *Yr14* | Hobbit | Adult-plant resistance (presumed). |
| *Yr15* | *T. turgidum* subsp. *dicoccoides* | Virulence unknown. |
| *Yr16* | Cappelle Desprez | Adult-plant resistance and durable resistance. |
| *Yr17* | *Ae. ventricosa* | More susceptible at low temperature. |
| *Yr18* | Terenzio | Adult-plant resistance. |

### *Durable resistance – global experience and lessons to Indian wheat breeders.*

Durable disease resistance remains effective in a cultivar even though it may be widely grown over a long period of time in an environment that favors disease epidemics. This descriptive term does not provide an explanation for the basis of inheritance of this trait. Durable resistance has the following dimensions: 1. covers a large area, 2. grown for many years, and 3. high inoculum load and favorable weather. On the basis of multilocational data on triticale, cultivar Coorong was selected from a CIMMYT trial for widespread cultivation in Australia, because the alien gene *Sr27* gave total resistance to stem rust. Almost immediately after the commercial release of Coorong, stem rust was observed because the pathogen developed matching virulence in Australia. The durability of genotype, therefore, cannot be assessed by means of small field trials or multilocation evaluation for a few seasons. The *Sr26* gene, derived from *Thinopyrum elongatum*, has been used in Australia since 1970, is present in a number of wheats, and is designated as durable. Multilocation tests do not guarantee resistance nor are the alien genes are always durable. Vanderplank rationalized that non-specific or horizontal resistance will neither lead a cultivar into boom-and-bust cycle nor exert any directional selection pressure on the pathogen and, therefore, will be durable. Although Vanderplank considered durable resistance to be a polygenic trait, he cited a number of examples such as the maize–*P. polysora* system in Africa, where a single resistance gene contained the disease for a number of years.

The oat cultivar Red Rustproof is still durable to crown rust even after one-hundred years. The wheat cultivars Thatcher and Lee have withstood stem rust for 55 and 30 years, respectively. Cappelle Desprez has expressed a moderate resistance to stripe rust at the adult-plant stage for the last 20 years. Cappelle Desprez carries both seedling and adult-plant resistance with genes *Yr3a* and *Yr4a*. No detectable race-specific component has been detected in the adult-plant stage in Cappelle Desprez; but all cultivars with *Yr3a* and *Yr4a* have not been durable. Genetic analysis of Cappelle Desprez shows that chromosomes 5BS and 7BS contribute substantially to durable resistance. Further analysis showed that the long arms of homologous chromosomes 5A, 5B, and 5D increase susceptibility, whereas the short arms of these chromosome had the opposite effect. Cappelle Desprez appears to possess an optimal balance between the effects of genetic loci in increasing resistance and those favoring susceptibility.

Several lines derived from H44 and Hope also exhibit durable stem rust resistance. Cultivars such as Thatcher, Lee, Hope, Kenya Page, Africa Mayo, and Selkirk, which have been used globally, possess the *Sr2* adult-plant resistance gene. This gene is tightly linked with the pseudo-black chaff gene and when present in combination with other genes, as in Selkirk, produces a durable resistance. In Australia, wheats with five to six different resistance genes are cultivated. Gene *Sr36* derived from *T. timophevii* (*SrTt-1*) is present in cultivars Mengavi, Mendos, Timson, Cook, Timgalen, and Shortim and in various blends,with *Sr5*, *Sr6*, *Sr7a*, *Sr8*, *Sr9c*, *Sr11*, and *Sr17*. In race surveys, the occurrence of matching virulences was detected for most of the genes either alone or in combination. However, combined virulence for *Sr36* was very low in frequency in Australian wheat despite the fact that *Sr36* was released in varietal background as early as 1967. Therefore, like *Sr2*, combining *Sr36* with other resistance genes can render wheat cultivars durable.

Many host resistance genes that are matched by the pathogen survive in breeding populations for a long time, because these gene are not totally overcome by the pathogen and they still carry some amount of residual resistance. In the barley–*Erysiphe graminis hordei* system, they are referred to as defeated genes. In the wheat–*P. striiformis* system, segregation for resistance to stripe rust can be obtained through minor gene effects, temperature-sensitive genes, adult-plant genes, and various forms of disease resistance. The breeding strategy and selection methodology needs to be viewed accordingly.

### *Pyramiding resistance genes – one of the effective approaches to curtail fast emergence of new, virulent mutants of rust pathogens.*

The idea of pyramiding genes was conceived as an alternative to breeding for polygeneic traits. When only a single resistance gene is present in a host, it soon becomes susceptible. Subsequently, adding one or more resistance genea in that cultivar will increase resistance. Conversely, if four or five cultivars with single resistance genes are grown, all of them are exposed to the same pathogen population and this does not reduce vulnerability to epidemic. However, if these genes are brought into one background, because of additive gene action, the wheat will have resistance to a wide spectrum of pathotypes and the resistance will be durable. Virulence is gained at the cost of fitness, so a pathotype able to infect all the resistance genes in such a cultivar is likely to be less fit in nature and may not induce an epidemic. The approach of pyramiding resistance genes also might prolong their usefulness.

Pyramiding resistance gene provides greater durability if the pathogen is solely dependent on an asexual life cycle and mutation and recombination are less pronounced (Marshall 1977). Combinations of resistance genes have provided good field resistance to wheat stem rust in Australia for several years (McIntosh 1992). Because the alternate host of *P. graminis tritici* is nonfunctional, in Australia pyramiding resistance genes has paid rich dividends. In North America, resistance gene combinations involving *Sr2* have provided durable resistance to stem rust, and *Lr13* and *Lr34* when combined with other leaf rust resistance genes also have provided durable resistance (Kolmer et al. 1991). Pyramiding resistance genes has provided durable resistance in some cases. For instance, the French cultivar Cappelle Desprez has durable resistance to eyespot; the other source is VPM, derived from a cross involving the wild grass *Ae. ventricosa*. Molecular markers linked to these genes have been identified (Worland et al. 1988; Koebner and Martin 1990). Seedlings with both these genes with better eyespot resistance (Doussinault and Douaire 1978) can be selected using molecular markers facilitating selection for better resistance. In view of the rust-management philosophy described above, several unexploited gene(s) may be useful for pyramiding in popular Indian wheat cultivars (Table 8).

**Table 8.** Suggested sources of adult-plant resistance for strengthening leaf and stripe rust resistance in Indian wheats.

| Gene | Source | Remarks |
|---|---|---|
| **LEAF RUST** | | |
| *Lr2a* | Webster (CI 3780) | Useful component of multiple gene resistance. |
| *Lr11* | Hussar (CI 4843) | Temperature insensitive, slow ruster. |
| *Lr12* | Spring | Adult-plant resistance. |
| *Lr17* | Timson | Useful in multiple gene resistance. |
| *Lr20* | Thew, Chinese spring | Durable resistance. |
| *Lr21* | *Ae. tauschii* var. *meyeri* | Adult-plant resistance. |
| *Lr22* | *Ae. tauschii* | No known virulence. |
| *Lr28* | *Ae. speltoides* | No virulence in India. |
| *Lr30* | Terenzio | Slow ruster. |
| *Lr32* | *Ae. tauschii* (RL 5497-1) | Wider stability. |
| *Lr35* | *Ae. speltoides* | Adult-plant resistance. |
| *Lr37* | *Ae. ventricosa* | Effective field resistance. |
| *Lr38* | *Th. intermedium* | Virulence unknown. |
| Slow rusters (adult-plant genotypes possessing useful seelding resistance genes in India (Kumar et al. 1999). | | |
| *Lr34* alone | HP 1731, C 306 | |
| *Lr34+Lr10+Lr13* | NIAW 34, HD 2329 | |
| *Lr34+Lr23* | GW 232, HI 977, HI 1077, GW 173, PBW175 | |
| *Lr34+Lr26* | PBW 343, PBW 373, HS 240, UP 2363, WH 594, WH 596 | |
| *Lr34+Lr23+Lr26* | DL 802-3, HS 317, Gabo, Frontana | |
| **STRIPE RUST** | | |
| *Yr4* | Hybrid 46 | Low level of virulence in India. |
| *Yr5* | *T. aestivum* subsp. *spelta album* | Rare virulence (in snowy conditions only). |
| *Yr10* | Moro PI 178383 | No known virulence in India. |
| *Yr11* | Joss Cambier | Adult-plant resistance. |
| *Yr12* | Mega | Adult-plant resistance. |
| *Yr13* | Maris Himtsman | Adult-plant resistance. |
| *Yr14* | Hobbit | Adult-plant resistance. |
| *Yr15* | *T. turgidum* subsp. *dicoccoides* | Virulence unknown. |
| *Yr16* | Cappelle Desprez | Adult-plant resistance and proven durable resistance |
| *Yr17* | *Ae. ventricosa* | More susceptible at low temperature |
| *Yr18* | Terenzio | Adult-plant resistance. |

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## *Genetics of leaf rust and leaf blight resistance in different crosses of common wheat.*

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**Abstract.** Leaf blight caused by *Alternaria triticina* (HLB) and leaf rust caused by *Puccinia triticina* are two of the important diseases of wheat that are widespread in India. Postulating the genes in most of the released cultivars, a chi-square test applied for HLB and leaf rust separately. The HLB reaction in the $F_2$ generation was a 3:1 (susceptible:resistant) ratio was observed in two crosses, and we conclude that the susceptible reaction is governed by a dominant gene(s) in both the crosses. A 15:1 ratio fitted in three crosses showed that susceptible reaction is governed by duplicate gene(s). Tests also were used for leaf rust reactions to check the validity of expected ratio in the $F_2$ generation. The 3:1 ratio (susceptible:resistant) fit three crosses and this resistant type reaction is governed by a dominant gene(s). Two crosses fit a 15:1 ratio indicating a resistant type infection governed by duplicate gene(s).

**Introduction.** Among cereals, wheat is ranked second after rice and is the staple food, especially in northern India, where most people are vegetarian. The crop is grown successfully between an altitude of 30°0–60°0 N and 27°0–40°0 S. Wheat is extensively cultivated under diverse agroclimatic conditions in India covering most of the states except Kerala. All wheat cultivated in India is spring type but grown during the winter. Wheat, the main food crop of India, contributes significantly to the central pool. The cultivation of wheat in India started very early, during prehistoric times and, thus, the origin of wheat is still a matter of speculation. Wheat research to develop high-yielding cultivar and improve management techniques started about a century ago in India. A large number of valuable cultivars were bred and released for commercial cultivation. These cultivars were tall and mainly suited to low-input management with low yield potential. However, a turning point came in the history of wheat breeding during mid-1960s with the introduction of semidwarf, photo-insensitive, high-yielding Mexican wheat breeding material developed at CIMMYT under the guidance of Nobel Laureate Dr. Norman E. Borlaug. These cultivars were tested under the All India Coordinated Wheat Improvement Project and, as a result, three genotypes, Lerma Rojo, S 308, and Sonora 64, which out yielded the old tall wheat cultivars, were released for general cultivation in major wheat-growing areas of India.