

Wheat Breeding for Durable Rust Resistance and High Yield Potential in Historical Prospective and Current Status

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Abstract Epidemics of leaf, stripe and stem rusts on wheat have induced significant losses in the past during the early nineteenth century and have destroying role in reducing product yield bringing about socio-economic variability worldwide. The old tall varieties with qualitative resistance couldn't continue for longer period because of the advancement of new virulent pathogen races. But varieties like Yaqui-50, Lyalpur-73, and Lerma Rojo-64 were released during early period of green revolution, still linked with durable resistance to stripe, leaf and stem rust. Advancement of new rust races like virulence's *Yr27* and *Yr9* followed by the appearance of *Ug99* and its mutants lead the breeders to review their breeding plan. Breeders are presently relying upon to gather minor genes and their use in grouping with major genes to develop rust resistance in wheat varieties. The minor genes, *Lr46/Yr29*, *Lr34/Yr18*, *Sr2/Yr30*, are being broken in wheat breeding at CIMMYT and different region. The germplasm with this kind of resistance have shown existence stability over space and time. At Ayub Agriculture Research Institute, Faisalabad the home of green revolution in Pakistan, this approach has been established since 1994-95. The durable resistance assortments were crossed in a top cross/back cross technique and the segregating populations were improved by adopting mass strategy, which brought about the advancement of material having preferred yield and rust resistance over the pre-existing assortments (e.g., Inqlab-91, MH-97). Five varieties, Shafaq-06, Lasani-08, AARI-11, Millat-11 and Galaxy-13 from these crosses have been approved for general cultivation. Essentially, the material developed and circulated by CIMMYT, Mexico having this sort of resistance is being worldwide adopted. The simple sequence repeat markers (SSR) for above mentioned durable genes are accessible and can be used in early selection of superior varieties.

Keywords Breeding, Durable Resistance, Leaf Rust, Resistance Genes, Stem Rust, Stripe Rust, Wheat Varieties

1. Introduction

Wheat (*Triticum aestivum* L.) is the world's widely cultivated cereal crop along with maize and rice. The expected global wheat production for the year 2016 is 734.2 Mt, which is slightly higher than the demand of 716.2 Mt [11]. Global Wheat production has increased enormously since green revolution in 1960's and supported in reducing starvation and lack of healthy nutrition. Emerging nations, which expend sixty percent of total wheat production, have demonstrated higher yield increment contrasted with established nations in the past [59].

The three rusts, stripe, leaf or stem caused by *P. striiformis*, *P. triticea* and *P. graminis* f. sp. *tritici*, respectively, causing severe epidemics worldwide and therefore receive main attention in breeding program. The pathogen is very specialized having significant variant in their generation for virulence/avirulence against specific resistance genes. Emergence of different rust races via migration, mutation, and recombination between prevailing genotypes followed by selection is also common. Recent identification of new virulent *Ug99* races such as PTKST, TTKSP, TTKSF, and TTKSF+ (http://rusttracker.cimmyt.org/?page_id=22) and three highly virulent leaf rust races including FBPT, MCDS and CCPS⁴¹ present a significant threat to wheat production in South Africa, necessitating collaborative and integrated management approaches of the diseases.

Host-plant resistance against wheat diseases is the most appropriate, economically sustainable strategy to minimize yield losses contrasted to the application of crop protection

fungicides [39]. Breeding strategy for durable rust resistance has always remained a dynamic practice [57]. Van der Plank was first epidemiologist to openly describe the theoretical basis of the theories of resistance [60]. This strategy was commonly suggested for breeding against stripe rust resistance by Johnson [22], leaf rust resistance by Caldwell [7], and for stem rust resistance by Borlaug [6]. The use of such concepts in breeding against leaf rust resistance, generally known as slowly rusting, has been a leading force in CIMMYT wheat development structures for almost forty years with main impacts [32].

Diseases resistance can be generally classified as race specific or race non-specific. Race specific resistance controlled by major genes is frequently overcome by the emergence of new virulent races of the pathogen through sexual recombination or single step mutation [27, 58]. While race non-specific resistance also known as durable resistance controlled by minor gene, is long lasting. Thus advancement in breeding for durable resistance is slow, requiring identification and gene pyramiding into desirable varieties [4]. Screening for durable resistance genes need appropriate phenotyping to precisely identify their response in the field. Often varieties with durable resistance may show vulnerability at seedling stage but adult plants stage show low disease incidence. So it can be concluded that genetic improvement in wheat has generated at least twenty seven times its significance in benefits against leaf rust resistance breeding in spring wheat alone [32].

The main objectives of this study were to (1) access durable resistance against stripe, leaf and stem rust in selected wheat varieties through breeding strategies and (2) discuss a prospect of latent material maker strategy in wheat breeding.

Breeding for Rust Resistance in Pre-green Revolution Era

No serious effort was made in wheat development until the first half of the 19th century. The traditional tall wheat varieties were normally known as landraces, which was selected through growers own choice of good seed for next season crop cultivation [10]. In Australia, Farrer proposed due thought for developing wheat rust resistant varieties. He mainly concerned on the early head to day maturity of varieties to escape rust and carefully selected the parents for hybridization work. To cross with Australian material early maturing germplasm was also imported from India. Back cross technique was used to produce rust resistance into Australian germplasm. A list including the different works of leaf wax presence, stomata size, and thickness of the cuticle and leaf width and rust resistance was prepared. These characteristics were remarkably like those one which are now considered as liable to decide durable disease resistance.

Interspecific crosses between wheat and Einkorn (*T. monococcum*) were also developed for moving resistance in spring wheat. These crossing schemes were distant in India from 1896 to 1901 nevertheless couldn't adjust due to

emergence of new land races. Few varieties belong to subcontinent i.e., India, Majhi, Bansi, Pissi, Bakhshi, Nagpur hybrid, was found somewhat moderately resistant and it demonstrated that these genotypes may contain some major resistant genes against rust resistance [16]. As an isolation of pure lines was the key breeding technique utilized for the advancement of wheat genotypes of land races at that time, so it can be concluded that these major genes were coevolved with the spring wheat. For introgression of alien alleles, breeding with collected developed and wild species from regions of primitive agriculture was likewise conducted in this part of the world. Their concern is clearly shown in wide crosses through the parents of prominent varieties Besostaja along with its wild species Kavkaz and Aurora.

In Germany, a few varieties like early winter wheat hybrid assortments, for example, Carstens 5 and Strube 56 were produced with a decent level of field resistance in 1934. It was felt that no further improvement was possible in the Indian subcontinent, hybridization and pure line selection was began for better assortments' established in 1926 [1]. In this manner, with the usage of exotic and local germplasm, a number of crosses were attempted. Varieties C-591, C-518, C-250, and 1C-217 were produced from these crosses. In all aspects, these varieties were better than prior stock. The assortment C-271 contains Lr34, a durable rust resistance gene. It has been shown that, this gene was used as a part of wheat breeding consciously [26]. So it can be summarized that, in the beginning of wheat breeding, while the information concerning the hereditary qualities of rust resistance was less advance, nevertheless main concern was proposed for the collection of assortments with improved good resistance.

Breeding for Rust Resistance in the Green Revolution Era

In CIMMYT, semi dwarf and dwarf varieties developed primary the Green Revolution (Pénjamo 62, and Sanora *etc.*) had been reliable for achievement performance in Pakistan, India, and elsewhere. The lifetime of the Mexican cultivars was short as the emergence of different races of black rust has completed its useful life; but, there are exceptions too. The Lerma Rojo 64 had 11 years lifetime, while Yaqui 50, 52 and 53 Champingo maintained their resistance until they were moved by cash crop of high yielding cultivars [6]. The long existence of these assortments is owing to inherited backgrounds. During time period 1965 to 1985, the breeding technique has combined different CIMMYT genes. A large portion of the cultivated genotypes through this era comprise *Sr2* and 2-4 other genes for resistance to black rust (Table 1). These additional genes comprises *Sr36*, *Sr31*, *Sr30*, *Sr26*, *Sr24*, *Sr17*, *Sr12*, *Sr11*, *Sr10*, *Sr9g*, *Sr9e*, *Sr9b*, *Sr8a*, *Sr7b*, *Sr7a*, *Sr6*, *Sr5* [24, 43]. The similar approach was also implemented through the numerous national projects.

The significance of *Lr13* to brown rust was accepted in the mid-1970s, when it was moved alongside other genes in numerous wheat cultivars. A few cultivars contain in mix

Lr13 with other genes developed in Mexico, Pakistan and India is shown in Table 2. The *Lr13* itself could not give good resistance, although in combination with different genes that bears a high resistance level likely to be durable. The method for activity of *Lr13* complex program CIMMYT is a non-race particular sort of resistance. Their occurrence in grouping to *Lr34* gene in particular fellows of the Bluebird sequences gave them a lengthy time. Lyalpur-73 variety is another illustration of this grouping in Pakistan that although substituted at farmer's field with the introduction of new high yielding, yet even following thirty six years of freedom, still

has excessive resistance to brown rust (20MRMS) in trap nurseries.

The material developed in the mid -1960s had acquired resistance to yellow rust of the Andean regional varieties possessing a great resistance level. In Sudan, New Zealand, South Africa, and North Africa Anza was released resulting after cross of LR/N10B/3*ANE. It was observed a durable resistance against stripe rust by Johnson²² and such type of response was also observed by Anderson [43]. According to Singh the non-specific or durable resistance was concerned with the occurrence of *Yr18* gene [56].

Table 1. Pedigree and Selection Histories of Wheat Varieties Possessing Stem Rust Resistant Genes

Varieties	Parentage	Selection history	Resistant genes
Bluesilver	1153.388/AN//YT54/N10B/3/LR/4/D4946.A.4. 18.2.IY/Y53//3*Y50	II18427.0PAK	-
Hartog	VCM//CNO/7C/3/KAL/BB	CM8399-D-4M-4Y-2M-2Y-0M-0AUS	<i>Sr2, Sr8a, Sr9g, Sr30</i>
Yecora 70	CNO//SN64/KLRE/3/8156	II23584-26Y-2M-1Y-0M-0PAK	-
Maxipak	Penjamo 62'S' x Gabo 55	-	<i>Sr17</i>
Bluebird	CNO//SN64/KLRF/3/8156	II23584	<i>Sr2, Sr5, Sr6, Sr8a</i>
Pavon F 76	VCM//CNO/7C/3/KAL/BB	CM8399-D-4M-3Y-1M-1Y-1M-0Y-0 MEX	<i>Sr2, Sr8a, Sr12, Sr30</i>
Songlen	Lerma Rojo 64/Sonora64A/2/Timgalen	-	<i>Sr2, Sr5, Sr6, Sr8a, Sr36</i>
Selkirk	(McMurachy x Exchange) x Redman	-	<i>Sr2, Sr6, Sr7b, Sr9d, Sr17</i>
Hope	Marquis x emmer ("speltz")	-	<i>Sr2, Sr7b, Sr9d, Sr17</i>
LermaRojo 64	Y52/N10B//L52/3/2*LR	II8724-8Y-1C-6Y-0MEX	<i>Sr2, Sr6, Sr7b, Sr9e</i>
Sunco	SUN9E-27*4/3Ag14//WW15/3/3*Cook	SUN88E	<i>Sr5, Sr6, Sr8a, Sr24, Sr36</i>
Kalyansona	PJ62/GB55	II8156-0IND	-
Sonalika	1153.388/AN//YT54/N10B/3/LR/4/BA4946.A. 4.18.2.IY/Y53//3*Y50	II18427-4R-1M-0IND	<i>Sr2</i>

Table 2. Pedigree and Selection Histories of Wheat Varieties Possessing Leaf Rust Resistant Genes

Varieties	Parentage	Selection histories	resistant genes
Bluebird	CNO//SN64/KLRF/3/8156	II23584	<i>Lr1, Lr13, Lr34</i>
Mexipak 65	Penjamo 62'S' x Gabo 5	-	<i>Lr14a</i>
Ciano 79	BY/MAYA/4/BB//HD832.5.5/ON/3/CNO67/P J62	CM31678-R-4Y-2M-2122-OM-OMEX	<i>Lr16</i>
Lerma Rojo	Y52/N10B//L52/3/2*LR	II8724-8Y-1C-6Y-0MEX	<i>Lr13, Lr17</i>
Punjab 81	INIA/3/SN64/P4160(E)// SN64	-	<i>Lr10, Lr13, Lr34</i>
Yecora 70	CNO//SN64/KLRF/3/8156	II23584	-
Sonora64	YT54/N10B//2*Y54	II8469-2Y-6C-2Y-1C-0MEX	<i>Lr1</i>
Lyalpur 73	BB/NOR	II27100-307M-100A-0A-0PAK	<i>Lr1, Lr13, Lr34</i>
Kalyansona	PJ62/GB55	II8156-0IND	
Sonalika			<i>Lr13, Lr14a</i>
Bluesilver	1153.388/AN//YT54/N10B/3/LR/4/D4946.A.4 .18.2.IY/Y53//3*Y50	II18427.0PAK	-
Chamingo 53	-	-	<i>Lr34</i>
Pavon F 76	VCM//CNO/7C/3/KAL/BB	CM8399-D-4M-3Y-1M-1Y-1M-0Y-0M EX	<i>Lr1, Lr10, Lr13, Lr46</i>
Nuri 70	CNO//SN64/KLRE/3/8156	II23584-25Y-6M-0Y-0PAK	-
Chines Spring	CS/CNO.E//HORK/3/CS/CNO.E/4/2*CS	CMH84.4449	<i>Lr12, Lr34</i>
Dollarbird	WE-M/GTO//KAL/BB	CMA288-0AUS	-

Table 3. Pedigree and Selection Histories of Wheat Varieties Possessing Stripe Rust Resistant Genes

Varieties	Parentage	Selection history	resistant genes
Veery	KVZ/BUHO//KAL/BB	CM33027	<i>Yr7, Yr9</i>
Lerma Rojo	Y52/N10B//L52/3/2*LR	II8724-8Y-1C-6Y-0MEX	<i>Yra</i>
Lyalpur 73	BB/NOR	WE-M/GTO//KAL/BB	<i>Yr 18</i>
Chamingo 53	MARROQUI-588/NEWTATCH	K-62053	<i>Yr 18</i>
Bluebird	CNO//SN64/KLRF/3/8156	II23584	<i>Yr6, YrA, Yr18,</i>
Sonalika	1153.388/AN//YT54/N10B/3/LR/4/BA4946.A .4.18.2.IY/Y53//3*Y50	III8427-4R-1M-0IND	<i>Yr2, YrA,</i>
PBW343 (Attila)	ND/VG9144//KAL/BB/3/YACO/4/VEE#5	CM85836-0IND	<i>Yr Sulkirk (Yr 27)</i>
Ciano 79	BY/MAYA/4/BB//HD832.5.5/ON/3/CNO67/P J62	CM31678-R-4Y-2M-21Y-0M-OM EX	<i>Yr Sulkirk (Yr 27)</i>
Pavon F 76	VCM//CNO/7C/3/KAL/BB	CM8399-D-4M-3Y-1M-1Y-1M-0 Y-0MEX	<i>Yr6, Yr7, Yr29</i>
Dollarbird	WE-M/GTO//KAL/BB	CMA288-0AUS	<i>Yr6, Yr7, Yr29*</i>
Chines Spring	CS/CNO.E//HORK/3/CS/CNO.E/4/2*CS	CMH84.4449	<i>Yr 18</i>
Barani 83	BB/GLI/3/GTO/7C//BB/CNO	CM32347.3M-1Y-1M-1Y-1K-0A- OPAK	<i>Yr7</i>

During early decade of green revolution varieties released including *Yr18* are given in Table (3). It has been reported in a number of cultivars e.g. Barani-83, PBW-12, WL-2265, Seri-82 (*Yr9, Yr2, Yr7*), Pavon-76 (*Yr29, Yr7, Yr6*), Pak-81 (*Yr9, Yr7*) (Badebo *et al.* 1990). Pavon and Veery with *Yr7* gene had been released in various republics individually with various names which demonstrate the extensive use of *Yr7* genes.

2. Emergence of New Rust Races

Due to worldwide large scale dissemination of cultivars 1B-1R translocation, monoculture condition created. This leads the development of different new races of rust causing devastating a severe wheat yield worldwide danger. A virulent strain of stripe rust, *Yr9* was first identified in North Africa during 1986 and then emigrated in South Asia. In 1991, it seemed in Yemen once to get to the wheat fields in South Asia it took only four years [52]. This caused great loss of performance on their way to Syria, Egypt, Turkey, Iraq, Iran, Pakistan and Afghanistan more than 1 billion US \$. Similarly *Yr27* appearance and development taking after the similar path that poses the main danger toward wheat generation in Pakistan and India, where super assortments Inqilab-91 and PBW343 were based resistance quality *Yr27*. Varieties with stem rust resistance gene *Sr31* remained effective more than thirty years. During 1990, wheat cultivars having 1B-1R translocation made a situation of monoculture in Asia, Africa and different regions of the world. Pretorius [39] described that Pgt confines that were risky on *Sr31* were gathered primary in Uganda during 1999 and after that extent all over East Africa, Kenya and Ethiopia in 2005. The race, known as TTKS (Ug99), is dangerous in maximum mega wheat cultivars and can bring about yield losses up to 100%. Jin [21] identified another virulent race of *Sr25* in India. This race is named as RRTTF as indicated by the American framework. Therefore, location of destructive

races like *Sr25* alarmed breeders to improve durable resistance in wheat varieties adopting advance breeding techniques.

3. Genetic Basis of Durable Resistance

Durable resistance to brown, stripe and stem rust depend on additive impact of genes typically control by minor genes. Genomic studied at CIMMYT Mexico revealed that, minimum ten to twelve different types of genes tangled in a collection of CIMMYT germplasm, and by collecting four to five race non-specific genes, resistance near immunity can be attained [57]. Singh described that line with two to three race non-specific resistance genes deliver a high level of resistance. Most of such type of genes are undersigned only *Sr2/Yr30, Lr46/Yr29* and *Lr34/Yr18* and identified on specific chromosomal loci [57].

The cultivars with race-nonspecific resistance gene show nearly similar level of resistance against different races of pathogen worldwide. However, the varieties that have the major gene endurance race specifically do not have a lengthy life and distorted generally after four to five years. The brown and stripe rust response of a few varieties with race non-specific rust resistance is the similar at CIMMYT, Mexico and Faisalabad, Pakistan (Table 4). Fontana being released fifty years ago up till now has good resistance practically everywhere. There exist very rare cases that varieties with race specific resistance have remained effective over a longer period of time. William identified six independent chromosomal loci contributing to durable resistance against leaf and stripe rust in population resulting from Avocet S and Pavon. Even Avocet S and Morocco have certain genomic characteristics that contain some durable resistance gene due to which critical delay occur to become fully susceptible [62]. Thus, estimation and use of genetic resources for rust resistance tangled both cultivated wheat measured worldwide and wild species.

Table 4. Comparison of Leaf Rust Reaction of Varieties having Minor Gene Based Resistance in Mexico and Pakistan

Variety/Line	Minor Genes possessed	Usual rust reactions	
		Mexico	Pakistan
Nacozari 76	<i>Lr34+1</i>	30MSS	30M
Sonoita	<i>Lr34+1</i>	20MSS	10M
Baconora 88	<i>Lr34+1 or 2</i>	10MSS	20M
Frontana	<i>Lr34+ 2 or 3</i>	10MSS	15M
Trap#1	<i>Lr34+ 2 or 3</i>	10MSS	20M
Kukuna	<i>Lr34+ 3 or 4</i>	1M	5MR
Parula	<i>Lr34+Lr46+lor 2</i>	10MS	10M
Pavon 76	<i>Lr46+1</i>	30MS	40M

Table 5. Potential Rust Reaction of Finally Selected Advance Lines of AARI, Faisalabad in Pakistan

Genotype	Percentage	Leaf rust		Yellow rust	
		Bahawalpur	Faisalabad	Islamabad	Pirsabak
V-00183R (shafaq-06)	V87094/2 Inq-91	0	0	10MR	20MR
V-02192	SH88/V87094/MH97	0	20M	10R	5RMR
V-02156	SH-88/Weaver	5MR	40M	10RMR	20RMR
V-7096	Pb96/V87094/MH97	5MRMS	30MRMS	10R	40RMR
V-04179	Pb96/V87094/MH97	0	40M	10R	40RMR
V-03138	Luan/koh.97	10MR	30M	5R	15MR
Mumtaz#1	LU26/PRL/LU26/TRAP	10MR	5R	5M	10MR
Mumtaz#2	LU26/PRL/LU26/TRAP	15M	20M	10M	20M
Morocco		100S	100S	100S	100S

Sr2/Yr30 Gene

Sr2 gene was transferred from tetraploid emmer wheat variety Yaroslav to hexaploid wheat in 1920. It is located on chromosomal loci 3BS and pleiotropic to *Lr27* [54]. It is linked with *Pbc* (pseudo black chaff) that is used as a morphological marker to identify lines that carry such type of gene. *Pbc* genotypes have shown variable degree of stem rust disease. The disease severity 60 to 70% was observed contrasted with 100% severity of susceptible control in nurseries, for detection of the disease in Kenya. This does not give an adequate level of resistance when present alone, but the desired level of resistance can be accomplished in association with different genes.

In *Sr2* complex, a little bit information is known about the collaboration of *Sr2* and other linked genes. Acceptable quality resistance can be attained by combining four to five minor genes [25, 28]. Several cultivars of Kenya with *Sr2/Yr30* gene have been shown to be good source of durable resistance to stem rust [3, 33].

Lr34/Yr18 Gene

A large number of resistance genes to leaf and stripe rusts have been recognized and are being used in breeding programs. Varieties such as Fontana with *Lr34* gene have active durable

resistance against leaf rust. *Lr34* was first described in 1977 by Dyck, still provide the resistance against leaf rust and have been genetically indistinguishable from *Yr18* gene giving adult plant resistance (APR) [36]. This gene is highly linked to leaf tip necrosis (*Ltn1*), barley yellow dwarf virus (*Bydv1*) and powdery mildew resistance (*Pm38*) genes [30].

If complex *Lr34/Yr18* present, only the level of disease can go high, nonetheless in grouping with different genes could provide real management [31]. In greenhouse and growth chamber with low temperature resistance level of plants with *Lr34* is too much higher. McIntosh [37] demonstrated that *Lr34* appear to be dominant under natural conditions in daily normal temp 0-20 °C and aids in lessening disease development. Environment has a significant influence on the intensity of the terminal illness against leaf rust. Singh demonstrated that *Yr18* can indicate inadequate resistance in some ecological circumstances [50].

In the current technique of getting new resistance to leaf rust assortments has developed from a selection of genes in individual pyramid of several genes, which could provide a durable resistance against different strains of wheat rust [29]. Genes for resistance against leaf rust about 60 have been distinguished in wheat and its wild species [48]. Qualitative Trait Loci (QTL) studies were used for genetic mapping for leaf rust in several populations [46].

Lr46/Yr29 Gene

Lr46 located on chromosomal loci 1B was identified in variety Pavon by crossing with leaf rust susceptible variety Lal Bahadur [56]. Its second minor gene providing durable resistance against leaf rust. The gene for resistance to stripe rust gene *Yr29* and *Lr46* leaf rust are firmly connected with each other and characterized by its phenotypic marker leaf tip necrosis (*Ltn2*) [61]. Its impact is practically identical to *Lr34/Yr18* which provides incomplete resistance to crop.

Infested crops with such type of gene have length dormancy period contrasted with control without this genetic factor [34]. Crop containing such type gene also exhibit greater abortion rates fungal groups without chlorotic or necrotic impacts and furthermore lessen the measure of the spore size. Plants also do not show necrotic response to pathogen conferring such type of gene. The presence of *Lr46/Yr29* is highly correlation with the plant leaf by showing leaf tip necrosis (*Ltn2*) [46]. Efforts are in progress for the colonization of this gene.

Gene Pyramiding

The process of incorporation of several genes in a single variety is required to develop a durable disease resistance cultivar. Most scientists in the world use this approach for three wheat rusts. Numerous gene pyramids have been effective, though some have immediately been rendered ineffective [47]. At least in a few cases, *Lr13* and *Lr16*; and undesignated genes for yellow rust [13, 49] *Lr27* and *Lr31*[54], *Lr13* and *Lr34* [9]; *Lr2a* and *Lr16*[12]; seem to have an additive impact in combination [33] Combination of some resistance gene, for example, the 'Sr2 complex' for stem rust resistance, the 'Frontana complex' for leaf rust resistance [44], a resistance of Little Joss and Anza assortments for stripe rust [22], have indicated long time stability. These complexes give the fundamental resistance in the developing bread wheat germplasm at CIMMYT. Such durable resistance can be consolidated with different qualities to provide diversity [45]. The breeding philosophy for creating quality pyramids includes the identification of hereditarily distinctive sources of resistance, followed by the combination of these resistances into a high yielding and improved background.

The resistance in at least 15 cultivars appeared to be due to *Lr34* [50]. Several other cultivars with high seedling infection types to one or more of the predominant field prototypes were also partially resistant in the field [51]. High level of durable resistance occurred in some varieties even in the absence of known seedling resistance genes in major APR and slow rusting to brown rust have been reported in various cultivars of Mexican origin; Indian origin [88]; and other origins [44]. According to Rajaram (1972) adult plant resistance can be defined as resistance absent in seedlings, but expressed in the adult stage of the plant. Similarly, durable rust resistance may also be defined as a source that continued effective after the extensive development over a

significant period [23].

Combining Minor Genes for Durable Rust Resistance

It's challenging task to accumulate race non-specific gene to achieve preferred level of resistance in the cultivars, because it need the pedigree of parentages having specific genes, crossing them with precise strategies proceeding back cross method preserving required population mass and collection of desirable varieties from isolating populations [55]. An example of breeding for incomplete or durable resistance is the outside CIMMYT wheat breeding program, Faisalabad, Pakistan. Under artificial inoculation the 1200 successions was selected with an assortment of leaf rust (TKT / RN, TKT / PR, JS/ KSR, PHTTL, PGRTB and stripe rust (80E85) races. The succession (Table 5) with durable resistance for stripe/leaf rust resistance was carefully screened [20]. For resistance and high yield the selected parents were crossed to accumulate minor genes for durable resistance.

The selected parentage was used to make top, back and double crosses. Bulk collection was done to progress the filial generations sustaining highest chromosomal diversity. With 0 to 20 % disease severity and with MS/MR/R field response spikes were collected preferably at harvesting stage. Many advance lines were screened from this germplasm and established for rust reaction with high yield. From this germplasm two cultivars Lasani-08 and Shafaq-06 were allowed for broad cultivation in Punjab, Pakistan [17, 18]. These varieties showed high yield and rust resistance against stripe and leaf rust races such as *Lr26*, *Lr13*, *Lr10*, *Lr27*, *Lr9*. Lasani-08 was also evaluated against the race of stem rust (Ug99) in Kenya and Sindh, which showed acceptable resistance in 2007 [19].

4. Conclusions

The continuously varying nature of wheat stripe, leaf and stem rust pathogen have a major risk for prospect world wheat production. Learning from epidemic and losses due to emergence of rust races the researcher planned the approach of pyramiding durable resistance genes. The system of combining adult plant resistance genes was established by understanding rust resistance mechanism common in old semi-dwarf wheat varieties such as Lyalpur-73, Yaqui-50, and Lerma Rojo-64 which engaged resistance due to then unidentified durable resistance genes. Ayyub Agriculture Research Institute (AARI) and CIMMYT developed an approach of pyramiding durable resistance genes alone or in grouping with race specific genes to overcome the newly appeared strains of stripe, leaf, and black rust. Recent wheat varieties produced at AARI, Faisalabad, including Shafaq-06, Lasani-08, Millat-11, AARI-11 and Galaxy-13 are solid evidence of prospective durable adult plant resistance pyramiding approach to manage threats of stripe, leaf and stem rusts.

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