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COMBATING UG-99 - CURRENT SCENARIO

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ABSTRACT

The yield potential of wheat crop is not achieved because of rust diseases pressure. Stem rust (SR) in wheat is one of the destructive diseases and has potential to cause severe damage. Although Stem Rust had been controlled successfully during three decades throughout the world with the deployment of semi-dwarf resistant cultivars in the last half of previous century, appearance of Ug-99 (a virulent race against *Sr31*) in Ugenda during 1999 created an alarming situation worldwide. Diverse germplasm was found susceptible to this aggressive race as most of the wheat varieties cultivated throughout the world had *Sr31* gene. The appearance of the Ug-99 race catalyzed a collective effort to recognize sources of stem rust resistance genes against new virulent strains and incorporate these genes into wheat lines. The previously well controlled disease has re-emerged as a threat to wheat farming. Scientific community addressed the dilemma in time and efforts did not go waste. Diversity in pathogen was explored and new sources of resistance against Ug-99 and its derivatives were identified and new wheat germplasm is being deployed in the wheat cultivating regions. This achievement is attributed to the teamwork of experts and serves as an example for research workers in future. However, this issue demands an amplified emphasis on pathogen evolution and virulence mechanisms. A major role of the Borlaug Global Rust Initiative (BGRI) is to keep 'the eye on the ball' with regard to all these aspects.

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INTRODUCTION

Wheat (*Triticum aestivum L.*) is the most important food consumed by approximately 40% of the whole inhabitants of the world. Crop holds the status of 'Queen of cereals' because of area under cultivation (240 M ha), production (750 Mt) worldwide and the most traded commodity among food grains (Bhavani *et al.*, 2019; Afzal *et al.*, 2015). Crop is cultivated in vast range of longitude and latitude under diverse categories of meteorological conditions, elevation, or soil. With the requisition of wheat set to rise by at least 50% to feed population in 2050, the current rate of progress will not be enough to achieve the target. International economies are concentrating on improving wheat production. Experts have planned long-term strategies to develop yield through addressing challenges of growers to achieve the optimal yield. Main challenge is protecting yield potential from biotic as well as abiotic stresses (FAO, 2017).

BIOTIC CONSTRAINTS IN WHEAT CULTIVATION AND THEIR MANAGEMENT

Large yield gains over the next many years will be needed to meet rising demand of food. Crop cultivation suffers various constraints leading to reduced yield (Afzal *et al.*, 2015). Emergence of diseases of plants and quick dispersal across the planet cause pressures on food security influencing yield as well as quality of crops (Afzal *et al.*, 2020). Prominent diseases of wheat those threaten grain production include the rusts, bunts, smuts, powdery mildew, barley yellow dwarf virus and head blight (scab). A key element to meet demand of food for quickly growing population is improved management of diseases of plants. Management of plant disease is defined as decrease in quantity of injury caused. Complete control is infrequent but not desired even, nevertheless lucrative control when improved yield is not a reduced amount than the cost of disease management (quantifying cost benefit ratio) and is relatively probable. Qualified plant pathologists describe principles of disease management in the literature of plant pathology i.e. Exclusion, eradication, protection, resistance, therapy, and avoidance of insect vector and weed hosts (Ul Haq and Ijaz, 2020). Knowledge of disease cycle selects how to manage disease effectively (De Wolf and Isard, 2007). Resistance and susceptibility against diseases is a genetic character transferred from parents to progeny (Biffen, 1905). This principle is practiced in evolution of disease resistant genotypes through breeding (Randhawa *et al.*, 2019). Application of chemicals and cultural practices are also helpful tools used to mitigate damage caused by diseases.

Rusts in wheat

Wheat crop is prone to several diseases caused by various pathogens which have been caused crop failures leading to starvation repeatedly in past. Among several diseases of wheat, rusts are the most significant fungal diseases (Figueroa *et al.*, 2017). Rust diseases are capable of causing severe damage in wheat due to their capability to move for long distance, and evolve new aggressive pathotypes (Kang *et al.*, 2010). Rusts, are the most important since the ancient time. (Boyd, 2005). Rusts in wheat have been classified caused by different species of *Puccinia*, stem or black rust (SR) caused by *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & Henn. (*Pgt*). Leaf or brown rust (LR) caused by *Puccinia triticina* Eriks. (*Pt*), and stripe or yellow rust (YR) caused by the *Puccinia stritiformis* Westend. f.sp. *tritici* Eriks. (*Pst*) (Waqar *et al.*, 2018). All these diseases cause severe damage decreasing yield, nutritive worth, and value significantly. According to an estimate yellow rust can induce 70% yield losses under favorable environmental conditions (Chen, 2005; Chen, 2013). Leaf rust has an extensive terrestrial incidence damages substantially (Bolton *et al.*, 2008). Yield losses attributed to leaf rust ranges from 30-70% (Kolmer *et al.*, 2005). Stem rust causes losses up to 1.12 billion US Dollars universally which results mainly as a result of diminished end-use quality of the crop and reduced yield (Pardey *et al.*, 2013). Amount of losses is subject to factors like the degree of vulnerability of wheat varieties planted by growers, environment, time of infection, disease duration and disease development rate (Chen, 2005). Ideal temperature requirements in three rusts are not same. Stem rust flourishes in the warm temperatures and stripe rust requires the low temperature, while leaf rust grows in mild temperature (Roelfs *et al.*, 1992). Despite the fact, their ecological circumstances are unlike, these rusts are existing universally, anywhere wheat is cultivated, they might exist at the same time in one field commonly, during various growth stages of host development and in different severities. Wheat producing areas are appropriate differentially for the development of three rust diseases (Saari and Prescott, 1985). Wheat stem rust, the polio of agriculture has been the most damaging disease among wheat rusts (Bariana *et al.*, 2007; Bhavani *et al.*, 2019). Because of the enormous economic damage caused by wheat rusts, scientific community has focused this field intensively.

Stem rust

Stem rust (Black rust) is a most damaging wheat disease caused very severe crop losses until the mid of the previous century (Saari and Prescott, 1985). The disease was detected occasionally till 1980 in Europe (In France and Switzerland) on ancient wheat cultivars, in addition in Eastern and Southern European countries which were not deploying resistant cultivars. Plant pathologists revealed essential information of the pathogen's lifecycle that is used to develop disease management strategies (Schmid and Peterson, 2001) while breeders incorporated stem rust resistance into wheat cultivars. The *Sr31* resistant gene was among the most effective resistant genes. The gene was introgressed into bread wheat with the 1BL.1RS translocation from *Secale cereale* cv. *Petkus* (Rye) to wheat (McIntosh *et al.*, 1995; Sandiswa *et al.*, 2014). Wheat with *Sr31* became widespread quickly universally since along with *Sr31*, the segment of rye chromosome carried supplementary genes for resistance to other rust diseases and genes for enhanced grain yield (Iqbal *et al.*, 2010). World was mostly safe from stem rust for more than thirty years during second half of previous century (Schumann and Leonard, 2000; Singh *et al.*, 2008b). It is not surprising that there are many wheat experts who have not perceived this disease in the field (Afzal *et al.*, 2015). It is rationale that disease has not been addressed by scientific community during the era mentioned.

DETECTION OF VIRULENCE TO RESISTANCE AGAINST STEM RUST

This disease re-emerged as a hazard with the discovery of Ug-99, in Uganda in 1998 (Pretorius *et al.*, 2000). The original race was first characterised in Uganda in 1999 (hence the name Ug-99), is designated as 'TTKSK' (Pretorius *et al.*, 2012) following the North American nomenclature system (Roelfs, 1988). Development and proliferation of Ug-99 race group posed hazard to production of wheat seriously worldwide (Singh *et al.*, 2011). Novel variants of Ug-99 emerged that are additional virulent to *Sr24* (Mukoyi et al., 2011), *Sr36* (Jin et al., 2009), and *SrTmp* (Newcomb *et al.*, 2016) subsequently inserting more cultivars vulnerable. The incidence and spread of Sr31-virulence strains in the Ug-99 race group in Eastern Africa and other virulent strains causing epidemics and local eruptions in Ethiopia (Olivera *et al.*, 2015), Europe (Lewis *et al.*, 2018) and Central Asia (Shamanin *et al.*, 2018), designates that the disease is developing as a hazard to wheat production in major wheat production regions. The Ug-99 race group, was infectious on almost all the wheat varieties cultivated everywhere in the world (Afzal *et al.*, 2015). Variants of Ug-99 have spread all over southern and eastern Africa, Zimbabwe, Tanzania, Iran and in Egypt (Pretorius *et al.*, 2010; Mukoyi *et al.*, 2011; Hale *et al.*, 2013; Nazari *et al.*, 2009; Patpour *et al.*, 2016). The regional epidemic of wheat stem rust in Germany in 2013 (Olivera *et al.*, 2012) was proceeded by a sequence of periodic occurrence in republics incorporating UK, Denmark, and Sweden (Hovmøller *et al.*, 2019). The incidence and dispersal of *Sr31*-virulent strains in Eastern Africa and other races producing epidemics and localized outbreaks in Ethiopia, Europe and Central Asia (Olivera *et al.*, 2015; Bhattacharya, 2017; Olivera Firpo *et al.*, 2017; Lewis *et al.*, 2018; Shamanin *et al.*, 2018; Rouse *et al.*, 2011; Newcomb *et al.*, 2016), shows that the disease is re-emerging as a threat to wheat cultivation. Races in the Ug-99 group have been observed across South, East and northern regions of Africa, and the Middle East and have the potential to spread in other wheat cultivating areas of the world (Park *et al.*, 2011). The genes which performed very effectively against original race (TTKSK) have become ineffective with the development of variants virulent to stem rust resistance genes.

Race TKTTF, also identified as the “Digalu race,” infested the wheat cultivar Digalu in Ethiopia, causing up to 100% yield losses during 2013 and 2015 (Olivera *et al.*, 2015). Digalu was released in 2005 and became the most commonly grown wheat cultivar in Ethiopia beginning in 2011 subsequently a 2010 stripe rust epidemic in Ethiopia (Hundie *et al.*, 2019). Digalu was resistant to race TTKSK conferred by *SrTmp* but was prone to race TKTTF (Olivera *et al.*, 2015). After the stem rust epidemic in 2013, race TKTTF became the leading race in Ethiopia (Olivera Firpo *et al.*, 2017). Because Digalu is resistant to TTKSK, this outbreak emphasised the prerequisite to choose wheat genotypes with resistance to both race TTKSK and other *Pgt* races, together with TKTTF (Hundie *et al.*, 2019). This situation demands exploitation of resistance genes in combinations to achieve better results (Rouse *et al.*, 2011).

In Pakistan, Iqbal *et al.* (2010) analyzed samples collected from Sindh and lower Punjab during the 2009 season and analyzed at Murree in Pakistan and Canada. Work explored all isolates were recognized as single race RRTTF. This isolate is characterized to be virulent on *Sr13*, *Sr36*, and *SrTemp* and avirulent on *Sr8a, 9e, 22, 24, 25, 26, 27, 31, 32, 39, 40*. DNA fingerprinting for Ug-99 of urediniospores were carried at PBI, University of Sydney and obtained negative results. Finding of combined study during 2009 revealed that Ug-99 did not prevail in Pakistan. In stem-rust-prone localities of Pakistan such as southern part of Punjab and Sindh, local stem rust strains could also develop to produce more virulent strains.

PERSPECTIVES OF UG-99 INCURSION IN SOUTH ASIA

A study has been conducted under the supervision of Professor Gilligan from Cambridge University and was published by Meyer et al., 2017. Experts affiliated with different institutes (the University of Cambridge, International Maize and Wheat Improvement Centre and the UK Met Office) worked in collaboration to predict at what time and in what way lineage of Ug-99 are most probable to be disseminated. Field disease surveillance data from the International Maize and Wheat Improvement Centre and meteorological data from the United Kingdom Met Office were used as input for the modelling outline of spore dispersal on regional and continental scales through identification aerial dispersion trajectories and assessment of amounts of Pgt-spores between donor and recipient regions. The finding of work conducted highlighted the role of Yemen for the spread of the disease between continents. The important situation for disease spread is from Yemen directly to Pakistan or India. In case of a severe epidemic in Eastern Yemen designate 30% chance for spread to occur. Another key set-up for wheat rust dispersal is from Yemen through Middle East, particularly Iran, to Central and Southern Asia. A moderate outbreak of Ug-99 in Iran more than 1000 hectares then spores would expect disperse to Afghanistan, and from there more to the northern plains of Pakistan and India. Yet, spread along this path is limited to a rather short time-window, wheat is reaped in South Asia before. In the light of above discussion, it is concluded we need to keep ourselves aware with the alteration in race pattern of Pgt worldwide. However, the modelling work also suggests the aerial spread of the disease from Yemen to South Asia is not likely, reason being spread events likely on less than 24 hours in 365 days.

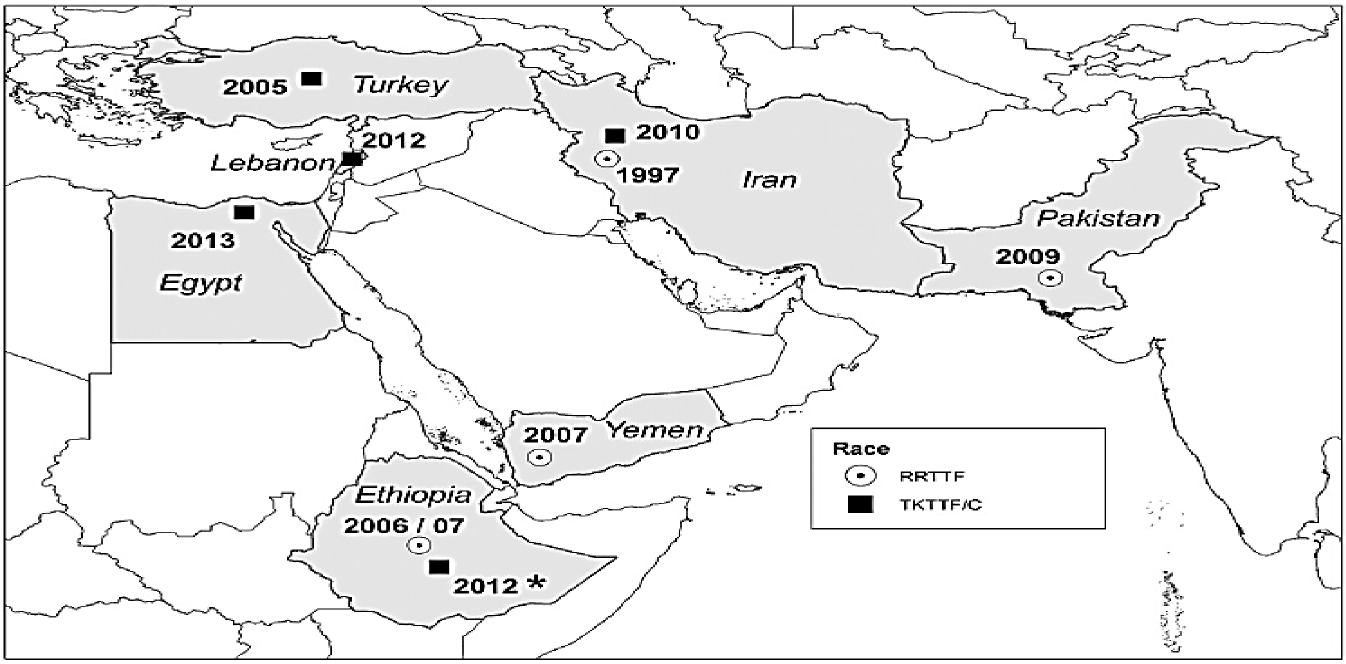

Figure 1. Dispersion of Ug-99-Race Group in Africa and Asia (Singh *et al.*, 2015).

REACTION OF WHEAT SCIENTISTS AGAINST UG-99

Bill and Melinda Gates Foundation and institution of a Global Rust Initiative (later Borlaug Global Rust Initiative, BGRI) (www.globalrust.org) sponsored Wheat project in September 9, 2005 in a meeting held at Nairobi, Kenya with the objective to defend the most important crop against this challenging disease, by application of modern information of the biology of pathogen and recent breeding tools. Work was conducted following underlying approach (Afzal *et al.*, 2015):

1) Monitoring the spread of race Ug-99
2) Detection of resistant sources
3) Distributing selected material
4) Incorporation of resistance through breeding

Experts in various fields contributed in war against Ug-99 and generated sufficient data. Few of which is referred as under:

1- Monitoring the spread of race Ug-99

Global Cereal Rust Monitoring System (GCRMS) has been executed under the canopy of BGRI, Consultative Group on International Agricultural Research (CGIAR) centers, progressive research laboratories, national agricultural programs and UN-FAO, to assimilate and circulate advanced data on black rust occurrence in addition to the dispersal of races. The GCRMS has resulted in the development of a solid, quickly growing, synchronized universal rust surveillance network.

The pathogens of rusts in wheat are aggressive as they change, and their asexual spores disseminate by wind over extensive distances, results in breakdown of crop resistance leading to damage crop production severely. A coordinated approach including regular disease surveillance, consolidation research volume, and development of resistant varieties and confirming their acceptance at farm level is the key of successful management of rust diseases leading to increased wheat production. Scientific community addressed the complications of pathogen diversity both prevailing and likely through monitoring. Adequate current data has been produced concerning several aspects of strain i.e. diversity of pathogen. More than fifteen countries are producing homogenous field surveillance statistics on incidence and severity of rust diseases in wheat, and in future this number is likely to increase more (Singh *et al.*, 2011). Thirteen strains have been acknowledged within the Ug-99 lineage in Africa, Yemen and Iran, whereas few of which prevailing in some localities year after year dominantly (Newcomb *et al.*, 2016; Singh *et al.*, 2015; Bhardwaj *et al.*, 2019). *P. graminis* f. sp. *tritici* population in Ethiopia is diverse exceedingly (Admassu *et al.*, 2009). TKTTF, TRTTF, and JRCQC, have been perceived in Ethiopia together with TTKSK (Olivera *et al.*, 2015; Olivera *et al.*, 2012). It appeared that Ug-99 will spread like a tsunami from Central East Asia across the world resulting crop failure in the subcontinent (Afzal *et al.*, 2015; Singh *et al.*, 2006; Singh *et al.*, 2008a; Singh *et al.*, 2011). Most notably it was virulent to the Mega-variety, Attila and Sibs cultivated in many regions that were being sown from Kenya to India and Afghanistan under numerous various names. Stem rust could damage severely, if the new races travel to main wheat producing areas in South Asia, where its prevalence has not yet been described, particularly the Punjab, South Asia's breadbasket, which feeds hundreds of millions of inhabitants of Indo-Pak. The genes *Sr2, Sr23, Sr25, Sr33, Sr35, Sr45* and *Sr50* are recognized to be effective genes against the prevailing race pattern (Singh *et al.*, 2015). Regardless of the fact stem rust strains virulent against *Sr31* do not exist in Pakistan, we focus and observe rust constantly, crop surveillance and varietal deployment is in place and there is active preparation to any rust hazard to wheat. A trial was conducted to postulate 117 Pakistani wheat genotypes using DNA markers. Markers for the genes *Sr2*, *Sr6*, *Sr22*, *Sr24*, *Sr25*, *Sr26*, *Sr31*, and *Sr38,* were analysed. Stem rust resistance genes *Sr22*, *Sr24*, *Sr25*, and *Sr26* were not found from all varieties, while *Sr2*, *Sr6*, *Sr31*, and *Sr38* were detected at various frequencies. *Sr2* (9–79% by different markers) was found most frequently, subsequently *Sr31* (35%), *Sr6* (11%), and *Sr38* (9%). These findings showed that resistance against stem rust in Pakistani varieties is narrow based and genes potentially effective against new stem rust races are lacking. Hence, it is a need of hour to integrate genes *Sr22*, *Sr24*, *Sr25*, and *Sr26* into Pakistani wheat varieties. Diverse markers designed for adult plant resistance gene *Sr2* showed dissimilar frequencies of gene in the varieties tested. Development of consistent and effective markers are needed to be for marker-assisted selection (MAS) of this and other genes (Ejaz *et al.*, 2012). The information is being exploited successfully to evolve strategies to control disease.

2-Detection of new sources of resistance against stem rust in wheat

Recognizing genes resistant against the predominant pathotypes and introgression of effective genes into wheat varieties is most practical approach to control rusts. But on the other hand there is no supply of innovative, effective, cloned resistance genes kept in freezers in workshops that can be liquefied and then installed rapidly in farmers' fields to prevent potential disaster that may impend food security as seen in the Ug-99 prevalence.

Resources of germplasm play key role to achieve extreme output of breeding for crop improvement. Wild wheats are a compliant source of possessing genes resistant against stem rust. Certainly, many resistance genes derivative from wild wheats performed effectively against the Ug-99 races group. An exciting observation is that genes originated from *Triticum aestivum* were found ineffective frequently (Jin *et al.*, 2007). *Aegilops* species has been utilized recurrently in crossing with wheat to allocate genes resistant against *Pgt* (Schneider *et al.*, 2007; Olson *et al.*, 2013a, 2013b). Location situated between 30° and 45°N latitude, is one chief wheat-producing zone of the earth is rich in wheat germplasm resources (Hawkes, 1981). Germplasm banks have been maintained worldwide to make genetically diverse resistance sources accessible to breeders. This strategy ensures broad genetic base in wheat crop. The significance of preserving plant genetic diversity has been known since long before, and there are among 410,000 (Tanksley and McCouch, 1997) and 800,000 accessions sustained in almost 80 germplasm banks for wheat round the world (Ortiz *et al.*, 2008). Characterization is essential to identify the potential of landraces conserved to put genetic diversity into practice (Tanksley and McCouch, 1997). Currently, assessment of vital phenotypic characters is a preventive aspect for shifting of genes from genebank germplasm into breeding lines. Phenotypic assessment of various genetic resources can be mainly challenging attributable to difference in growth habit and phenology (Hoisington *et al.*, 1999). Usage of molecular markers can complement phenotypic and physiologic information (Huang *et al.*, 2002). Nevertheless, it is not likely that assessments in field situations can be substituted as a consequence of work conducted to make resources of genes accessible to breeders. Data of genetic diversity in germplasm is convenient to utilize resources of genes more effectively. Landraces of wheat deliver advantageous source of genetic diversity (Villa *et al.*, 2005; Warburton *et al.*, 2006). Wheat landraces have been substituted with varieties in maximum areas under wheat production that are the product of planned breeding programmes.

Some central ethics occur in this situation:

a- Wild wheats are rich source of resistance, it is rational to track and exploit this valued source.

b- It is not confirmed that the ease or trouble of crossing chromosome matching with wheat and the resistance incorporated is certainly durable. It is stated, the far related species do not surely contain the viable resistance genes. An example of this is *Sr31* from rye, which capitulated to destructive stem rust pathotype TTKSK after several years of utilization in agriculture successfully. The key advantage about rotating to wild or remotely related species is that resistance genes are promptly found.

c- Achievement in wide crossing or chromosome designing cannot be predicted ahead. Consequently, it is reasonable to acquire full benefit of the probabilities of achievement by intensifying and trying hybridization and transfer of chromosome from alien sources with collection of species, accessions, or landraces.

Major features leading the utilization of wild species as a source of vigorous traits from agricultural point of view are (a) Acquiring of a productive cross breed and (b) Transfer the segment of chromosome having genes resistant to wheat successfully. Effective hybridization, maintenance of the First filial generation, and recovery of possible recombinants may be influenced by chance hereditary features as well as chromosome physical heterozygosity. Species with genomes more distantly related to wheat frequently show diminished rates of homoeologous pairing whereas closely related to wheat determine high rates of recombination (Mujeeb-Kazi *et al.*, 2013). The reported number of stem rust resistant genes are about sixty in which *Sr2, Sr55, Sr56, Sr57* and *Sr 58* are genes effective at booting stage (McIntosh *et al.*, 1995).

3-Distributing selected material

By the end of 2006, 95 percent of the commercial cultivars were susceptible against Ug-99 (Singh *et al.*, 2015). Because genes lose effectiveness in the war of survival between host and pathogen, supplementary genes are required in necessary backgrounds to fight wheat rusts (Bhardwaj, 2012). Furthermore, existance of various and pyramided resistance is prerequisite for application in wheat breeding programs for rust resistance.

Wheat entries collected from various countries were screened at Kenya, it was revealed a trend of improved resistance in wheat germplasm tested. Wheat advanced material from Pakistan, India, and Ethiopia was evaluated at Njoro field to detect the response of entries against Ug-99 during the main season 2014. Results demonstrated that 56.7% (Pakistan), 38.4(India), and 69.4% (Ethiopia) of test entries, exhibited disease severity <30%. This level is satisfactory for Pakistan and India; however, for Ethiopia, 32.8% entries clustered under near-immune and resistant groups have to be an acceptable choice for integration since stem rust exists in each season in the plateau of Eastern Africa, causing development of diseases earlier when climate is favorable for disease development (Singh *et al.*, 2015).

The struggle of the Bourlag Global Research Initiative, CIMMYT, Ethiopian Institute of Agricultural Research and Kenyan Agricultural and Livestock Research Organization have been very fruitful in coaching numerous individuals and in categorizing germplasm according to their response against infection of *Pgt* (Rahmatov *et al.*, 2016; Singla and Krattinger, 2016), and Germplasm development (pre-breeding), (Olivera *et al.*, 2018; Rouse *et al.*, 2011). Pakistan is one of the allies of the BGRI, is vigorously contributing in germplasm evaluation in Ethiopia and Kenya.

4- Incorporation of resistance through breeding

A narrow genetic base in host plant results emergence of diseases in epidemic causing enormous loss (Fu and Somers, 2009; Warburton *et al.*, 2006). Diversity for rust resistance within a region is the key factor for managing wheat rusts. The promising wheat gene pool has a limited hereditary bases for resistance to the current virulent races. Utilization of genes from all genepools is compulsory to ensure broad base of resistance against diseases. Deployment of rust resistant wheat cultivars is taken on sensitively in diverse wheat cultivating regions based on the race pattern of the various species of *Puccinia* in rust resistance cultivars of wheat. Wheat rust resistance used in plant breeding programs is classified in two categories (Table 1).

Table 1. Characterization of complete and partial resistance.

Complete resistance	Partial resistance
Monogenic	Polygenic
Hypersensitive	Non-hypersensitive
Race-specific	Race-nonspecific
Vertically controlled by major genes	Horizontally controlled by minor genes
Non-Durable	Durable

Since the chance of a resistance gene when arranged alone are further by new races of pathogen overcome, monogenic resistance is additionally branded for "boom and bust cycles". Application of a single major gene for stem rust resistance in wheat commonly is not durable for resistance due to the recurrent development of novel infectious pathotypes of *P. graminis* (Stuthman *et al.,* 2007).

To alleviate the likely influence of rust epidemics in main wheat cultivating zones, it is crucial to recognize new approaches to get desirable traits through durable resistance. Evolution of promising sources of adult plant resistance (APR) based on several slow-rusting genes has also continued. Once the *Sr2* gene was only identified APR; nowadays, four extra genes—*Sr55, Sr56, Sr57,* and *Sr58*—have been identified and an additional quantitative trait locus recognized. Conventional crop development is slow and cannot keep pace with growing food anxieties. Biotechnology is being employed to increase yields.

SCOPE OF APPLICATION OF BIOTECHNOLOGY IN THE WAR AGAINST UG-99

Characteristic applications of biotechnology is an important pillar of research work conducted for development of society through improvement of crops with upgraded nourishing quality, resistance to pests and diseases reduced cost of production and vice versa.

Gene pyramiding has been suggested as a very practical procedure to improve durability of resistance (Bajgain *et al.*, 2015). Cloning of genes resistant against rust creates new horizons on rust management strategy in the near future through the advancement of several resistance gene complex (Singh *et al.*, 2015). Plant breeding procedure like Marker-assisted selection (MAS) is very advantageous (Young, 1996).

MOLECULAR MARKER TECHNOLOGY

Markers are remarkably transmissible through chromosomes and can be categorized at the seedling stage. Hence, identification of sources of resistance is carried with more certainty. Furthermore, MAS is highly supportive in categorizing the resistant genes pyramided in one genotype (Anderson, 2003). Effective breeding depend on the characterization of new sources of resistance by means of QTL or gene mapping and integration of these resistant genes into breeding lines to develop new genotypes resistant against disease. Furthermore, current research is concentrated on mapping and developing molecular markers linked to *Sr* genes and pyramiding. These markers will improve the effectiveness of combining *Sr* genes into cultivars that are adapted broadly but susceptible to Ug-99 and support for the development of new elite lines that are resistant to Ug-99 and its derivatives. Additionally, it is essential to use the potential genetic resources (Haile and Rouml, 2013).

Markers citation for stem rust resistance genes effective against *Puccinia graminis* f. sp. *tritici* race of Ug-99 and its variants are described herewith. *Sr2* (Spielmeyer *et al.*, 2003; Dundas *et al.*, 2007; Hayden *et al.*, 2004); *Sr13* (Simons *et al.*, 2010; Haile and Rouml, 2013; Olivera *et al.*, 2012)*, Sr22* (Periyannan *et al.*, 2010; Khan and Saini, 2009)*, Sr25, Sr26* (Liu *et al.*, 2011; Singh *et al.*, 2011; Dundas *et al.*, 2007)*, Sr27* (Singh *et al.*, 2011), *Sr28* (Rouse *et al.*, 2012)*, Sr31*(Mago *et al.,* 2005) *Sr32* (Yu *et al.*, 2011)*, Sr33* (Singh *et al.*, 2008a) *Sr35,* (Singh *et al.*, 2011), *Sr37* (Zeng *et al.*, 2014) *Sr39* (Mago *et al.*, 2010; Niu *et al.*, 2011)*, Sr40* (Wu *et al.*, 2016)*, Sr42* (Ghazvini *et al.*, 2012), *Sr43* (Xu *et al.*, 2009), *Sr45* (Singh *et al.*, 2011; Olson *et al.*, 2013a), *Sr46* (Rouse *et al.*, 2011; Singh *et* *al.*, 2011; Olson *et al.*, 2013b), *Sr47* (Klindworth *et al.*, 2012)*, Sr50* (*SrR*) (Mago *et al.*, 2004; Anugrahwati *et al.*, 2008) *Sr52* (Qi *et al.*, 2011)*, Sr53* (Qi *et al.*, 2011), *SrCad* (Hiebert *et al.*, 2010b) and *SrWeb* (Hiebert *et al.*, 2010a).

These identified markers will improve the potential of incorporating *Sr* genes into susceptible varieties to Ug-99 but widely adapted and assist for the development of new promising lines resistant to Ug-99 race group of *Pgt*. Biotechnology is being used as an instrument to recover resistance against biotic stress in wheat. Regulatory situation and customer acceptance will decide success of this technology in breeding and agriculture in time coming.

ROLE OF GENETIC ENGINEERING IN CROP IMPROVEMENT

Genetic engineering techniques have numerous applications in crops improvement, as they allow development of agronomic qualities such as biotic and abiotic stress tolerance and quality. Contrary to conventional breeding, recombinant DNA technology bring together genetic material from many sources, generating arrangements that would not else be found in the genome extending the opportunities for yield improvement by contribution new phenotypes and genotypes. Thus, genetic engineering has been ranked as the fastest developing technology in agriculture. Targeted genome editing (GE) skills, specifically clustered regularly interspaced short palindromic repeats (CRISPR)/ (CRISPR)-associated protein 9 (Cas9), have great potential to help in the breeding of crops that are able to produce high yields under stress. This is because of their little danger of off-target effects, high efficiency, and precision.

The usage of CRISPR/Cas9 system has been accepted very quickly with abundant illustrations of targeted mutagenesis in crop plants, including gene knockouts, modifications, and the activation and repression of target genes. The potential of the GE approach for crop improvement has been obviously established. Abdelrahman *et al.* (2018) reviewed the usage of the CRISPR/Cas9-mediated GE, as a source to produce crop plants with better flexibility when cultivated under stressful conditions, however recognized the acceptance of GE crops still remains a trial.

VARIETAL DEPLOYMENT AGAINST UG-99 IN WHEAT GROWING REGIONS OF AFRICA AND ASIA

Several wheat varieties were developed to combat Ug-99. List of some cultivars deployed in different wheat growing territories are enlisted (Table 2).

Table 2. Description of Ug-99 resistant cultivars evolved in major wheat growing regions.

Country	cultivars
Iran	AKBARI, ARG, BAM, GONBAD, PARSI, PISGHAM, SIRWAN, SISTAN, OFOGH, MEHRGAN, RAKHSHAHAN
Kenya	KENYA TAI, KENYA SUNBIRD, KINGBIRD, KENYA HAWK10, KENYA DEER, KENYA FALCON, KENYA HORNBILL, KENYA PEACOCK, KENYA PELICON, KENYA SONGBIRD, KENYA WEAVERBIRD
Pakistan	NARC2011, BARS2009, PAK13, DHARABI 11, SHAHKAAR 13, AAS11, BOURLAUG 2016
Afghanistan	MUQAWIM09, CHONTE#1, BAGHLAN
Egypt	MISR 1, MISR 2, MISR 3,
Nepal	BL3063, TILLOTTOM, DANPHE 1
Ethiopia	DANDA'A, KAKABA, HIDASE, HOGONA, SHORIMA, HULUKA, KINGBIRD, LEMU, WANE
Sudan	ZAKIA
Bhutan	BAJOSOKHAKA, GUMASOKHAKA, DRUKCHU, BUMDANKH KAA
Bangladesh	BARI GOM26, BARI GOM 27, BARI GOM 29
India	KRL210, MACS6222, MACS6273, MP1203, NIAW917, PBW527, PBW658, RAJ3777, UAS 304, UAS 347, VL907

CONCLUSION

Developing extra crops able to harvest high yields when cultivated under biotic/abiotic stresses is an important area, if food security is to be ensured in the face of ever-increasing human population. The emergence and dispersal of the Ug-99 and its derivatives in East and South Africa and elsewhere has brought activities of study of stem rust and research onto the universal wheat development schedule under the BGRI. Important achievement is exploring genetic diversity of host as well as pathogen, developing rust resistant varieties, and coaching wheat experts. Current varieties with resistance were recognized and new varieties with race-specific or APRs were released in several countries. CIMMYT has initiated to distribute new, high-yielding wheat germplasm resistant to races belonging to the Ug-99 lineage and other virulent races of *Pgt* recognized currently in Africa, the Middle East, and Asia. Durable rust management in wheat and sister crops is not simple matter of exploring resistance genes—it encompasses number of subjects like phytopathology, host-pathogen genetics, plant breeding, field crop management, agriculture extension, availability of funds and last but not least sowing of newly developed rust resistant varieties by growers. This demands a concentrated effort by scientists' skilled in various disciplines, and institutions responsible for development of varieties, seed increase, and their supply and advancement. Global progressive agencies concerned with food security can play a critical part in management of stem rust by sustenance the aforesaid activities, which should also help alleviate the stem rust hazard in further wheat-growing areas.

To meet the prospect of changes in virulence pattern of the rust pathogens, post-release monitoring of pathogens and considerations of host gene homogeneity/diversity are noteworthy continuing problems. Improvement of our comprehension of stem rust is the need of hour. We also need to endure hard work to progress our elementary acquaintance of the ecology of pathogen and use novel tools in wheat breeding for rust management. Our present knowledge based on more than half century data, must be modernized. This is indispensable because conditions have changed entirely as a result of green revolution.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHORS CONTRIBUTIONS

Amir Afzal substantially contributed to the conception and design of the article and interpreting the relevant literature. Sayed Rashad Ali Shah drafted and commented the design of the article. Muhammad Ijaz and Muhammad revised and edited the article.