Vol. 21(3), pp. 222-239, March, 2025
DOI: 10.5897/AJAR2024.16853
Article Number: C4733B773088
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Evaluation of Kenyan wheat (*Triticum aestivum* L.) varieties for stem rust (*Puccinia graminis* f.sp. *tritici*) response under field conditions

B. Otukho[1,3]*, M. Oyier[2], G. W. Wanyoike[3] and J. O. Owuoche[3]

[1]Kenya Agricultural and Livestock Research Organization (KALRO), Food Crops Research Institute (FCRI), P. O. Box Private Bag-20107, Njoro, Kenya.
[2]Kenya Plant Health Inspectorate Service, P. O. Box 1679, Nakuru, Kenya.
[3]Department of Crops, Horticulture and Soils, Egerton University, P. O. Box 536-20115, Njoro, Kenya.

Received 31 December, 2024; Accepted 4 March, 2025.

Stem rust (*Puccinia graminis*) is a disease that globally has unceasingly threatened wheat. This study aimed to evaluate the response of 120 wheat varieties to stem rust under artificial inoculation for 3 seasons at Kenya Agricultural and Livestock Research Organization, Njoro. Resistance was quantified using the area under disease progress curve (AUDPC) and final disease severity with varieties exhibiting ≤300 and ≤30%, respectively considered resistant. Evaluation of Kenyan wheat varieties for yield and rust resistance is important; this study showed that 8.5 and 7.14% of varieties released in the 1920 and 1940s showed a disease severity of ≤30% across all seasons. In varieties released in the 1970s, 41.42% exhibited stem rust severity of ≤30%. Only 17.14% of varieties released in the 1990s, showed stem rust severity of ≤30%. Between the off-season of 2021 and the main season of 2022 varieties exhibiting AUDPC > 500 surged from 5 to 43. A response of *0* – trace (*TR)* observed on Kenya *(K.) Cheetah,* suggests the variety has resistant genes to the prevailing stem rust races. Varieties Mentor, K. Sungura and *K.* Leopard released in the 1960s, consistently showed a disease reaction of *0* to *10* moderately resistant (MR) across the seasons. This study suggests there is variable resistance amongst old Kenyan varieties.

Key words: *Puccinia graminis*, artificial inoculation, Kenyan wheat varieties, area under disease progress curve, final disease severity.

INTRODUCTION

Stem rust, caused by the fungus *Puccinia graminis* f.sp. *tritici* (*Pgt*) has been one of the most devastating diseases of wheat (*Triticum aestivum* L.) worldwide. In Kenya, it has been an ongoing challenge in wheat production since the early 1900s, with severe devastation experienced between1906 and 1917 (Pinto and Hurd, 1970). Wheat stem rust remains a long-standing threat to wheat production in Kenya due to variations in the virulence of the *Pgt* populations and the ability to spread over long distances by wind (Singh et al., 2015). The

*Corresponding author. E-mail: bernard.otukho@kalro.org/otukhobernard@yahoo.com.

importance of the disease is exacerbated, given its wind-borne mode of dispersion and the fact that there is wheat grown all around the year in different wheat-producing areas within the country. The significance of the disease in particular depends upon the prevalence of aggressive and virulent races of the pathogen and their compatibility with the genetic constitution of the host in a given environment (Kolmer, 2005). The introgression of the *Sr2* gene into most Kenyan wheat varieties in the 1970s resulted in the elimination of stem rust disease until 1999 when a virulent race *Ug99* emerged (Singh et al., 2011). This fungal disease can lead to significant yield losses if left unmanaged, making it a constant threat to wheat production (Dean et al., 2012). Stem rust disease affects the culm, leaf and inflorescence of wheat reducing the number of kernels per spike and consequently causing shriveling of kernels (Brinton and Uauy, 2019). The resistance of cultivars grown by the farmers usually became ineffective within a few years of release because of the emergence of new races. In Kenya, *Ug99* has resulted in massive yield losses in wheat because of new races that overcome resistant genes that constitute the newly released wheat varieties. Stem rust is the most dangerous form of rust to wheat crops, and when attacking a variety with no genetic resistance, losses to stem rust can be total (Soko et al., 2018). In Kenya, studies have indicated that stem rust can cause grain losses of up to 66% and a further reduction of up to 42 and 17% of the grain weight and hectoliter mass respectively (Macharia and Wanyera, 2012; Wanyera et al., 2016). In Ethiopia, yield losses due to stem rust have been reported to be 61-100% depending on the susceptibility of the variety and environmental conditions (Mideksa et al., 2018). Newcomb et al. (2016) observed that all 15 wheat lines that contained genes *SrTmp, SrND643, Sr9H, Sr28* and *SrCad* which were earlier on resistant to *Ug99* showed susceptibility to the new *Ug99* variants. This demonstrates that *Ug99* has been constantly evolving to overcome host resistance. The evolution of the *Ug99* pathogen in Kenya is mainly supported by the fact that the country has favourable wheat growing conditions throughout the year leading to the availability of host plants and the buildup of the inoculum (Abou-Zeid et al., 2018; Ambika and Meenakshi, 2018). Although more than 15 races from the *Ug99* lineage and its derivatives have been identified across 14 countries, races *TTKTK*, *TTKTT*, and *PTKTK* have shown virulence against the *SrTmp* and *Sr31* genes in Kenya (Fetch et al., 2016; Newcomb et al., 2016).

Since the inception of wheat growing in Kenya, yield losses due to rust infection were kept at a minimum level by requiring each farmer to grow several cultivars with different resistance genes (Dixon, 1969). Since 1908, wheat research in Kenya which has been a center for testing germplasm from different parts of the world through CIMMYT, has strived to keep up with the pace of the evolving virulent stem rust races (Oggema, 1972; Singh et al., 2011). Despite significant progress in breeding for rust resistance between 1908 and 1973, with the release of 132 wheat cultivars in Kenya, the average commercial lifespan of a wheat cultivar during the 1960-1970 period was 4.4 years due to the prevalence of prevalent races and the emergence of new ones (Pinto and Hurd, 1970; DePauw and Buchannon, 1975). Cultivars Africa Mayo and Kenya Page released in 1960 and 1963 showed adequate resistance in field nurseries despite being susceptible at the seedling stage to several prevalent races (Wanyoike et al., 2022). Dixon (1969) reviewed the status of wheat breeding in Kenya and indicated that the main sources of resistance were from Frontana, Kenya 58-Newthatch, Mida-McMurachy-Exchange'; C.I. 12632 and C.I. 12633, better known as Wis. 249 and Wis. 245, respectively. However, the resistant genes in these cultivars have since lost their effectiveness against several prevalent races. In a study conducted by Evans et al. (1969) on 39 elite wheat lines at both seedling and field experiments, 14 lines were identified with both seedling and field resistance to prevalent stem rust races in Kenya. The lines from a single cross Wisconsin-245/II-50-17 and a backcross CI8154/2*Frocor were two of the 14 identified to have effective stem rust resistance in Kenya and were used by Canadian breeders in their partial backcrossing programme. Most of the Kenyan cultivars released from 1973 to 1989 were based on the partial backcross programme using either 'Romany' or 'Tobari 66' as recurrent parents (Fetch et al., 2021). In Kenya, more than 95% of local commercial varieties are susceptible to stem rust, while only a few old wheat varieties have shown some resistance (Wanyera et al., 2006; Njau et al., 2010).

The use of fungicide as an alternative strategy for the control of stem rust disease cannot be ignored in Kenya but fungicide use in control of stem rust can increase the cost of production due to the multiple applications required to protect the crop before it matures. Many fungicides are also effective at specific growth stages of the crop and application timing is necessary by closely monitoring to detect the disease in individual fields and across the regions. The fungicide choice and the timing of the applications during crop growth may require up to three applications during growth. This may be further complicated by the fact that the severity of stem rust is related to inoculum pressure, environmental conditions and variety susceptibility (Cook et al., 1995). Badly timed sprayed crops can suffer much disease when the fungicide is applied too late or does not control the disease effectively. The management of stem rust by growing resistant varieties therefore is the most desirable method of controlling stem rust. Genetic resistance breeding provides the most effective, economical and environmentally friendly strategy to control wheat stem rust because in most cases under suitable environments, the pathogen develops resistance to fungicides especially when applied at sub-optimal concentrations (Oliver, 2014). Up to sixty stem rust (*Sr*) resistance genes have been identified in wheat and its wild relatives (MacIntosh et al., 2017) most of which confer race-specific resistance. Combating this problem of newly emerging races of stem rust has led to adopting alternative measures that involve race-specific and race non-specific that are durable (Ellis et al., 2014). Among these, non-specific resistance effective against multiple races of disease is more durable than those under the control of major genes (Bhavani et al., 2019). APR exhibits quantitative resistance, resulting from the additive effects of minor genes that slow disease progress by increasing the latent period, reducing infection, and spore production (Figlan et al., 2017; Stuthman et al., 2007). The phenotypic effect of such genes is relatively minor to moderate, however, additive effects of 4 to 5 APR genes in combinations can result in very high levels of resistance (Knott, 1982; 1988; Huerta-Espino et al., 2020). The use of resistant variation is considered an important control strategy; nevertheless, resistance must be durable given that the use of single, race-specific genes has often led to the breakdown of resistance due to the rapid pathogen population replacement by new virulent races (Pretorius et al., 2017; Singh et al., 2015).

Genetic stem rust resistance in wheat is a critical aspect of wheat breeding programmes to improve crop productivity and food security. It is therefore crucial to evaluate Kenyan wheat varieties to identify which cultivars and lines are resistant to the predominant races of stem rust races. Measuring genetic gain in a trait such as the resistance to stem rust is essential when assessing the breeding strategies and achievements in any breeding programme (Ortiz et al., 2022). Various methodologies have been used to quantify the progress of breeding including the direct comparisons of the resistances of old and modern varieties in the same environment (Slafer and Andrade, 1989). The information obtained from previous evaluations of genotypes under various environmental conditions helps to develop broad-spectrum resistance (Crespo-Herrera et al., 2017; Cormier et al., 2013). Genotype × Environmental interactions can limit genetic progress in plant breeding programmes by reducing the association between phenotypic and genotypic values (Comstock and Moll, 1963). Stem rust disease in Kenya has been effectively controlled since the 1980s with the widespread use of wheat cultivars with the Sr*31* resistance gene. However, *Sr31* has lost its effectiveness following the emergence and spread of the Ug99 race variants, and there is an urgent effort to identify new germplasm resources effective against these continuously evolving races of the disease.

Therefore, the objective of this study was to evaluate Kenyan wheat varieties that have been released since the inception of the wheat breeding programme for their stem rust reactions in the field over different seasons. Wheat varieties evaluated and found to be resistant may be used as donor parents in the Kenyan breeding programme to provide resistance to stem rust.

MATERIALS AND METHODS

A 3-season experiment was conducted during the main season of 2020, the off-season of 2021 and the main season of 2021, at Kenya Agricultural and Livestock Research Organization (KALRO), Njoro (35º 56′ 60″ E; 0º 20′ 60″ S) Nakuru County, in Rift Valley, Kenya. This site is located at an elevation of 2,120 m above sea level. The following meteorological data were obtained from a weather station adjacent to the research station: cool temperate climate with an annual mean temperature of 21°C and a bi-modal rainfall of 1000 mm, respectively. The site in the highlands of the central Rift Valley experiences temperatures between 9 and 22°C that favours rust infection. The soil in this area is predominantly well-drained Mollic Andosols (Jaetzold et al., 2012) which is suitable for wheat growing.

Wheat varieties

A set of 120 (Supplementary Table 1) spring wheat genotypes with diverse pedigree, plant stature and maturity used in this study were released at different times, and vary in stem rust resistance, morphology and kernel qualities. They are grown for commercial purposes by farmers and have been used in various breeding programmes worldwide as sources of rust resistance (McIntosh et al., 1995). These varieties were obtained from the gene bank at Kenya Agricultural Livestock and Research Organization (KALRO)-Njoro. They were grouped in years' (the 1960, 1970, 1980s, 1990, 2000, and 2010s), according to their year of release shown in Supplementary Table 1.

Experimental procedure

The experiment was conducted during the main season of 2020, the off-season of 2021, and the main season of 2021. Because the planting site experiences a bi-modal rainfall, for this study, the off-season experiments were conducted from January to April, while main season experiments were conducted from May to September of each of the years the study was carried out. During the main season is also when a majority of wheat farmers that are neighbouring the planting site are also planting their crops. To minimise confounding effects, the experiment was conducted in a field previously under canola (*Brassica napus*), cultivated and harrowed to a fine tilth suitable for wheat growth using a disc plough and harrow, respectively. Each entry was sown in an experimental unit consisting of double rows (0.75 m in length with a row spacing of 20 cm), at an equivalent seed rate of 102.9 kg/ha, adjusted from 95% to 100% germination. The seed was sown in rows spaced 20 cm apart while within the row, the seed was placed at a distance of approximately 5 cm apart. At sowing time, Di-ammonium Phosphate (DAP) (18:46:0) fertilizer was applied at the rate of 125 kg/ha sufficient to supply an equivalent of 22.5 kg N/ha and 25.1 kg P/ha. Immediately after sowing, pre-emergence herbicide, STOMP (Pendimethalin 455 g/L) was applied to control the germination of weeds. Because of the limited amount of seed in some varieties, the experiment was laid out in an augmented design with 2 replications. The blocks and replications were separated from each other by a 0.5 m alleyway. The experimental plots received no fungicide application. To create epiphytotic conditions in the field, a mixture of stem rust susceptible cultivars namely; Cacuke, Eagle 10, Robin, PBW343 and six CIMMYT lines carrying *Sr24* planted perpendicular to all the test plots and at the borders separating the replicates to act as stem rust disease "spreader rows"; a source of stem rust inoculum to generate an artificial stem rust disease inoculation environment in the field. Stem rust *urediniospores* of locally predominant *Ug99* and variant races *TTKSK*, *TTKST*, *TTKTK* and *TTKTT* were collected using a motorized vacuum suction pump from a disease trap nursery at the International stem rust phenotyping platform. The collected *urediniospores* were dissolved in a litre of water, mixed thoroughly by shaking in a container and filtered through a cheesecloth sieve resulting in a dark brownish liquid with a concentration of approximately 3 × 10^5 spores ml^{-1} (Gilchrist-Saavedra et al., 2006). At the booting stage (GS 37-60) of plant growth, the inoculum was injected into disease spreader rows plants using a hypodermic syringe and by also spraying them with rust inoculum using the ultra-low volume sprayer to initiate stem rust infections. For effective disease infection, inoculations were conducted during the late afternoon when the weather was cool. The inoculation of spreader rows was done twice at an interval of 7 days.

At tillering stage (GS 20-29) (Zadoks et al., 1974), each experimental plot was top-dressed with Calcium Ammonium Nitrate (CAN) fertilizer at an equivalent rate of 100 Kg/ha and this supplied an additional 33 kg N/ha. Growth of weeds was restricted by applying a post-emergence herbicide, Hussar Evolution (Fenoxaprop-p-ethyl 64 g/ha + Idosulfuron methyl sodium 8 g/ha + Mefenpyr-diethyl 24 g/ha) to control broad-leaved and grass weeds. A soil moisture meter (Model PMS714, Film Badge Service Company) was used to monitor the level of soil moisture at an interval of 7 days. Immediately after planting, the experiment was irrigated to field capacity to initiate germination and sustain the growth of seedlings. Thereafter, the frequency of irrigation was determined by the level and retention of the soil moisture whenever there was inadequate rain. During the rainy season, the experiment depended on moisture exclusively from the rainfall. The sucking and chewing pests of wheat plants were controlled by the application of a systemic insecticide, Thunder OD 145 (imidachloprid 30 g/ha + beta-cyfluthrin 13.5 g/ha), twice at tillering (GS 20-29) and ear emergence (GS 50-69) stages.

Data collection

Each entry was evaluated for stem rust infection based on a modified Cobbs scale ranging from 0 to 100% (Peterson et al., 1948). The evaluation was done at an interval of 10 days when the susceptible check attained a 50S stem rust reaction. The response to infection was based on the type of *uredinia* pustules with the presence or absence of necrosis or chlorosis that is, immune (*0*), trace (*TR*), resistant (*R*), moderately resistant (*MR*), moderately susceptible (*MS*), moderately susceptible to susceptible (MSS), and susceptible (*S*). Final disease severity (FDS) values of ≤ 30% and >30 were considered as high and low levels of resistance, respectively.

Statistical analyses

The area under the disease progress curve (AUDPC) is a useful quantitative measure of disease intensity over time and is used for comparison purposes across years, locations, or management regimes. In wheat pathology, the most used method for estimating the AUDPC is the trapezoidal method, which helps to discretize the time variable (in this case, days were used) and calculate the average disease intensity between each pair of adjacent time points (Madden et al., 2007). In this study, AUDPC for each variety was calculated according to the following formula adopted from Shaner and Finney (1977):

$$A_k = \sum_{i=1}^{n} \left[\left(\frac{Y_{i+n} + Y_i}{2} \right) \right] [t_{i+1} - t_i] \quad (1)$$

where A_k = AUDPC, Y_i= disease injury intensity at the i^{th} observation, t_i=time in days at the i^{th} observation, and *n*= total number of observations. Analysis of variance was thereafter conducted using *PROC GLM* procedure in Statistical Analysis System version 8.2 software (SAS, Institute, Cary NC., 2010) by applying the following statistical model:

$$Y_{ijkl} = \mu + S_i + R_{j(i)} + G_k + SG_{ik} + \mathcal{E}_{ijkl} \quad (2)$$

where $Y_{ijkl}$is the effect of the experimental units, μ is the general mean, S_i = effects due to i^{th} season , R_j is effects due to j^{th} replicate in i^{th} season , G_k is effects due to genotype, SG_{ik} =effects due to i^{th} season by k^{th} genotype in the j^{th} replicate and $\mathcal{E}_{ijklm}$ is the error term. In this study, effects due to genotype and replicate were considered as fixed effects. The sum of squares was used to partition the contribution of the factors used in the statistical model. To test all pairwise comparisons among means of the fixed effects, the Tukey's *HSD* was calculated for each pair of means using the following equation (Tukey, 1949) by applying "*MEANS/TUKEY*;" statement on SAS software:

$$W = q_\alpha(t\,, v\,)\sqrt{\frac{EMS}{n}} \quad (3)$$

where *W* = Tukeys's honestly significance difference test, EMS = the error mean square within samples based on v degrees of freedom; $q_\alpha(t\,, v\,)$ = the upper tail critical value of the studentized range for comparing *t* different populations and *n* = the number of observations.

To determine unaccounted proportion of variation in statistical model, coefficient of variation (CV) was computed using the following formula:

$$\text{Cv} = \frac{sd}{\bar{X}} \times 100$$

where *sd*= pooled standard deviation, and $\bar{X}$= general mean.

In order to determine the dispersion of data from the mean value of each variety, standard error (SE) was calculated using the following formula:

$$\text{SE} = \frac{sd}{\sqrt{n}}$$

where *n* is the number of samples and *sd* is the sample standard deviation.

RESULTS

In this study, analysis of variance showed that effects due to seasons, variety and season × variety interaction were significant (*p*≤ 0.001) (Table 1). From the results of this study, it was clear that the interaction between variety × season accounted for 55.21% of variation in the statistical model used in the analysis. This was followed by season and variety which accounted for 23.26 and 20.79% variation, respectively. Only a small proportion of 0.43%

Table 1. Mean squares for area under disease progress curve for Kenyan wheat varieties evaluated over three seasons at KALRO-Njoro, Kenya.

Source of variation	df	Mean square	Contribution to the model (%)
Season	2	1457830.24***	23.26
Block (Season)	15	2585.51	0.31
Variety	119	137196.13***	20.79
Season × Variety	236	29329.36***	55.21
Error	17	3141.14	0.43
Cv (%)		18.02	
R^2		0.99	

***Significant at $P \leq 0.001$, df -degree of freedom; Cv- Coefficient of variation.

Table 2. Mean values and range for area under disease progress curve for resistance to stem rust over three cropping seasons at Kalro, Njoro.

Season	Area under disease progress curve	
	Mean ± SE	Range
Main Season 2020	192.63±16.43[c]	0-855.0
Off-Season 2021	386.94±23.55[a]	0-910
Main Season 2021	353.33±24.87[b]	0-1010
[b]Robin	667.5	-
[c]Kingbird	240.1	-
MSD	17.83	-
Mean[a]	310.97±13.29	-

Means followed by the same letters are not significantly different at $p < 0.05$; *MSD* Tukey's minimum significance difference; [a]Mean values are a combination for 3 seasons; SE Standard error. [c]Resistant control and [b]Susceptible control.

was due to error and this resulted in Cv of 18.02%. Differential seasonal effects were observed on varieties tested for stem rust infection in the field. Mean AUDPC ranged from 0-855, 0-910 and 0-1010 for wheat grown during the main season of 2020, off season of 2021 and main season of 2021, respectively (Table 2). The results showed that a wide range of AUDPC occurred during main season of 2021 and this was due to high disease severity that affected wheat during this period. In off season of 2021, mean AUDPC of 386.94 was observed during the off season compared to AUDPC of 192.63 observed during the main season. Only mean AUDPC value of main season of 2020 was lower than the AUDPC for variety Kingbird which had a mean of 240.1. Therefore, it can be concluded from this study that severity of disease was high during the off season of 2021 compared to main season of 2020 by a magnitude of 50.2% (Table 2). The mean AUDPC observed on wheat evaluated during main season of 2021 was significantly lower than the AUDPC noted during off-season 2021, although the latter had the widest AUDPC range of 0-1010. The susceptible check variety *Robin* showed a very high AUDPC value of 667.5 compared to mean AUDPC value of 667.5.

The level of stem rust infection across the seasons was low for varieties released between 1920 and 1950. However, a high stem rust infection was observed on varieties released between 1960 and 1980 and severity increased gradually on varieties released in the 1990s and 2000s (Figure 1). In this study, the response of the varieties to stem rust infection varied with seasons. Combining all the susceptible severities, high disease infection was observed in varieties evaluated during the main season of 2020 (Figure 1). It appears that the environmental conditions during the off season of 2021 were favourable for stem rust infection. The prevalence of the disease was higher during the main season of 2021 compared to the main season of 2020 and the off season of 2021 (Supplementary Table 2). The trend showed an increasing number of susceptible varieties, with the highest severity observed among varieties released in the 1990 and 2000s. Varieties released in the 1920s displayed disease severity ranging from 10 to 60%, while those released in the 1940s reacted to stem rust infection with severity ranging from 10 to 70% across the seasons. Despite the high disease severity ranging from 40 to 70%, observed during the off-season of 2021 and the main season of 2021, 8.5 and 7.14% of the varieties released during 1920 and 1940, respectively reacted to stem rust infection with disease severity of ≤30%. It was

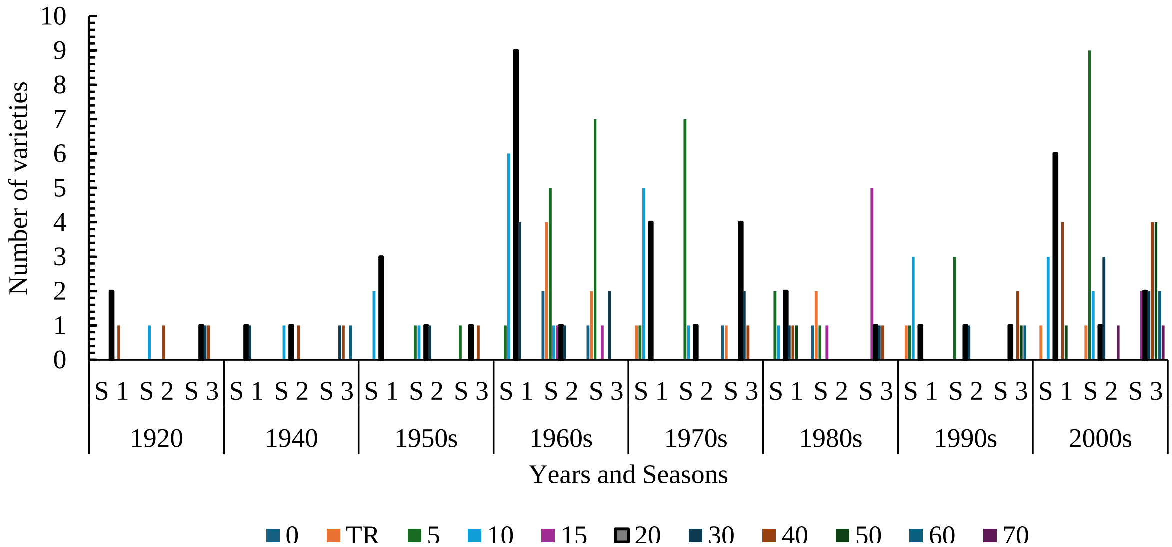

Figure 1. Severity of stem rust on Kenyan wheat varieties released from 1920s to 2000s, evaluated during main season 2020 (S1), off season 2021 (S2) and main season 2021 (S3) at Njoro, Kenya.

evident that *Governor* was resistant with low levels of disease infection ranging from *TR* to *30MS*.

Varieties released in the 1960s demonstrated a variable response to stem rust infection during the testing period. During the main season of 2020 and off season of 2021, the test varieties were resistant with 28.57 and 21.42% of them showing disease severities ranging from 5 to 30% and 0 to 30%, respectively (Figure 1). However, during the main season of 2021, stem rust infected variety *Salmayo* with a severity of 40%, while variety *Brewster* was susceptible with a severity of 50%. In this study, 35.71% of the varieties released in the 1960s were resistant to stem rust infection with severity between 5 and 20% during the entire testing period and this was an indication that these varieties were resistant to prevailing rust races.

The number of varieties that manifested resistance with disease severity of ≤30% increased among those released in 1970s across all the 3 seasons with 41.42% being resistant. During the main season of 2020 and off season of 2021 varieties K. Nyangumi (Sr12, Sr57, Sr58), K. Fahari, K. Tembo and K. Paka (Sr12, Sr57) displayed low disease severity ranging from *TR* to 10% while during main season of 2021, 12.85% of the varieties showed disease severity ranging from 40 to 70%, a susceptible reaction. For varieties released in the 1980s, the proportion showing disease severity of ≤ 30% reduced to 32.85%. This study also revealed that varieties Kwale (Sr2 Sr12), K. Kongoni (Sr2, Sr57), K. Popo (Sr12), Mbuni and Paa responded to stem rust infection with severities ranging from 0 to 15% during the off-season of 2021 (Supplementary Table 2).

Regarding the AUDPC values, wheat varieties were categorised as R, MR, MS and S for values of 0 to 150, 151-300, 301-500 and > 500, respectively. Based on the computed AUDPC values ranging from 0 to 150, a proportion of 48.93, 71.6, and 19.23%, of the tested varieties were categorised as resistant, across the three seasons. The number of varieties with the highest AUDPC > 500 due to stem rust infection increased from 5 in the off-season of 2021 to 43 in the main season of 2021. In addition, it was observed that 31.93% of the varieties evaluated for stem rust showed high AUDPC during the main season of 2021.

Among the wheat varieties with different stem rust gene constitutions, 21 showed resistance of 0 to 30MS infection types resulting in AUDPC values ranging from 0 to 420 under field conditions (Table 3). Over the 3 cropping seasons variety K. Cheetah which has Sr12 and *Sr57* genes exhibited an immune response of 0 – TR, while varieties Mentor, K. Sungura and K. Leopard (*Sr2*, *Sr58*) released in the 1960s, consistently showed resistance to disease infection with reaction of 0 to 10MR across the seasons (Table 3). In addition, varieties Gem with a reaction of TR-10MR, K. Page (Sr2, Sr17,), K. Kudu (Sr2, Sr580; reaction of 5 to 10M), K. Civet (Sr2, Sr12 Sr58, Sr57; reaction of 0-10MR) and Goblet (reaction of TR-5MR) which were released in the 1960s, showed variable resistant reactions (Table 3) and disease severity of 5 to 10%. Wheat varieties Morris which has a combination of Sr2, Sr57 and Sr58 genes showed a reaction of 5-30MS and 0-5MR during the two seasons testing period. Variety K. Tumbili which has a combination of Sr12 and Sr57 genes and a triticale T-238-1-5-8-17-10 parent showed a reaction of 10-15MR to stem rust infection. Although the genes in varieties Lenana (TR – 10MS), Yaqui (5-20MR), Kenya 6295-4A (5-20MR) and Tama B (5-10MR) have not been ascertained,

Table 3. Means of 21 (17.5%) of Kenyan wheat varieties evaluated for stem rust resistance in the field at KALRO-Njoro, Kenya over 3 seasons.

Variety[a]	Year of release	Final Disease severity (FDS)			Area Under Disease Progress Curve			
		Main season 2020	Off season 2021	Main season 2021	Main Season 2020	Off Season 2021	Main Season 2021	Mean
Robin[b]	2011	60MS-70S	40-60S	40MS-70S	440	742.5	820	667.5
Falcon (*Sr57*)	2016	TR-5M	10-15MR	5R-10MR	72.3	178.3	153.5	134.7
K. Kingbird[c] (*Sr2*, *Sr57, Sr58*)	2012	5MR-20M	15MR-30M	10-20MR	167.2	272.0	267.2	240.1
NjoroBWII (*Sr12*)	2001	15MS-50MS	20MS-50MSS	15MS-30MS	436.7	602.5	330.8	456.7
K. Tumbili (*Sr12*, *Sr57*)	1984	NA	15MR	10MR	-	140.8	119.7	130.3
K. Popo (*Sr12*	1982	10-20MR	TR-30MSS	10MS-10MR	107.5	329.5	157.2	198.0
K. Nyangumi (*Sr2*, *Sr12*, *Sr57*)	1979	0-5MS	-	-	76.0	-	-	76.0
K. Zabadi (*Sr12*, *Sr57*)	1979	5R-20MS	NA	TR-10MR	163.5		142.0	152.7
K. Swara	1972	TR-10MS	5MR-15MR	10MR	12.2	64.5	157.2	78.0
Gem	1964	TR-5MR	TR-10M	TR-5R	10.2	15.8	6.8	3.6
Mentor	1967	5M-5MR	TR-5MR	TR-10MR	107.2	9.1	119.7	78.6
K. Sungura	1969	0	0-5R	TR-15MR	0	27.7	81.8	54.8
K. Page (*Sr17*, *Sr2*)	1963	0	5-10MR	10-30MS	0	173.3	300.2	157.8
K. Leopard (*Sr2*, Sr58)	1966	5R	TR-10MR	0-5MR	109.8	179.5	62.2	117.2
K. Kudu (*Sr2, Sr58*)	1966	5M-10MR	10MR	10M	153.5	217.0	157.2	175.9
K. Civet (*Sr2, Sr12 Sr58, SR57)*	1966	0-5R	TR-10MR	0	2.70	173.3	0	88.0
K. Cheetah (*Sr12*,*57*)	-	0-10R	0-10M	TR-5R	49.7	84.1	30.2	54.7
Goblet	1967	NA	TR-5MR	5R	0.0	78.3	72.2	75.2
Morris (*Sr2, Sr57 Sr58*)	1964	NA	5-30MS	0-5MR	-	265.8	83.5	174.6
Lenana	1963	TR	5-10MR	5MR-10MS	-	159.5	157.2	158.3
Yaqui	1950	NA	5-20MR	5MS-10MR	382.3	265.8	156.8	268.3
Kenya 6295-4A	NA	TR	10-20MR	5MR	177.2	183.3	156.8	172.5
Tama B	NA	5M-5MR	5-10MR	5MR	29.7	148.3	81.8	86.7

[a]K .=Kenya; R=resistant, MR=moderately resistant, MRMS (M)=moderately resistant to moderately susceptible, MS=moderately susceptible, MSS=moderately susceptible to susceptible. [c]Resistant control for stem rust, and [b]Susceptible control for stem rust.
Source: Wanyoike et al. (2022).

they showed variable resistance at different magnitudes of disease reactions during the evaluation periods. Among the semi-dwarf varieties released in the 1970s, varieties K. Nyangumi (Sr2, Sr12, Sr57; 0-5MS), K. Zabadi (Sr12, Sr57; TR-20MS) and K. Swara (TR-15MR) showed a disease infection ranging from 0 to 20MS. Although the variety K. Swara showed good resistance against stem rust, it is necessary to determine the resistance gene present in this variety. Variety K. Popo released in 1982 displayed TR – 30MSS infection type with a high AUDPC value during the main seasons of 2020 and 2021. As mentioned earlier on, varieties Falcon (released 2016) and K. Kingbird (released 2012) which possess Sr57 and Sr2 genes respectively showed resistant reactions ranging from TR-20MR S in the field (Table 3).

DISCUSSION

In this study, significant variation due to season for AUDPC could be attributed to differences in variability of temperature and moisture. Mideksa et al. (2018) recorded that changes in atmospheric composition and the physical climate, including temperature, rainfall and humidity affected the economic importance, geographical distribution and management of stem rust of wheat in Ethiopia. The significant effects due to a variety in AUDPC values were due to the variation of genetic resistances and seasonal climatic conditions. Wheat varieties can exhibit varying levels of resistance to stem rust hence influencing disease progression and severity (Singh et al., 2011). Significant season × variety interaction observed for AUDPC showed that differential response of varieties to seasons resulting in disease response of the varieties being not consistent across the seasons. The interaction between variety × season accounted for the highest variation (55.21%) in the model and this could be due to the differential response of the varieties across the seasons for disease infection. The differential response of varieties to stem rust infection could be attributed to the variable seasonal weather conditions that favoured prevalence of different stem rust races.

The existence of such variation as noted in this study is often advantageous for breeders to enhance selection against stem rust disease infection. The observed variation in the final disease severity of stem rust reaction across the 3 seasons was also most likely due to seasonal variation caused by weather related factors coupled with the bimodal rainfall distribution that provided a green bridge between the seasons that could host the stem rust pathogen and assist the movement of primary inoculum from one crop to the next. The experimental site normally experiences warm temperatures of 21 to 25°C which can favour stem rust infection especially at the booting stage of wheat. Wheat tested during off season of 2021 showed higher stem rust infection compared to main season of 2020 and 2021 probably due to the buildup of inoculum from the previous season and the favourable weather conditions. The bimodal rainfall distribution of the area of the study provided a green bridge between two seasons that could host the pathogen and assist the movement of primary inoculum from one crop to the next. This condition enhanced the epidemic occurrence of stem rust during the off season of 2021. This allowed the rust pathogen to thrive on its host without interference from other plants and extended spore survival period into off season. The increase in the proportion of varieties exhibiting high disease severity of >30% among varieties released in the years 1990s and 2000s can be attributed to the varieties carrying fewer and less effective resistance genes compared to cultivars released in previous decades. The Kenyan wheat varieties released in the 1980s and 1990s are susceptible with an average disease severity of > 40% indicating a serious erosion of the resistance in the wheat varieties over time considering that breeding of these varieties was done in the absence of the predominant current stem rust races (Njau et al., 2009).

Varieties released during the 1960s and 1970s showed APR due to the presence of the *Sr2* complex which has been identified as an important source of *Sr* resistance. The effectiveness of gene *Sr2* is enhanced when it is in combination with other minor genes (McIntosh et al., 1995; Jackline et al., 2018). Variety K. Sungura showed low disease infection due to the presence of Thatcher which carries race-specific resistance genes Sr12, Sr16, Sr5, SrTc and Sr9g derived from parent Morris. Genes Sr12 and Sr16 from Thatcher contributed to field resistance providing APR to stem rust (Vanegas et al., 2008; Hiebert et al., 2016). Nazareno and Roelfs (1981) observed that lines possessing both Sr12 and SrTc exhibited better field resistance compared to those lacking both genes; however, gene expression against disease infection sometimes is not effective due to background effects.

In the current study, variety Leopard exhibited resistance with reactions ranging from 0-10 MR due to the presence of the *Sr57* gene tracked from *Lageadinho* which originated from *Frontana* as documented in the pedigree. The decline of the disease incidence among the varieties released in the 1990s can be attributed to a period of breeding wheat varieties with the absence of race non-specific stem rust races. In this study, varieties like *Heroe* and *Chozi* released in 1998 and *Duma* released in 1994 were susceptible, with an average disease infection of *40S* probably because they possess race-specific type of resistance. Njau et al. (2009) reported that varieties *Chozi* and *Duma* exhibited disease scores ranging from *30MS* to *60S* suggesting a decline in the resistance package of spring wheat germplasm over time particularly when breeding was done in the absence of some races. In this study, variety *Goblet* showed a moderately susceptible response to stem rust during the main season of 2020 possibly due to the presence of *Sr*6, *Sr11* and *Sr9g* genes tracked back to *Gabo-54* and *Lerma 52*. The expression of resistance conferred by gene *Sr6* is often affected by temperature and background (Watson and Luig, 1968). Ydyrys et al. (2020) observed that gene *Sr11* was ineffective as demonstrated by a reaction of 50MS and an AUDPC of 607.5 on a Kazakhstan isogenic line. Variety *K. Civet* and *K. Page* exhibited MR to S reactions probably due to the presence of genes from *Kenya-354* tracked to *Warigo*/*Sterling* and *Page*, respectively carrying *Sr2*, *Sr17* and *Sr7b* genes. Gene *Sr17* is temperature sensitive and is only effective against stem rust at low temperatures but when the temperature is higher than 25°C, the resistance becomes ineffective (Sun et al., 2023). In addition, variety *K. Kudu* exhibited a stem rust reaction of 10S probably due to the presence of *Sr5*, *Sr16*, *Sr18*, *Sr42* and *Sr7b* genes derived from *Kenya-184-P*. The *Sr16* gene was reported to be ineffective against *Ug99* variant races (Jin et al., 2007) and gene *Sr7b* which also originates from wheat cultivars confers resistance to the races that are dominant in Australia but not to *Ug99* races that are predominant in Kenya.

Based on the findings of this study, wheat varieties displaying AUDPC values of less than 300 were characterized as partially resistant. This is in line with Wanyoike et al. (2022) and Singh et al. (2015) who reported that AUDPC is the most effective parameter for identifying resistant cultivars against stem rust because it considers the progression in the severity of infection of a variety within a given time period. Variety K. Nyangumi, K. Zabadi and K. Swara released in 1970 were resistant likely due to the presence of tracked genes Sr2 and Sr57 from Tezanos-Pintos-Precoz, Tobari 66 in their pedigree. Wanyoike et al. (2022) observed that K. Nyangumi, K. Zabadi and K. Swara despite being susceptible to yellow rust that is caused by a fungal pathogen *Puccinia striiformis*, also known as the stripe rust of wheat, these varieties displayed low AUDPC values ranging from 19.8 to 34.5. Gene *Sr57* increases the duration of the latent period and reduces the number and size of *uredinia* at post-seedling stages (Singh et al., 2005). Variety *K. Popo* possessing genes *Sr2*, *Sr6*, *Sr57*, *Sr11*, and *Sr15* tracked from *Tobari*-66, showed susceptibility during seasons 1 and 3 probably due to the presence of race-specific and temperature-sensitive genes *Sr6*, *15*, and *11*. Gene *Sr15* located on chromosome 7AL, is ineffective at temperatures above 26°C (Gousseau, 1985). Furthermore, the uncharacterized nature of a significant portion of the population's APR resistance arises from the masking of major genes and the quantitative nature of APR genes (Merrick et al., 2021).

In this study, Kingbird showed a moderate level of resistance ranging from TR to 20MS over 4 seasons suggesting to presence of resistance alleles. Merrick et. al. (2021) also observed that Kingbird was moderately resistant with scores ranging from 5M to 20M over 3 seasons associated with APR genes Sr2, Sr57 and Sr58. This also aligns with Bhavani et al. (2011) findings, which highlight the additive effects of Sr2, Sr57 and Sr58 genes involved in stem rust resistance in Kingbird.

Conclusion

The breeding of resistant cultivars is the most cost-effective and eco-friendly strategy to protect wheat from stem rust. In this study, resistance to *Pgt* of old and new Kenyan wheat varieties was evaluated at the adult plant stage using their final severities to the disease and their respective AUDPC values. The results indicate that old Kenyan wheat varieties, *Mentor*, *K. Sungura* and *K. Leopard* that were released in the 1960s exhibited adult plant resistance which could be associated with the presence of APR genes. These varieties may be used in breeding for durable resistance to stem rust in combination with other major genes. Varieties *Gem*, *K. Page*, *K. Kudu*, *K. Civet* and *Goblet* released in the 1960s, and evaluated with a moderately resistant to a susceptible reaction could be of value in stem rust management strategies. These lines could be exploited as donor parents in wheat breeding programmes to develop high-yielding and stem rust disease-resistant wheat varieties. Wheat varieties released in the 2000s mainly consisting of *Sr 24* and *Sr 31* in their genetic makeup, displayed susceptible reactions due to the breakdown of these genes as a result of the evolving new and virulent races of stem rust such as *TTKTT* and *TTKTT+*. APR is effective in reducing disease severity leading to more resistant lines progressively. There is progress in resistance to stem rust through the utilization of APR genes in rust management in wheat. The use of race-specific types of resistance solely should be avoided to minimize epidemics, considering that in many cases their expression is highly modified by environmental factors, especially temperature. Based on the gene tracking from the pedigrees, varieties *Morris*, *Lenana*, *K. Tumbili*, *Yaqui*, *Kenya 6295-4A* and *Tama B* were resistant and may be possessing unknown stem rust-resistant genes hence require genotyping to determine the specific *Sr* genes carried in these varieties.

ACKNOWLEDGEMENTS

This study was financially supported by the International Maize and Wheat Improvement Centre (CIMMYT) through the AGG project in collaboration with the Kenya Agricultural and Livestock Research Organization (KALRO), Njoro.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abou-Zeid AM, Abd El-Hamed AS, Abd El-Wahab, MMH (2018). Evaluation of new wheat genotypes with genetic diversity for stem rust resistance and some yield components under Egyptian field conditions. Egyptian Journal of Plant Breeding 22:849-871.

Ambika R, Meenakshi D (2018). Wheat stem rust race Ug99: A shifting enemy. International Journal of Current Microbiology and Applied Sciences 7(1):1262-1266.

Bhavani S, Singh RP, Argillier O, Huerta-Espino J, Singh S, Njau P (2011). Mapping of durable adult plant stem rust resistance in six CIMMYT wheats to Ug99 group of races. In: Oral presentation. BGRI. Tech. Work., (McIntosh, R.A. ed), 13(16):43-53.

Bhavani S, Hodson DP, Huerta-Espino J, Randhawa MS, Singh RP (2019). Progress in breeding for resistance to Ug99 and other races of the stem rust fungus in CIMMYT wheat germplasm. Frontiers of Agricultural Science and Engineering 6(3):210-224.

Brinton J, Uauy C (2019). A reductionist approach to dissecting grain weight and yield in wheat. Journal of Integrative Plant Biology, 61(3):337-358.

Comstock RE, Moll RH (1963). Genotype-environment interactions. Statistical Genetics and Plant Breeding 982:164-196.

Cook RJ, Hims MJ, Clark WS, Stevens DB (1995). Fungicides for Controlling Leaf Diseases of Winter Wheat: Evaluation, Timing and Importance of Varietal Resistance. Project Report 103. Highgate Hill, London, UK: Home-grown Cereals Authority.

Cormier F, Faure S, Dubreuil P, Heumez E, Beauchêne K, Lafarge S. Le Gouis J (2013). A multi-environmental study of recent breeding progress on nitrogen use efficiency in wheat (*Triticum aestivum* L.). Theoretical and Applied Genetics 126:3035-3048.

Crespo-Herrera LA, Crossa J, Huerta-Espino J, Autrique E, Mondal S, Velu G (2017). Genetic yield gains in CIMMYT's international elite spring wheat yield trials by modelling the genotype × environment interaction. Crop Science 57:1-13.

Dean R, Van Kan JA, Pretorius Z, Hammond-Kosack KE, Di Pietro A, Spanu PD, Foster GD (2012). The Top 10 fungal pathogens in molecular plant pathology. Molecular Plant Pathology 13 (4):414-430.

DePauw RD, Buchannon KW (1975). Post-seedling response of wheat to stem rust. Canadian Journal of Plant Science, 55(2):385-390.

Dixon GE (1969). A review of wheat breeding in Kenya. Euphytica 9(2):209-221.

Ellis JG, Lagudah ES, Spielmeyer W, Dodds PN (2014). The past, present and future of breeding rust resistant wheat. Frontiers in Plant Science 5:641.

Evans LE, Martens JW, Green, GJ, Hurd EA (1969). Sources of resistance to wheat stem rust in East Africa. Canadian Jounal of Plant Science. 49(6):649-654.

Fetch TG, Zegeye T, Park RF, Hodson D, Wanyera R (2016).

Detection of wheat stem rust races TTHSK and PTKTK in the Ug99 race group in Kenya in 2014. Plant Disease 100:1495-1495.

Fetch TG, Park RF, Pretorius ZA, Depauw RM (2021). Stem rust: its history in Kenya and research to combat a global wheat threat. Canadian Jounal of Plant Pathology. 43:S275-S297.

Figlan S, Baloyi TA, Hlongoane T, Terefe TG, Shimelis H, Tsilo TJ (2017). Adult plant resistance of selected Kenyan wheat cultivars to leaf rust and stem rust diseases. Cereal Reseach Communications, 45(1):68-82.

Gilchrist-Saavedra L, Fuentes-Dávila G, Martínez-Cano C, López-Atilano R M, Duveiller E, Singh RP, Henry M, García A (2006). Practical guide to the identification of selected diseases of wheat and barley.2nd Edition. Mexico,pp.12-15.

Gousseau HDM, Deverall BJ, McIntosh RA (1985). Temperature-sensitivity of the expression of resistance to Puccinia graminis conferred by the Sr15, Sr9b and Sr14 genes in wheat. Physiological Plant Pathology 27(3):335-343.

Hiebert CW, Kolmer JA, McCartney CA, Briggs J, Fetch T, Bariana H, Spielmeyer W (2016). Major gene for field stem rust resistance co-locates with resistance gene Sr12 in 'Thatcher'wheat. PloS one. 11(6):e0157029.

Huerta-Espino J, Singh R, Crespo-Herrera LA, Villaseñor-Mir HE, Rodriguez-Garcia MF, Dreisigacker S, Lagudah E (2020). Adult plant slow rusting genes confer high levels of resistance to rusts in bread wheat cultivars from Mexico. Frontiers in Plant Science 11:824.

Jackline TE, Njoka FM, Ombori O. Njau PN (2018). Introgression of stem rust resistance into popular Kenyan wheat varieties to improve production.Journal of Advances in Biology and Biotechnology 17(1):1-11.

Jaetzold R, Hornetz B, Shisanya CA, Schmidt H (Eds., 2005-2012): Farm Management Handbook of Kenya. -Vol. I-IV (Western, Central, Eastern, Nyanza, Southern Rift Valley, Northern Rift Valley, Coast), Nairobi. Farm Management of Kenya, Vol. 11C: National Conditions and Farm Management Information. East Kenya (Eastern and Coast Provinces). Farm Management Branch, Ministry of Agriculture, Nairobi, Kenya.

Jin Y, Singh RP, Ward RW, Wanyera, R, Kinyua M, Njau P, Fetch T, Pretorius ZA, Yahyaoui A (2007). Characterization of Seedling Infection Types and Adult Plant Infection Responses of Monogenic Sr Gene Lines to Race TTKS of Puccinia graminis f. sp. tritici. Plant disease 91(9):1096-1099. https://doi.org/10.1094/PDIS-91-9-1096

Knott DR (1982). Multigenic Inheritance of Stem Rust Resistance in Wheat 1. Crop Science 22(2):393-399.

Knott DR (1988). Using polygenic resistance to breed for stem rust resistance in wheat, pp. 39-47. In: Breeding strategies for resistance to the rusts of wheat (Simmonds, N.W. and Rajaram, S. ed.). CIMMYT, Mexico.

Kolmer JA (2005). Tracking wheat rust on a continental scale. Current opinion in plant biology 8(4):441-449. https://doi.org/10.1016/j.pbi.2005.05.001

Macharia JK, Wanyera R (2012). Effect of stem rust race Ug99 on grain yield and yield components of wheat cultivars in Kenya. Journal of Agriculture, Science and Technology 2:423-431.

Madden LV, Hughes G, Van den Bosch F. (2007). The study of plant disease epidemics. St Paul: APS Press.

McIntosh RA, Wellings CR, Park RF (1995). Wheat rusts and the genetic bases of disease resistance, pp 1-5. In: Wheat Rusts an Atlas of Resistance Genes (Cloud-Guest, A. ed.). CSIRO, Australia.

McIntosh RA, Dubcovsky J, Rogers J, Morris C, Xia XC (2017). Catalogue of gene symbols for wheat. Available at: https://shigen.nig.ac.jp/wheat/komugi/genes/macgene/supplement 2017.pdf.

Merrick LF, Burke AB, Chen X, Carter AH (2021). Breeding with major and minor genes: genomic selection for quantitative disease resistance. Frontiers in Plant Science,12:713667.

Mideksa T, Fininsa C, Hundie B 2018. Analysis of climate variability effects on wheat stem rust (Puccinia graminis f. sp. tritici) epidemics in bale and arsi zones of Oromia regional state, Ethiopia. American Journal of Biological and Environmental Statistics 4:49-65.

Nazareno NRX, Roelfs AP (1981). Adult plant resistance of Thatcher wheat to stem rust. Phytopathology. 71:181-185.

Newcomb M, Olivera PD, Rouse MN, Szabo LJ, Johnson J, Gale S, Luster DG, Wanyera R, Macharia G, Bhavani S, Hodson D, Patpour M, Hovmoller MS, Fetch TG, Jin, Y (2016). Kenyan isolates of Puccinia graminis f. sp. tritici from 2008 to 2014: Virulence to SrTmp in the Ug99 race group and implications for breeding programs. Phytopathology 106(7):729-736. doi: 10.1094/PHYTO-12-15-0337-R.

Njau PN, Jin Y, Huerta-Espino J, Keller B, Singh RP (2010). Identification and evaluation of sources of resistance to stem rust race Ug99 in wheat. Plant Disease. 94(4):413-419.

Njau PN, Wanyera R, Macharia GK, Macharia J, Singh R, Keller B (2009). Resistance in Kenyan bread wheat to recent Eastern African isolate of stem rust, Puccinia graminis f. sp. tritici, Ug99. Journal of Plant Breeding and Crop Science 1(2):22-27.

Oggema MW (1972). The genetics of resistance to Puccinia graminis tritici in eight wheat varieties from Kenya. Doctor of Philosophy in Plant science. The university of Minitoba.

Oliver RP (2014). A reassessment of the risk of rust fungi developing resistance to fungicides. Pest management science, 70(11):1641-1645.

Ortiz R, Reslow F, Cuevas J, Crossa J (2022). Genetic gains in potato breeding as measured by field testing of cultivars released during the last 200 years in the Nordic Region of Europe. Journal of Agricultural Science 160(5):310-316.

Peterson RF, Campbell AB, Hannah AE (1948). A diagrammatic scale for estimating rust intensity of leaves and stem of cereals. Canadian Journal of Research 26:496-500. doi: 10.1139/cjr48c-033.

Pretorius ZA, Singh RP, Wagoire WW, Payne TS (2000). Detection of virulence to wheat stem rust resistance gene Sr31 in Puccinia graminis f. sp. tritici in Uganda.Plant Disease 84:203. doi: 10.1094/PDIS.2000.84.2.203B.

Pinto FF, Hurd EA (1970). 70 years with wheat in Kenya. East African Agricultural and Forestry Journal 36:24.

SAS Institute (2010). SAS® user's guide: Statistics version 9.2 for windows. SAS Institute, Carry NC.

Shaner G, Finney RE (1977). The Effect of nitrogen fertilization on the expression of slowmildewing resistance in knox wheat. Phytopathology, 1977:67:10511056.

Singh RP, Hodson DP, Huerta-Espino J, Jin Y, Bhavani, S, Njau P, Herrera-Foessel S, Singh PK, Singh S, Govindan V (2011). The emergence of Ug99 races of the stem rust fungus is a threat to world wheat production. Annual Review of Phytopathology 49:465-81. doi: 10.1146/annurev-phyto-072910-095423.

Singh RP, Hodson DP, Jin Y, Lagudah ES, Ayliffe MA, Bhavani S, Rouse MN, Pretorius ZA, Szabo LJ, Huerta-Espino J (2015). Emergence and spread of new races of wheat stem rust fungus: continued threat to food security and prospects of genetic control. Phytopathology, 105:872-884.

Singh RP, Huerta-Espino J, William HM. (2005) Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. Turkish Journal of Agriculture and Forestry, 29:121-127.

Slafer GA Andrade FH (1989). Genetic improvement in bread wheat (Triticum aestivum) yield in Argentina. Field Crop Research 21(3-4):289-296.

Soko T, Bender CM, Prins R, Pretorius ZA (2018). Yield loss associated with different levels of stem rust resistance in bread wheat. Plant Dis. 102:2531–2538.

Stuthman DD, Leonard KJ, Miller-Garvin J (2007). Breeding crops for durable resistance to disease. Advances in Agronomy, 95:319-367.

Sun H, Wang Z, Wang R, Chen S, Ni X, Gao F, Li T (2023). Identification of wheat stem rust resistance genes in wheat cultivars from Hebei province, China. Frontiers in Plant Science 14:1156936.

Tukey JW (1949). Comparing individual means in the analysis of variance. Biometrics, pp 99-114.

Vanegas CDG, Garvin DF, Kolmer JA (2008). Genetics of stem rust resistance in the spring wheat cultivar Thatcher and the enhancement of stem rust resistance by Lr34: Stem rust resistance in TcLr34. Euphytica, 159:391-401.

Wanyera R, Kinyua MG, Jin Y, Singh RP (2006). The spread of stem rust caused by Puccinia graminis f. sp. tritici, with virulence on Sr31 in wheat in Eastern Africa. Plant Disease 90(1):113-113.

Wanyera R, Wamalwa M, Odemba M, Wanga H, Kinyanjui P, Onyango V, Owuoche J (2016). Management of wheat rusts at different growth stages using Nativo 300 SC (trifloxystrobin 100 g/L+ tebuconazole

200 g/L) fungicide. Australian Journal of Crop Science 10(9):1273-1280.

Wanyoike GW, Owuoche JO, Charimbu MK, Macharia G, Randhawa, MS (2022). Evaluation of Kenyan wheat (Triticum aestivum L.) cultivars for rust resistance, yield and yield components. Australian Journal of Crop Science 16(5):587-595.

Watson IA, Luig NH (1968). Progressive increase in virulence in Puccinia graminis f. sp. tritici. Phytopathology, 58(3), pp 70-73.

Ydyrys A, Sarbaev A, Morgounov A, Dubekova S, Chudinov V (2020). Isogenic Lines: Reaction to the Kazakhstan Population of Stem Rust (Puccinia graminis f. sp. tritici). AGRIVITA, Journal of Agricultural Science, 43(1):221-232.

Zadoks JC, Chang TT, Konzak CF (1974). A decimal code for the growth stages of cereals. Weed Research 14(6):415-421.

Supplementary Table 1. List of Kenyan wheat cultivars release since 1940 to 2016 that were used in the study.

No.	Variety[a]	Origin	Pedigree	Year of release
1	Kasuku	Kenya	LG3-ST2×LD.379×LD.357	2021
2	K. Hyrax	Kenya	-	2018
3	K. Pelican	Kenya	KSW/5/2*Altar84/Ae.Aquarrosa(221)//3*Borl95/3/Ures/Jun/Kauz/4/WBLL1	2016
4	K. Songbird	Kenya	KSW/5/2*Altar84/Ae.Squarrosa(221)//3*Borl95/3/Ures/Jun/Kauz/4/WBLL1	2016
5	Falcon	Kenya	KSW/5/2*Atlar84/Ae.Squarrosa(221)//3*Borl95/3/Ures/Jun/Kauz/4/WBLL1	2016
6	Peacock	Kenya	Quaiu/3/Pgo/Seri/Bav92	2016
7	Weaverbird	Kenya	Prinia/3/Altar84/Ae.Sq//2*Opata/4/Chen/Aegilops Squarrosa(TAUS)//BCN/3/BAV92	2016
8	K. Deer	Kenya	PBW343*2/Kukuna*2//Yanac	2016
9	Hornbill	Kenya	Pastor//Hxl7573/2*Bau/3/Sokoll/WBLL1	2016
10	K. Tai	Kenya	ND643/2*WBLLI	2012
11	K. Sunbird	Kenya	ND643/2*WBILL1	2012
12	K. Wren	Kenya	Thelin#2/Tukuru	2012
13	K. Korongo	Kenya	Babax/Lr42//Babax*2/4/SNI/Trap#1/3kauz*2/Trap//Kauz	2012
14	K. Kingbird	Kenya	TAM-200/TUI/6/PAVON-76//CAR-422/Anahuac-75/5/Bobwhite/Crow//Buckbuck/Pavon-76/3/Yecora-70/4/Trap-1	2012
15	K. Hawk12	Kenya	URES/JUN//KAUZ/3/Babax/4/Tilhi	2012
16	Eagle10	Kenya	EMB16/CBRD//CBRD	2011
17	Robin	Kenya	Babax/Lr42//Babax*2/3/Tukuru	2011
18	K. Ibis	Kenya	Kwale/Duma	2008
19	Njoro BWII	Kenya	IAS-58/4/Kalyansona/Bluebird//Cajeme-71/3/Alondra/5/Bobwhite	2001
20	Yombi	Kenya	Mbuni/SRPC-64//YRPC-5	1998
21	Heroe	Kenya	Mbuni/SRPC-64//YRPC-1	1998
22	Chozi	Kenya	F-12-71/Cocoraque-75//GenaRO-81	1998
23	Mbega	Kenya	Bonanza/Yecora-70/3/F-35-75//Kalyansona/Bluebird	1993
24	Duma	Kenya	Avrora/UP-301//Gallo/Super-X/3/Pewee/4/Maipo/May74//Pewee	1993
25	K. Ngamia	-	Bucky/Maya-74/4/Bluebird//HD-832/Olesens-Dwarf/3/Ciano-67/Penjamo-J62	1993
26	K. Chiriku	Kenya	KTB/(SIB)Carpintero	1989
27	Pasa	-	Buckbuck/Chat	1989
28	Kwale	Kenya	Kavkaz/Tanori-71/3/Maya-74 (Sib)//Bluebird/INIA-66	1987
29	K. Kongoni	Kenya	CI-8154/2*Frocor//3*Romany/4/Wisconsin-245/II-50-17/CI-8154//2*Frocor/3/Tobari-66	1981
30	K. Popo	Kenya	Klein-Atlas/Tobari-66//Centrifen/3/Bluebird/4/Kenya-Fahari	1982
31	K. Kulungu	Kenya	-	-
32	Mbuni	Kenya	Zaragoza-75/3/LD-357-E/Thatcher//Gallo	1987
33	Paa	Kenya	Kavkaz/3/Ciano-67/Chris//Olesens-Dwarf	1981
34	K. Tumbili	Kenya	Ktb/Giza-155//Nadadores-63/T-238-1-5-8-17-10/3/Klein-Atlas/Tobari-66//Centrifen/Bluebird	1984
35	K. Zabadi	Kenya	Correcaminos/Inia-67//K-4500-2/3/Kenya-Swara//Tobari-66/Ciano-67	1979
36	K.Nyangumi	Kenya	Tezanos-Pintos-Precoz//Selkirk-Enano*6/Lerma-Rojo-64/3/Africa-Mayo-48/4/Kenya-Swara/Kenya-4500	1979

Supplementary Table 1. Contd.

37	K. Ngiri	Kenya	CI8154/2*FROCOR//5*WRT.TC/3/ 2*TOBARI 66	1979
38	K. Kanga	Kenya	MENCO/3/WIS245/SUP.51//2*F1/F/Y K4496.L.5.A.A	1970
39	K. Fahari	Kenya	TOBARI 66//SRPC572/CI.8154/ 2*FROCOR/3/3*TOBARI 66	1977
40	K. Kifaru	Kenya	Wisconsin-245/II-50-17//CI-8154/2*Frocor/3/3*Tobari-66	1976
41	K. Tembo	Kenya	WIS245/11-50-17//CI8154/2*FROCOR/3/ 2*TOBARI 66	1975
42	K. Nyoka	Kenya	CI8154/2*FROCOR//3*ROMANY	1975
43	K. Nungu	Kenya	WIS.245/II-50-17//C18154/2*FR/3/2*TOB.66	1975
44	K. Paka	Kenya	WIS245/11-50-17//CI8154/2*FROCOR/3/ 2*TOBARI 66	1975
45	K. Mbweha	Kenya	CI-8154/2*FROCOR/3/2*GABO-54/ 36896//II-53-526	1974
46	K. Nyati	Kenya	Africa Mayo/2*Romany	1973
47	K. Swara	Kenya	CI-8154/2*FROCOR/3/TIMSTEIN/ 2*KENYA//Y-59.2.B	1972
48	Romany	Mexico	Colotana-262-51/Yaktana-54-A	1966
49	K.Sungura	Kenya	ID-1877/Morris,Kenya-4365-B4D5	1969
50	1061. K.4	-	MIDA // MCMURACHY / EXCHANGE /3/ RIO NEGRO	1969
51	Trophy	Kenya	Timstein/2*Kenya-RF-324//2*Yaqui-50	1968
52	Beacon-Ken	Kenya	Frontana//Kenya-58//Newthatch/3/3*Bonza	1968
53	Gizza 155	Egypt	-	-
54	Bonny	-	Y53×BZA^2	1967
55	Mentor	Australia	NA	1967
56	Goblet	Kenya	Gabo-54/Lerma-52//Gabo/3/Kenya/General-Urquiza	1967
57	TokenKen	-	Timstein/2*Kenya-RF-342//2*Yaqui-50	1966
58	Bounty	Kenya	Timstein/2*Kenya-RF-324//Bonza-55	1966
59	K. Kudu	-	Kenya-131/Kenya-184-P	1966
60	K. Jay	-	Equator×318 384/5.BJ.6.B.1.	1962
61	K.Leopard	Kenya	Lageadinho/3*Kenya-354-P//CI-12632/3*Kenya-354-P	1966
62	K. Grange	-	Kenya-360-F×Granadero-Klein	1966
63	K. Civet	Kenya	CI-12632/3*Kenya-354-P	1966
64	K. Plume	Kenya	MME×Kenya 184-P	1966
65	Fanfare	-	Frocor-Frontana ×Yaqui	1964
66	Gem	-	BT908/Frontana//Cajeme 54	1964
67	K. Hunter	Kenya	EqII ×318.0.3.B.22 ×(Hope-Timstein)×Regent 869.B.4.C.1.	1964
68	Brewster	-	(H58-TC2)× Frontana-Thatcher4	1964
69	Fronthatch	Kenya	FRONTANA / KENYA58 // NEWTHATCH	1964
70	Salmayo	-	Salles/Mcmurachy//Mayo-48	1963
71	Tama	Kenya	Yaktana-54/Lerma-52	1963
72	K. Page	Kenya	(Mentana-Kenya 58× Page)	1963
73	Africa Mayo	Mexico	Africa/Mayo-48	1960

Supplementary Table 1. Contd.

74	K-362-B-1-A	Kenya	EQUATOR × 294M	1956
75	K. Farmer	Kenya	Australian 27×192 Q 338.AC.2.E.2.	1954
76	Impala	S.Africa	NA	1957
77	Yaqui	Mexico	NEWTHATCH/MARROQUI-588	1950
78	K-184-P	Kenya	RELIANCE/KENYA-73-D	1951
79	K. Ploughman	Kenya	DC×CERES 721×112E 318.0.3.B.2.	1950
80	Rhodesian Sabanaro	-	Single Plant Sel.	1949
81	K-294-B-2A-3	Kenya	AUSTRALIAN-26-A/KENYA-117-A	1948
82	Kentana 48	-	KENYA-C-9906/MENTANA	1948
83	Kenya 131	Kenya	A.8 × FLORENCE	1939
84	Kenya 58	Kenya	NA	-
85	K. Standard	Kenya	NA	1930
86	K. Governor	Kenya	NA	-
87	Equator	-	A field selection	1920
88	K. Cheetah	Kenya	Warigo/Sterling	NA
89	Catcher	-	Thatcher/Santa- Catalina //Frocor	1963
90	Kenya 8	-	NA	NA
91	Kenya 7	-	NA	NA
92	Menco	-	Mentana/Kenya//Frontana/Cinco	1963
93	Morris	-	Thatcher//Kenya117a/Mida/3/Frontana/4*Thatcher/4/Thatcher/5/Frontana/4*Thatcher	1964
94	Reliance 261 M	-	RELIANCE / KENYA 68	-
95	Lenana	-	Yaqui- 48/Kentana-48	1963
96	K. Simba	-	PARULA/VEERY #6//MYNA/VULTURE	2000
97	K318-AJ-4A-1	-	KENYA-112/CERES	-
98	K 256 G	-	NA	-
99	Fury	Kenya	FROCOR/MENTANA/KENYA-2/MCMURACHY/YAQUI-50	1964
100	K117DA	-	MARQUIS×A.8	1939
101	K. Kunguru	-	NA	NA
102	Kenya 155	Kenya	NA	NA
103	K. Waren	Kenya	NA	NA
104	Supremo	Ethiopia	NA	NA
105	Kenya 6295-4A	-	NA	NA
106	K 6290 B	-	NA	NA
107	Kenya 6820	-	NA	NA
108	K324	-	NA	NA
109	K7B 58	-	NA	NA
110	Jacana	Kenya	NA	NA

Supplementary Table 1. Contd.

111	B192	-	NA	NA
112	K122	-	NA	NA
113	Kenya 5	-	NA	NA
114	Tama B	-	NA	NA
115	Tobari 66	Mexico	TEZANOS-PINTOS-PRECOZ/SONORA-64-A	1966
116	CI 14393	-	NA	NA
117	R64	-	NA	NA
118	K360H	-	NA	NA
119	K6106-8	-	NA	NA
120	Kenya KBB	Kenya	NA	NA

aK= Kenya, NA=Not available.
Source: http://wheatatlas.org/varieties.

Supplementary Table 2. Bread wheat cultivars released at different times that exhibited variable levels of resistance to stem rust at the adult stage at KALRO-Njoro, Kenya over four seasons and the postulated genes they may contain.

Variety[a]	Year of release	Country	Final disease severity			Area under disease progress curve (AUDPC)			Postulated genes
			Main season 2020	Off season 2021	Main season 2021	Main season 2020	Off season 2021	Main season 2021	
Kasuku	2021	Kenya	NA	5M-10MS	10MS-60S	NA	130	820	
K. Hyrax	2018	Kenya	NA	0-5M	10-20MS	NA	177.5	222.5	
K. Pelican	2016	Kenya	TR-10MS	5MR-5MS	20MS-50MS	130	75	480	*Sr12*, *Sr57*
K. Songbird	2016	Kenya	TR-20MSS	20M-30M	30-40MS	165	282.5	560	Sr12
Falcon	2016	Kenya	TR-20MS	TR-5M	10-15MR	200	87.5	167.5	*Sr57*
Peacock	2016	Kenya	TR-30S	TR	20MS-40S	385	0	445	*Sr2*, *Sr57*
Weaverbird	2016	Kenya	5MS-40S	TR-5MR	20MS-60S	235	17.5	860	*Sr2*, *Sr57*
K. Deer	2016	Kenya	TR-40S	5MR-5MS	10-20MR	310	57.5	300	
Hornbill	2016	Kenya	TR-10MS	5M-20M	30-70S	130	187.5	595	*Sr12*, *Sr57*
K. Tai	2012	Kenya	5MR-20MS	5MR-5MS	10MS	240	127.5	*NA*	
K. Sunbird	2012	Kenya	5MR-40MS	5MS-10MS	10-30MS	310	112.5	295	Sr12
K. Wren	2012	Kenya	5MR-20MS	20MS-30MS	30MS-50S	165	340	745	
K. Korongo	2012	Kenya	5R-40MSS	10MS-30MS	40-70S	385	370	895	*Sr12*, *Sr57*
K. Kingbird	2012	Kenya	TR-20MR	TR-5MR	10-15MR	127.5	122.5	205	
K. Hawk12	2012	Kenya	5MS-20MSS	5MR-10MR	10MS-30S	295	95	410	Sr12
Eagle10	2011	Kenya	5MR-40MSS	5M-5MR	20MR-40S	460	92.5	445	Sr12
Robin	2011	Kenya	10MS-50MSS	60MS-70S	40-60S	440	742.5	820	Sr12
K. Ibis	2008	Kenya	0-TR	TR-5MR	30-60S	0	247.5	820	-
Njoro BWII	2001	Kenya	0-10MR	NA	20MS-40S	72.5	17.5	560	*Sr12*

Supplementary Table 2. Contd.

Yombi	1998	Kenya	TR-20S	NA	-	165	NA	NA	*Sr12*, *Sr57*
Heroe	1998	Kenya	TR-10MS	20M-30M	10MS-40S	35	282.5	445	*Sr57*
Chozi	1998	Kenya	TR-10MSS	5-10MR	30MS-50S	72.5	165	595	*Sr12*
Mbega	1993	Kenya	TR-5MR	10MS-40MS	30-60S	17.5	300	745	-
Duma	1993	Kenya	TR-10MSS	5MS-10MS	10-40S	165	180	445	*Sr57*
K. Ngamia	1993	-	TR	TR-10M	10-20MS	0	35	260	*Sr12*
K. Chiriku	1989	Kenya	TR-5MS	NA	10MS-60S	75	0	670	*Sr12*, *Sr57*
Pasa	1989	-	TR-5MS	NA	15-30MS	17.5	0	335	-
Kwale	1987	Kenya	0-10MR	0-TR	10-MS	130	17.5	185	*Sr2*, *Sr12*
K. Kongoni	1981	Kenya	5MR-20MSS	10MR-15M	15MS-40S	240	132.5	560	*Sr2*, *Sr57*,
K. Popo	1982	Kenya	TR-30MSS	TR	10-20MR	420	35	300	*Sr12*,
K. Kulungu	1982	Kenya	TR	NA	-	0	70	-	-
Mbuni	1987	Kenya	5MR-20MS	0	10-20MR	185	35	260	-
Paa	1981	Kenya	TR-50MS	5M-5MR	10-20MS	232.5	57.5	260	-
K. Tumbili	1984	Kenya	TR-40MS	NA	5-20MR	330	17.5	300	*Sr12*, *Sr57*
K. Zabadi	1979	Kenya	TR-20MS	NA	5MR	165	NA	75	-
K. Nyangumi	1979	Kenya	TR-5MS	0-5MR	-	92.5	17.5	NA	-
K. Ngiri	1979	Kenya	TR-20MSS	TR-10M	15-20MR	165	125	280	*Sr57*
K. Kanga	1977	Kenya	TR-20MS	NA	-	165	NA	NA	-
K. Fahari	1977	Kenya	TR-10M	TR-5MR	20-30MS	92.5	17.5	335	-
K. Kifaru	1977	Kenya	5MR-20MSS	5M-5MR	10-40MS	165	162.5	370	*Sr2*, *Sr12*
K. Tembo	1975	Kenya	5MR-10MR	0-5MR	10-30MS	92.5	17.5	370	-
K. Nyoka	1975	Kenya	NA	5M-5MR	30MS-60S		57.5	-	-
K. Nungu	1975	Kenya	TR-20MS	5-10MR	10MS-40S	165	75	560	-
K. Paka	1975	Kenya	TR-10MS	5M-5MR	20-30MS	92.5	57.5	335	*Sr12*, *Sr57*
K. Mbweha	1974	Kenya	5MS 10MSS	5MS-20MS	20MS-50S	165	187.5	710	-
K. Nyati	1973	Kenya	5M-30MSS	NA	-	295	NA	NA	*Sr2*, *Sr12*
K. Swara	1972	Kenya	TR-10MS	TR-5MR	TR	130	17.5	0	-
Romany	1970	Mexico	TR	NA	-	0	0	-	*Sr5*, *Sr6*,*Sr7a*, *Sr30*
K. Sungura	1969	Kenya	TR-10MR	0	0-TR	150	0	0	-
1061 K4	1969	-	NA	5MS-20MS	20-40MS	NA	167.5	635	-
Trophy	1968	Kenya	TR-20MS	TR	TR-15MR	107.5	0	205	-
Beacon-Ken	1968	Kenya	TR-20MR	5M-5MR	TR-10MR	185	57.5	150	*Sr2*, *Sr12*, *Sr57*
Gizza 155	1968	Egypt	5MS-20MSS	5MR-20MR	5MS-40S	185	240	255	-
Bonny	1967	-	TR-10MR	20M-30M	40MS-70S	35	370	855	-
Mentor	1967	Australia	TR-10MR	5M-5MR	TR-5MR	110	57.5	75	-
Goblet	1967	Kenya	TR-20MS	NA	TR-5MR	260	0	55	-
Token- Ken	1966	-	5MR-20MS	TR	5MS-10MR	127.5	35	150	-

Supplementary Table 2. Contd.

Bounty	1966	Kenya	10MR-30M	NA	-	295	70	-	*Sr2*, *Sr12*, *Sr57*
K. Kudu	1966	-	TR-10S	5M-10MR	10MR	130	95	150	-
K. Jay	1966	-	NA	NA	-	-	-	-	-
K. Leopard	1966	Kenya	TR-10MR	TR	TR-10MR	72.5	0	150	-
K. Grange	1966	-	NA	NA	-	-	0	-	-
K. Civet	1966	Kenya	TR-20MS	0-TR	TR-10MR	145	0	150	*Sr57*
K. Plume	1965	Kenya	10MS-30MSS	NA	-	295	NA	NA	*Sr2,Sr6,Sr7a,Sr8a,Sr12, Sr17*
Fanfare	1964	-	NA	5M-5MR	15-20MR	-	75	300	*Sr2*, *Sr57*
Gem	1964	-	TR-30MSS	TR-5MR	TR	445	0	0	-
K. Hunter	1964	Kenya	TR-10MS	NA	-	72.5	0	-	-
Brewster	1964	-	5MS-20MSS	10MR-20MS	30-50S	260	220	745	*Sr12*
Fronthatch	1963	Kenya	NA	5MR-10MR	20MR-40S	-	145	595	-
Salmayo	1963	-	TR-20MSS	TR-15MR	30MS-40S	202.5	72.5	560	-
Tama	1963	Kenya	TR-30MS	NA	-	295	NA	NA	*Sr12*, *Sr57*
K. Page	1963	Kenya	TR-5M	0	5-10MR	17.5	0	150	*Sr17.sr2*
Africa Mayo	1960	Mexico	TR-20M	5M-5MR	10MR	300	75	150	-
K-362-B-1-A	1957	Kenya	TR	0-10M	20-30MS	0	90	410	-
K. Farmer	1954	Kenya	5MR-20MSS	TR-10M	30MS	295	72.5	-	*Sr9b, Sr7a, Sr10, Sr11*
Impala	1954	S. Africa	TR-10MS	10MR-20M	40-50S	72.5	190	710	*Sr12*, *Sr57*
Yaqui	1954	Mexico	TR-20MR	NA	5-20MR	127.5	0	300	-
K-184-P	1951	Kenya	5MS-20M	20MS- 30MS	-	185	265	*NA*	-
K. Ploughman	1950	Kenya	5MR-10MR	TR-5MS	10-30MS	130	17.5	335	-
Rhodesian Sabanaro	1949	-	5MR-30MSS	TR-10M	30-40S	275	55	485	-
K-294-B-2A-3	1948	Kenya	5M-20MS	30MS-40MS	40-70S	295	450	895	-
Kentana 48	1948	-	NA	5M-20M	40-50S	NA	222.5	635	-
Kenya 131	1939	Kenya	TR-20MR	NA	-	145	105	*NA*	-
Kenya 58	1937	Kenya	5MS-20MSS	10MS-40MS	20MS-40S	260	295	560	-
K. Standard	1929	Kenya	5M-40MS	30MS-40MS	30-40MS	405	380	560	-
K. Governor	1925	Kenya	TR-20MS	NA	20-30MS	330	0	335	-
Equator	1920	-	TR-20MS	TR-10M	30MS-50S	145	92.5	595	*Sr7a*, *Sr12*, *Sr57*
K. Cheetah	-	Kenya	TR	0-TR	0-TR	0	0	0	*Sr12*, *Sr57*
Catcher	1963	-	5MS-30MS	5MS-20MS	40-50S	295	187.5	745	*Sr2, Sr6,Sr8a Sr9gSr12*
Kenya 8	-	-	NA	10MR-20M	40-60S	-	240	860	-
Kenya 7	-	-	5MR-10MS	20MR-60S	40-50S	130	502.5	710	*Sr8155B1*
Menco	1963	-	TR	5M-5MR	5-10MR	-	197.5	150	*Sr12*, *Sr57*
Morris	1964	-	TR-20MS	NA	5-20MS	295	17.5	300	-
Reliance 261 M	-	-	TR-20MSS	20MS-30MS	20-30MR	145	410	450	-

Supplementary Table 2. Contd.

Lenana	-	-	TR	TR	5-10MR	0	17.5	130	-
K. Simba	-	-	5MR-20MS	5M-10M	40-60S	240	95	820	-
K318-AJ-4A-1	-	-	NA	5MR-10M	10-40MS		112.5	485	-
K 256 G	-	-	5MR-20MR	10MR-20M	30-40MS	107.5	260	485	-
Fury	1964	Kenya	5R-40MSS	20M-40M	50-60S	445	375	860	-
K117DA	-	-	5MS-60MSS	10MR-20MR	30-60S	515	150	705	-
K. Kunguru	-	-	TR-10MR	NA	-	35	35	*NA*	-
Kenya 155	-	Kenya	NA	40MS-60S	50-70S	NA	605	895	-
K. Waren	-	Kenya	NA	40MS-60MS	40-60S	NA	565	785	-
Supremo	-	Ethiopia	NA	TR-10M	30-50S	NA	75	635	-
Kenya 6295-4A	-	-	NA	TR	10-20MR	NA	105	185	-
K 6290 B	-	-	NA	0-5MR	TR	NA	192.5	0	150
Kenya 6820	-	-	5MR-10MS	TR	TR-5MR	130	0	75	-
K324	-	-	TR-10MR	NA	-	35	0	*NA*	-
K7B 58	-	-	NA	NA	-	-	0	*NA*	-
Jacana	-	Kenya	NA	10M-20MS	30-50S	-	150	635	-
B192	-	-	NA	5M-20MS	40-60S	-	205	820	-
K122	-	-	NA	10M-30MS	20-60S	NA	352.5	820	-
Kenya 5	-	-	NA	30MS-60MS	40-70S	NA	555	855	-
Tama B	-	-	NA	5M-5MR	5-10MR	NA	57.5	150	-
Tobari 66	-	Mexico	NA	5MS-15MS	30MS-40S	NA	130	595	-
CI 14393	-	-	NA	5M-10M	10MR-30MS	NA	110	295	-
R64	-	-	NA	0-5MR	20MR/MS	NA	55	335	-
K360H	-	-	NA	0-5MR	20MS-40MS	NA	55	555	-
K6106-8	-	-	NA	5M-5MR	15-20MS	NA	75	300	-
Kenya KBB	-	Kenya	NA	5MR-10MS	30MS-60S	NA	92.5	705	-
KB 256-G	-	-	NA	5MR-10MS	10-40MS	NA	112.5	560	-

[a]K = Kenya; R=resistant; presence of hypersensitive necrotic flecks but no uredinia, MR=moderately resistant; small pustules surrounded by necrotic areas, MS=moderately susceptible; medium-sized pustules with no necrosis, MRMS; moderately resistant moderately susceptible, MSS=moderately susceptible to susceptible; medium to large sized pustules without necrosis, S=susceptible; large pustules with no necrosis. NA=not available.