Multi-Pathotype Testing of Selected Kenyan Wheat Germplasm and Watkin Landraces for Resistance to Wheat Stripe Rust (*Puccinia striiformis* f. sp *tritici*) Races

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Abstract: Wheat stripe rust, caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*), is one of the key diseases of economic importance in wheat worldwide. Host resistance, which follows the gene-for-gene hypothesis between the host and pathogen, has been used in wheat lines to resolve resistance specificities and postulate resistant genes. The objective of this study was to elucidate stripe rust resistance in a collection of Kenyan wheat lines and Watkin landraces to identify new sources of stripe rust (*Yr*) resistance. In this study, the resistance in twenty wheat lines was determined by comparing their infection type with those of twenty differential lines using isolates representing twelve *Puccinia striiformis* races from Kenya, Denmark, U.K., Sweden, and Eritrea at the seedling stage. Among the twenty wheat lines, none was resistant to all the twelve *Pst* races and isolate DK02d/12 (“Kranich” race) was virulent on all the genotypes except wheat genotype “Kenya Tai.” This genotype (“Kenya Tai”) had the highest resistance as it was resistant to all the twelve stripe rust races used in this study. From this study, the introduction and utilization of wheat genotypes with adult plant resistant (APR) stripe rust genes, such as *Yr15*, are important in breeding wheat genotypes with effective resistance to wheat stripe rust in Kenya and worldwide.

Keywords: gene postulation; pathotype; *Pst*; resistance; stripe rust; wheat

1. Introduction

Wheat (*Triticum aestivum* L.) is the second-most important cereal crop in Kenya, after maize; however, there is inadequate annual production due to abiotic and biotic factors leading to a deficit of over 60% [1]. Wheat stripe rust caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*) is one of the biotic factors that has been an important disease in Kenya for the past century [2,3] and its pathogenicity increases yearly [2,4,5]. The epidemiology of stripe rust is influenced not only by the deployment of resistance genes in wheat varieties, but also by climatic conditions that affect *Pst* infection and growth and by wind movements across areas where wheat is grown. Among the countries in East Africa, stripe rust is important in Kenya, Ethiopia, and Uganda [6]; hence, regular virulence analysis is vital for disease management and the incorporation of resistant genes [7]. A stripe rust race (pathotype) is the compatible or incompatible interactions between the host and pathogen by characterizing the *Pst* on a set of resistant (R) genes carrying wheat differentials, and associated race surveys are undertaken in
many countries [8,9]. In Kenya and Ethiopia, wheat cultivars with stripe rust genes Yr9 and Yr27 broke down due to the evolution of stripe rust races virulent to Yr9 and Yr27 genes, resulting to yield losses of up to 40% in commercial cultivars like “Paa,” which carried the Yr9 gene [10,11]. These countries are at high risk of wheat rust’s diseases; therefore, it is necessary to identify and incorporate sources of resistance with improved durability in breeding programs to avoid major stripe rust epidemics [12,13].

The inheritance of resistance in wheat genotypes to wheat rust pathogens is due to R genes in the host plant and avirulent (Avr) genes in the wheat rust; thus, for every R gene in wheat, there is a corresponding Avr gene in the wheat rust pathogen [14,15]. Gene postulation has been used in several studies to identify stripe rust resistance genes in wheat lines from Nepal, Denmark, China, and Ethiopia [12,16–18]. Genes resistant to wheat rusts have been identified by testing genotypes and the differential sets (wheat lines with known genes) in different countries [19,20].

The aim of this study was to resolve the resistance specificities of major genes in Kenyan wheat genotypes by inoculating them with a panel of isolates of *Puccinia striiformis* of diverse origin and race at the seedling stage in the greenhouse. The isolates were selected from a previous study on virulence analysis of 54 *Pst* isolates collected within Kenya between 2009–2014 (unpublished data). The resistance spectra of the genotypes formed the elementary information for further gene postulation.

2. Materials and Methods

2.1. Genotypes

Twenty wheat genotypes consisting of Kenyan wheat varieties and Watkins landraces, together with twenty wheat differential lines, were used (Table 1). The Kenyan varieties were provided by the Kenya Agricultural and Livestock Research Organization (KALRO), Njoro, Kenya, and the Watkins lines were provided by John Innes Centre (JIC), Norwich U.K., through the Biotechnology and Biological Sciences Research Council under the Sustainable Crop Production Research for International (BBSRC SCPRID) award (BB/J012017/1). The virulence phenotyping of isolates was based on the infection type assessment of differential host genotypes with known yellow rust resistance genes. The differential sets consisted of European, world, avocet near isogenic lines, and others. The seeds of the differential sets were kindly provided by Prof. M.S. Hovmøller from the Global Rust Research Centre (GRRC), Slagelse Denmark.

### Table 1. Wheat (*Triticum aestivum* L.) genotypes and differential lines used for stripe rust (*Puccinia striiformis* (*Pst*)) virulence analysis.

| Variety/Landrace | Year of Release | Pedigree/Accession Name | Seed Source |
|------------------|-----------------|-------------------------|-------------|
| 1190713          |                 | Watkin                  | JIC, U.K.   |
| 1190026          |                 | Watkin                  | JIC, U.K.   |
| 1190034          |                 | Watkin                  | JIC, U.K.   |
| 1190826          |                 | Watkin                  | JIC, U.K.   |
| 1190120          |                 | Watkin                  | JIC, U.K.   |
| 1109524          |                 | Watkin                  | JIC, U.K.   |
| 1190527 (Panjabi)|                 | Watkin                  | JIC, U.K.   |
| 1190059          |                 | Watkin                  | JIC, U.K.   |
| Kenya Korongo    | 2012            | Emb16/CB/BRD/CB/BRD     | KALRO, Njoro|
| Kwale            | 1987            | Kinglet,Cm33089-9       | KALRO, Njoro|
| Kenya Wren       | 2012            | THELIN#2/TU/UK          | KALRO, Njoro|
| Duma             | 1993            | R674-AV/UP301/GLL/SX/3/PEW „S‘/MAI "S’/PEW ‘S‘-CM67245 | KALRO, Njoro|
| NJBWII           | 2001            | CM8181-12y-06PZ/5y-5m-0y-2AL-0AL-0M | KALRO, Njoro|
| Kenya Hawk12     | 2012            | Equator-II/Kenya-Ploughman | KALRO, Njoro|
| Eagle10          | 2010            | Babax/Lr42/Babax*2/4SN1/1/TRAPE/1/3/KAUZ*2/3/TR | KALRO, Njoro|
| Kenya Ibis       | 2012            | Kwaale/Duma             | KALRO, Njoro|
| Kenya Kingbird   | 2012            | TAM200/TU/1/6/PV/2/2/AN/S/2/BOW/CROW | KALRO, Njoro|
| Kenya Sunbird    | 2012            | ND643/2/2/WBLL1         | KALRO, Njoro|
| Kenya Tai        | 2012            | ND643/2/2/WBLL1         | KALRO, Njoro|
| Robin            | 2010            | Babax/Lr42/Babax*2/3/Turku | KALRO, Njoro|
| Host Differentials | Yellow Rust Genes (s) | Differential type/Grouping | Seed Source |
Table 1. Cont.

| Variety/Landrace | Year of Release | Pedigree/Accession Name | Seed Source |
|------------------|-----------------|-------------------------|-------------|
| Cartago          | None            | World                   | Flak10      |
| Chinese 166      | Yr1             | Others                  | Flak10      |
| Kalyansona       | Yr2,+           | World                   | Flak08      |
| Vilmoren 23      | Yr3,+           | World                   | Flak06      |
| Hybrid 46        | Yr4,+           | European                | Flak07      |
| Heines Kolben    | Yr6,+           | World                   | Flak06      |
| Avocet Yr6       | Yr6,AvS         | Avocet NIL              | Flak09      |
| Lee              | Yr7             | World                   | Flak09      |
| Avocet Yr8       | Yr8             | Avocet NIL              | Flak09      |
| Avocet Yr9       | Yr9,AvS         | Avocet NIL              | Flak12      |
| Moro             | Yr10            | World                   | Flak09      |
| Coatez           | Yr15            | Others                  | Flak09      |
| VPM1             | Yr17,+          | European                | Flak12      |
| Avocet Yr17      | Yr17,AvS        | Avocet NIL              | Flak09      |
| TP 981           | Yr25,+          | Others                  | Flak09      |
| Opata            | Yr27,+          | Others                  | Flak10      |
| Carstens V       | Yr32,Yr25,+     | European                | Flak06      |
| Avocet S         | AvS,+           | Avocet NIL              | Flak12      |
| Ambition         | Amb             | Others                  | Flak12      |
| Avocet SP        | SPAvS           | Avocet NIL              | Flak13      |

JIC—John Innes Centre, KALRO—Kenya Agriculture and Livestock Research Organization, NIL—near isogenic lines. Flak seed was sourced from the Global Rust Research Centre (GRRC).

2.2. Stripe Rust Isolates

Stripe rust isolates used in this study were provided by Prof. M.S. Hovmøller of GRRC, Denmark. A total of twelve stripe rust isolates of diverse origins from five countries (Kenya, Denmark, U.K., Sweden, and Eritrea) were used (Table 2). The isolates were selected due to their broad spectrum in terms of virulence, and because they represent different world regions that have been collected from for the last 40 years. Urediniospores used in this study had been previously (in a different study on virulence analysis, unpublished data) purified and developed on the susceptible wheat genotype “Cartago,” and subsequently stored over liquid nitrogen (−196 °C) at GRRC’s rust isolate bank in accordance with References [8,21,22].

2.3. Inoculation and Incubation of the Wheat Genotypes

Virulence assessment of the races on the resistance of the wheat genotypes based on their infection type (IT) was carried out on the Kenyan and Watkins lines, and differential sets. Seven seeds of each genotypes were sown in 6.5 cm × 6.5 cm square plastic containers filled with approximately 144 g of peat moss (PINDSTRUP MOSEBRUG A/S 8550 RYOMGARD, Denmark) and placed on a tray measuring 35 cm × 44 cm. The sown seeds were placed in a spore-proof greenhouse maintained at a temperature of 17 °C/12 °C day/night cycle. The stripe rust isolates were removed from the liquid nitrogen (−196 °C) and heat-shocked in a water bath at 40 °C for 2 min. At the two-leaf stage (feekes stage 1) [23], the wheat genotypes were inoculated with urediniospores (15 mg) of each isolate suspended in Novec™ 7100 using an air brush spray gun [24], then incubated in the dew chamber at 100% humidity and 10 °C for 24 h in total darkness. The inoculated plants were transferred to spore-proof greenhouse cabins with a 16-h/8-h day/night cycle, maintained at 17 °C/12 °C day/night cycle.

2.4. Field Experiment

Field experiments were conducted at the Kenya Agriculture and Livestock Research Organization (KALRO) in Njoro (0°20′ S, 35°56′ E, 2185 m above sea level), Mau Narok (01°55′ S, 35°52′ E, 2400 m above sea level), and Eldoret (0°41′ S, 36°31′ E, 2065 m above sea level) during the cropping cycle in 2016 and 2017. Each entry was sown in double rows measuring 0.2 × 0.75 m separated by 0.3 m and 0.5 m wide alleyways within and between the blocks, respectively. To facilitate inoculum build-up and uniform dissemination within the nursery, a continuous row of wheat variety “KS. Mwamba,”
susceptible to three types of rust, was planted perpendicular to all entries. The disease occurred naturally in all three environments.

2.5. Data Collection and Analyses

Infection types (IT) were noted 16 days after inoculation based on a 0–9 scale [25]. ITs of 0–4 were classified as resistant, ITs of 5–6 as intermediate, and ITs of 7–9 as susceptible. The resistance spectrum was based on a gene-for-gene hypothesis where the ITs produced by the *Pst* races on the wheat genotypes (Kenyan and Watkins lines) was compared with the ITs produced by the same races on the tester lines with known genes (differential lines) [16,26]. When the pathogen was avirulent, the response IT was classified as resistant; however, when the races were virulent on the host, the response IT was classified as susceptible and the intermediate reactions were classified as moderately resistant and moderately susceptible. The spectrum was comprised of resistant (R), moderately resistant (MR)/susceptible (MS), and susceptible (S) reactions. The disease in the field experiment was assessed during the peak of the wheat rust infection, immediately after heading. The host reaction and rust severity were taken from each entry. Estimates of disease severity were based on a modified Cobb scale [27,28] incorporating both the percentage of leaf area affected and the host response.

3. Results

3.1. Confirmation of Virulence Phenotype of the Twelve Yr Isolates and the Response of the Differential Lines to the Isolates

Collectively, the twelve *Pst* isolates were virulent on the following yellow rust (*Yr*) genes: *Yr1*, *Yr2*, *Yr3*, *Yr4*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr10*, *Yr17*, *Yr25*, *Yr32*, *YrAmb*, and *YrAvS*, and avirulent to *Yr15* and *YrSp* (Table 2). Isolates from Kenya and Denmark made up the majority of virulent isolates, consisting of 41.67% and 33.33%, respectively. The Kenyan isolates had a common virulence for yellow rust genes *Yr2*, *Yr6*, *Yr7*, and *YrAvS*, except KE86102/Yr9, which lacked virulence for *Yr7* and *Yr8*, but was the only Kenyan isolate with virulence for *Yr17*. Virulence for *Yr17* was present in the European isolates. Two pathotypes, KE70063 and KE131/14, had additional virulence for *Yr25* and *Yr27*; moreover, the latter also had virulence for *Yr1* and *Yr9*. The isolate from Eritrea had virulence for *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr25*, *YrAvS*, and an additional virulence for *Yr10* that was absent in the Kenyan isolates (Table 2). The Danish isolates (DK01/09; DK71/93) had virulence for 6 *Yr* genes, whereas isolates (DK09/11SP; DK02d/12) had virulence for 12 *Yr* genes, thereby representing isolates with a wide virulence spectrum. The other isolates from Europe (Sweden and United Kingdom) differed in virulence, SE100/09 being virulent on only five *Yr* genes and UK94/519 had virulence for seven *Yr* genes. Interestingly, the Swedish isolate and one Kenyan isolate were avirulent to *YrAvS*.

Wheat genotypes “Cartago” (susceptibility check) and “Kalyansona” (*Yr2*) were susceptible to all the twelve isolates (Table 3). “AvocetS” (*AvS*) was also susceptible to all the isolates except KE70063 and SE100/09 from Kenya and Sweden, respectively. On the other hand, “Cortez” (*Yr15*) was resistant to all the isolates, followed by “AvocetSP” (*SP, AvS*). “Hybrid46” (*Yr4*), “Moro” (*Yr10*), and “Ambition” (*YrAmb*) were resistant to ten out of twelve isolates, while “Opata” (*Yr27*) and “CarstansV” (*Yr32, Yr25*) were resistant to nine isolates (Table 3). “VPM1” (*Yr17*) and “Chinese166” (*Yr1*) were resistant to eight and seven isolates, respectively, and “AvocetYr17” was resistant to six isolates. Three varieties—“Vilmorin23” (*Yr3*), “AvocetYr8,” and “AvocetYr9”—were resistant to five isolates. “AvocetYr6,” “Lee” (*Yr7*), and “Tp981” (*Yr25*) were resistant to four isolates. “Heines Kolben” (*Yr6*) and “AvocetS” (*YrAvS*) were resistant to three and two isolates, respectively.

3.2. Wheat Genotypes and Resistance Responses to Stripe Rust Isolates Representing Distinct Races

Interpretation of the results for each cultivar was based on the race-specific responses when challenged by twelve isolates (races), which produced 20 unique resistant spectra. Some spectra appeared to represent single *Yr* resistance genes, whereas others represented two or more genes...
(often unknown). The susceptibility check “Cartago” proved to be susceptible to all isolates, whereas “Kalyansona” (Yr2+) showed an intermediate reaction (“MS”) to SE100/09 (race “Triticale 2006”) (Table 3). Thus SE100/09 had partial virulence to “Kalyansona,” either due to Yr2 or the additional “unknown” gene in this differential. “Vilmorin23” (Yr3+) showed resistance (R or MR) to seven isolates and susceptibility (S) to five isolates, with the former confirming avirulence to Yr3+ in these seven isolates and virulence to Yr3+ in the latter. “Hybrid46” showed resistance to 10 isolates and susceptibility to DK09/11SP, i.e., only the latter two isolates had virulence to Yr3+ (Table 3). Despite two differentials having carried Yr6, they revealed different spectra due to an uncharacterized R gene in AvocetYr6+. Thus, only resistance spectrum 6 (conferred by Heines Kolben) were considered for the postulation regarding Yr6 in this study.

Table 2. Pathotypes of Puccinia striiformis (Pst) used in seedling screening of the Kenyan varieties and Watkins landraces for resistance.

| Pathotype a | Sampling Year | Country | Virulence b |
|-------------|---------------|---------|-------------|
| KE79067     | 1979          | Kenya   | Yr2, Yr6, Yr7, Yr8, YrAvS |
| KE82017     | 1982          | Kenya   | Yr2, Yr6, Yr7, Yr8, YrAvS |
| KE70063     | 1970          | Kenya   | Yr2, Yr6, Yr7, Yr8, Yr25, Yr27 |
| KE86102 Yr9 | 1986          | Kenya   | Yr2, Yr6, Yr9, Yr17, YrAvS |
| KE131/14    | 2014          | Kenya   | Yr1, Yr2, Yr6, Yr7, Yr8, Yr17, YrAvS |
| ER02/03     | 2003          | Eritrea | Yr2, Yr6, Yr7, Yr8, Yr9, Yr10, Yr25, YrAvS |
| SE100/09    | 2009          | Sweden  | Yr2, Yr6, Yr7, Yr8, Yr10 |
| DK01/95     | 1995          | Denmark | Yr2, Yr3, Yr4, Yr9, Yr25, YrAvS |
| DK09/11SP   | 2011          | Denmark | Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr9, Yr17, Yr25, Yr32, YrAvS, YrAvS |
| DK71/93     | 1993          | Denmark | Yr1, Yr2, Yr3, Yr5, Yr25, YrAvS |
| DK02/12     | 2012          | Denmark | Yr1, Yr2, Yr3, Yr6, Yr7, Yr8, Yr9, Yr17, Yr25, Yr32, YrAvS, YrAvS |
| UK94/519    | Unknown       | United Kingdom | Yr1, Yr2, Yr3, Yr9, Yr17, Yr25, YrAvS |

a GRRC pathogen coding system; b Yellow rust virulence tested on differential genotypes carrying the resistant genes Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr8, Yr9, Yr10, Yr15, Yr17, Yr25, Yr27, Yr32; and resistance specificities in Ambition, Avocet SP, and Avocet S.

Tester Heines Kolben and AvocetS had a narrow resistance spectrum, where they showed resistance to Pst races DK71/93, UK94/519, DK01/95, KE70063, and SE100/09. “AvocetYr6,” “Lee,” and “TP981” showed resistance to Pst races KE82017, KE86102Yr9, DK09/11SP, KE79067, DK71/93, SE100/09, UK94/519, and DK01/95, and could not distinguish from the resistance spectrum of other testers. In the present study, Yr2 and Yr25 were the most frequent because the resistance spectrum of “Kalyansona” and “TP981” was covered by the resistance spectra of other testers. The testers “Vilmorin23,” “AvocetYr8,” and “AvocetYr9” showed resistance to Pst races KE82017, KE86102Yr9, DK09/11SP, KE131/14, KE79067, KE70063, DK71/93, SE100/09, UK94/519, DK01/95, and ER02/13. The tester genotype “Chinese166” showed resistance to Pst races KE82017, KE86102Yr9, KE79067, KE70063, SE100/09, DK01/95, ER02/13; “Vilmorin23” showed resistance to the same Pst races in “Chinese166” except DK01/95; and “TP981” showed resistance to Pst races in “Vilmorin23” except KE70063 and ER02/13. The resistance spectrum of testers “Vilmorin23” and “TP981” were covered by the resistance spectrum of another tester (Table 3).

Spectrum 1 (Yr1) consisted of differential “Chinese166” with infection types (ITs) 0–1 and 6–7 for the incompatible and compatible reactions, respectively. Spectrum 2 (None and Yr2) consisted of “Cartago,” “Kalyansona,” “1190120,” “K. Hawk12,” “Eagle10,” “K. Sunbird,” and “Robin” with ITs 6–8 and 4–7, which indicated the presence of an additional gene for Yr2 (Tables 3 and 4). Genotypes “1190120,” “K. Hawk12,” “Eagle10,” “K. Sunbird,” and “Robin” could have had the Yr2+, unknown gene. Spectrum 3 (Yr3,+) was comprised of a differential “Vilmorin 23” with ITs of 6–7 for compatible reactions and 0–4 for the incompatible reaction, which was an indication of the presence of a second gene to Yr3. Spectrum 4 (Yr4,+) was comprised of “Hybrid 46” with all the incompatible reactions 0; 0–1, then 5–7; 7 for compatible reactions, which is an indication of an additional gene to Yr4.
| Host Differentials | Resistant Genes (Yr) | KE82017 | KE86102 | DK9/11SP | KE131/14 | KE79067 | KE70063 | DK71/93 | DK02d/12 | SE100/09 | UK94/519 | DK01/95 | ER02/13 | Resistance Spectrum |
|-------------------|----------------------|---------|---------|----------|-----------|---------|---------|---------|---------|-----------|-----------|---------|---------|---------------------|
| Cartago           | None                 | 9-7     | 6-7     | 7-5      | 7-7       | 7-5     | 7-5     | 7-5     | 7-5     | 7-5       | 7-5       | 7-5     | 7-5     | 7-5                 |
| Chinese           | Yr1                  | 06-7    | 06-7    | 06-7     | 06-7      | 06-7    | 06-7    | 06-7    | 06-7    | 06-7      | 06-7      | 06-7    | 06-7    | 06-7               |
| Kalyarsona        | Yr2,                 | 6-7     | 6-7     | 7-5      | 6-7       | 6-7     | 7-5     | 6-7     | 7-5     | 6-7       | 7-5       | 6-7     | 7-5     | 6-7               |
| Vilnarin23        | Yr3,                 | 0-2     | 0-2     | 0-2      | 0-2       | 0-2     | 0-2     | 0-2     | 0-2     | 0-2       | 0-2       | 0-2     | 0-2     | 0-2               |
| Hybrid 45         | Yr4,                 | 0       | 0       | 0-2      | 0-2       | 0-2     | 0-2     | 0-2     | 0-2     | 0-2       | 0-2       | 0-2     | 0-2     | 0-2               |
| Heines            | Yr5,                 | 6-7     | 6-7     | 6-7      | 6-7       | 6-7     | 6-7     | 6-7     | 6-7     | 6-7       | 6-7       | 6-7     | 6-7     | 6-7               |
| Kolben            | Yr6,                 | 6-7     | 6-7     | 6-7      | 6-7       | 6-7     | 6-7     | 6-7     | 6-7     | 6-7       | 6-7       | 6-7     | 6-7     | 6-7               |
| Avocet Yr6        | Yr7,                 | 6-7     | 6-7     | 6-7      | 6-7       | 6-7     | 6-7     | 6-7     | 6-7     | 6-7       | 6-7       | 6-7     | 6-7     | 6-7               |
| Lee               | Yr8,                 | 0-3     | 0-3     | 0-3      | 0-3       | 0-3     | 0-3     | 0-3     | 0-3     | 0-3       | 0-3       | 0-3     | 0-3     | 0-3               |
| Avocet Yr8        | Yr9                  | 0-3     | 0-3     | 0-3      | 0-3       | 0-3     | 0-3     | 0-3     | 0-3     | 0-3       | 0-3       | 0-3     | 0-3     | 0-3               |
| Avocet Yr9        | Yr10                 | 1-2     | 1-2     | 1-2      | 1-2       | 1-2     | 1-2     | 1-2     | 1-2     | 1-2       | 1-2       | 1-2     | 1-2     | 1-2               |
| Movo              | Yr12                 | 0-2     | 0-2     | 0-2      | 0-2       | 0-2     | 0-2     | 0-2     | 0-2     | 0-2       | 0-2       | 0-2     | 0-2     | 0-2               |
| Coatzer           | Yr15                 | 0-4     | 0-4     | 0-4      | 0-4       | 0-4     | 0-4     | 0-4     | 0-4     | 0-4       | 0-4       | 0-4     | 0-4     | 0-4               |
| VPM              | Yr17                 | 0-1     | 0-1     | 0-1      | 0-1       | 0-1     | 0-1     | 0-1     | 0-1     | 0-1       | 0-1       | 0-1     | 0-1     | 0-1               |
| Avocet Yr17       | Yr17                 | 0-1     | 0-1     | 0-1      | 0-1       | 0-1     | 0-1     | 0-1     | 0-1     | 0-1       | 0-1       | 0-1     | 0-1     | 0-1               |
| TP 981            | Yr12                 | 0-2     | 0-2     | 0-2      | 0-2       | 0-2     | 0-2     | 0-2     | 0-2     | 0-2       | 0-2       | 0-2     | 0-2     | 0-2               |
| Opata             | Yr27,                | 0-4     | 0-4     | 0-4      | 0-4       | 0-4     | 0-4     | 0-4     | 0-4     | 0-4       | 0-4       | 0-4     | 0-4     | 0-4               |
| Carstens V        | Yr32,15,             | 0-1     | 0-1     | 0-1      | 0-1       | 0-1     | 0-1     | 0-1     | 0-1     | 0-1       | 0-1       | 0-1     | 0-1     | 0-1               |
| Avocet S          | Yr15                 | 0-1     | 0-1     | 0-1      | 0-1       | 0-1     | 0-1     | 0-1     | 0-1     | 0-1       | 0-1       | 0-1     | 0-1     | 0-1               |
| Ambition          | Yr17                 | 0-3     | 0-3     | 0-3      | 0-3       | 0-3     | 0-3     | 0-3     | 0-3     | 0-3       | 0-3       | 0-3     | 0-3     | 0-3               |
| Avocet SP         | Yr17                 | 0-3     | 0-3     | 0-3      | 0-3       | 0-3     | 0-3     | 0-3     | 0-3     | 0-3       | 0-3       | 0-3     | 0-3     | 0-3               |

a and b are infection type (ITs) and the reaction of genotype to the stripe rust isolates. R (resistant); MR (moderately resistant); MS (moderately susceptible); S (susceptible). ITs are given according to the scale of 0–9 [25]. The resistance response spectrum was according to Hovmøller [16].

Table 3. Seedling reaction of twenty testers with known yellow (Yr) genes to twelve isolates of *Puccinia striiformis* collected from European and East African countries.
Table 4. Seedling reaction of twenty wheat genotypes to twelve isolates of *Puccinia striiformis* collected from European and East African countries.

| Wheat Varieties | KE82017 | KE86102 Yr9 | DK09/11SP | KE131/14 | KE79067 | KE70063 | DK71/93 | DK02d/12 | SE100/09 | UK94/519 | DK01/95 | ERO2/13 | Resistance Spectrum |
|-----------------|---------|-------------|-----------|-----------|---------|---------|---------|---------|---------|-----------|---------|---------|------------------|
|                 | a       | b           | a         | b         | a       | b       | a       | b       | a       | b         | a       | b       | a b a b a b a b |
| 1190713         | 5–7     | S           | 1–3      | R         | 2–6     | M         | 2–3     | MS       | 0       | R       | 0–3   | R           | 6–7     | S       | 6–7     | 6–7     | S       | 6–7     | S       | 6–7     | 3–4   | MR       | 22     |
| 1190026         | 3–5     | MR          | 6–7      | S         | 6–7     | S         | 7–8     | S         | 3–6     | MS       | 6       | S         | 7       | S       | 7       | 1–2     | R       | 7       | S       | 7       | 7       | S       | 15     |
| 1190034         | 0–2     | R           | 1–2      | R         | 0–2     | R         | 0       | R         | 0       | R       | 5–7   | MS        | 3–5     | MS      | 1       | R       | 6–7     | S       | 6       | 2       | R       | 21     |
| 1190826         | 1–5     | M           | 5–6      | MS        | 6–7     | S         | 7–8     | S         | 3–6     | MS       | 6       | S         | 5–7     | MS      | 7–8     | S       | 2–3     | R       | 7       | S       | 7       | S       | 7       | S       | 20     |
| 1190120         | 3–5     | MS          | 6–7      | S         | 7       | S         | 7–8     | S         | 4–6     | MS       | 6–7     | S         | 7       | 7–8     | S         | 5–7     | MS      | 7       | S         | 7       | S       | 7       | S       | 7       | S       | 1      |
| 1190524         | 6–7     | S           | 5       | MS        | 5–7     | MS       | 6–7      | S         | 5–7     | S         | 0       | R         | 2       | R       | 3–5     | MS       | 7       | S       | 7       | S       | 22     |
| 1190527 (P)     | 0–1     | R           | 0–1      | R         | 0–3     | R         | 6–7     | S         | 0–3     | R       | 0–1   | R         | 7       | S         | 7       | S         | 5–6     | S         | 2–3   | R       | 7       | S       | 4–5     | MS       | 23     |
| 1190059         | 2       | R           | 2       | R         | 0–5     | M         | 2–4     | R         | 1       | R       | 5–6   | MS        | 7       | S         | 4–7     | MS      | 2       | R       | 7       | S         | 7       | S       | 2       | R       | 12     |
| K. Korongo      | 4–5     | MS          | 0       | R         | 6–7     | S         | 4–6     | MS       | 5       | MS       | 0–3   | R         | 7       | S         | 6       | S         | 4–6     | MS       | 7       | S       | 7       | S       | 6       | S       | 24     |
| K. Wren         | 6–7     | S           | 0–4      | R         | 6–7     | S         | 5–6     | MS       | 4–5     | MS       | 6–7   | MS        | 6–7     | S         | 4–6     | MS       | 7       | S         | 6–7     | S       | 7       | S         | 6–7     | S       | 24     |
| Duma            | 0–3     | R           | 0–2      | R         | 5–7     | MS        | 3–6     | MR       | 1–6     | M         | 5–7     | MS       | 3       | R         | 3–7     | M         | 0       | R       | 2       | R         | 2–3   | R       | 7       | S       | 18     |
| NjRBW2          | 0       | R           | 3–4     | MR        | 5–7     | MS       | 7       | S         | 0       | R       | 0     | R         | 1       | R         | 7       | S         | 0       | R       | 7       | S         | 7       | S         | 2–4   | R       | 25     |
| K. Hawk 12      | 6–7     | S           | 4–6     | MS        | 4–6     | MS       | 6–7     | S         | 6–7     | S         | 7       | 6–7     | 6–7     | S         | 7       | S         | 6–7     | S         | 7       | S         | 6–7     | S       | 7       | 1      |
| Eagle 10        | 6–7     | S           | 6–7     | S         | 7       | S         | 7       | S         | 6–7     | S         | 7       | S         | 6–7     | S         | 7       | S         | 6–7     | S         | 7       | S         | 6–7     | S       | 1      |
| K. Ibis         | 0–1     | R           | 0–1     | R         | 0–4     | R         | 0–3     | R         | 0       | R       | 0     | R         | 0–1   | R         | 7       | S         | 0–1     | R       | 6–7     | S         | 2       | R       | 2       | R       | 21     |
| K. Kingbird     | 5–7     | MS          | 0–3     | R         | 4–7     | S         | 4–5     | MS       | 5–6     | MS       | 4–6   | MS        | 1–3     | R         | 4–6     | MS       | 1–2     | R       | 2       | R         | 1–2   | R         | 0–1   | R       | 18     |
| K. Sunbird      | 7       | S           | 4–5     | MS        | 7       | S         | 6–7     | S         | 7       | 6–7     | 7       | S         | 7       | 7–8     | S         | 7       | S         | 7       | S         | 7       | S         | 1      |
| K. Tai          | 0–3     | R           | 0–1     | R         | 0–1     | R         | 3–4     | MR       | 3       | R       | 1–3   | R         | 3       | R         | 2       | R         | 2–3     | R       | 2       | R         | 2–3   | R         | 19     |
| Robin           | 7       | S           | 4–6     | MS        | 5–6     | MS        | 5–7     | MS       | 4–6     | MS       | 4–7   | MS        | 7       | S         | 5–6     | MS       | 5–7     | MS       | 6–7     | S         | 7       | S         | 7       | S       | 1      |

a and b are infection type (ITs) and the reaction of genotype to the stripe rust isolates. R (resistant); MR (moderately resistant); MS (moderately susceptible); S (susceptible). ITs are given according to a scale of 0–9 [25]; The resistance response spectrum was according to Hovmøller [16].
Spectrum 5 (Yr6, +) was comprised of differential sets “Heines Kolben” and “Avocet Yr6” with ITs of 6–7 for all the compatible reactions. Spectrum 6 (Yr7) was comprised of differential “Lee” with ITs of 2–3 and 6–7 for incompatible and compatible reactions, respectively. Spectrum 7 (Yr8) was comprised of differential “Avocet Yr8” with ITs of 6–7 for compatible and 0–3 for incompatible reactions. Spectrum 8 (Yr9, AvS) consisted of differential “Avocet Yr9” that had ITs of 0–1 and 6–7. Spectrum 9 (Yr10) consisted of differential “Moro” that had ITs of 0–2 and 6–7 for the incompatible and compatible reactions, respectively. Spectrum 10 (Yr15) was comprised of differential “Coatez,” which was resistant to all the isolates with ITs of 0–3. Spectrum 11 (Yr17, +) was comprised of differentials “VPM1” and “Avocet Yr17” ITs of 6–7 and 0–3 in response to isolate KE86102Yr9, which indicates an additional gene that conferred resistant to isolate KE86102Yr9 in “VPM1.” Spectrum 12 (Yr25,+) consisted of differential “TP981” and genotype “1190059” with ITs of 6–7 for a compatible reaction; however, “1190059” had ITs of 0–3 for isolates DK09/11SP, KE70063, and UK94/519 that were virulent on “TP981.”

It was susceptible to all the isolates except isolates KE70063 and SE100/09 with ITs of 0–4 and 6–7. Spectrum 16 (Amb, Sp, AvS) was comprised of differentials “Ambition” and “Avocet SP,” which were resistant to all the isolates except DK09/11SP and DK02d/12, respectively. Spectrum 17 (Yr1, Yr3, +) was comprised of differentials “Chinesel66” and “Vilmorin” with ITs of 0–3, 6–7, which is an indication of an additional or more resistance genes being present. Spectrum 18 (Yr7, Yr8, +) was comprised of “Lee,” “Avocet Yr8,” “Duma,” and “K. Kingbird” (Table 3; Table 4). “Duma” had a similar reaction to “Lee,” except that it was resistant to isolates KE82107 and SE100/09. Genotype “K. Kingbird” was resistant to ER02/13; however, this isolate was virulent on “Lee.”

Spectrum 19 (Yr15, Yr27, +) was comprised of differentials “Coatez,” “Opata,” and “K. Tai.” “Coatez” (ITs 0–3) was resistant to all twelve isolates tested, while “Opata” (ITs 0–4) was resistant to 10 out of 12 isolates and “K. Tai” with intermediate reactions (ITs 0–3, 3–4) could have an additional gene to Yr15 (Tables 3 and 4). Spectrum 20 (unknown) was comprised of genotype “1190826” that was susceptible to all isolates except SE100/09. Spectrum 21 (unknown) consisted of genotype “1190034” with ITs of 0–3, 5–7, and 6–7 that was susceptible to two isolates UK94/514 and ER02/13 (Table 4). This genotype could be carrying three genes, among which, one is an APR gene due to an intermediate reaction. Spectrum 22 (unknown) consisted of genotype “1190713” and “1190524” with ITs of 0–3, 5–7, and 6–7, which could have been carrying two to three unknown genes. Spectrum 23 (unknown) consisted of genotypes “1190524” with ITs of 0–2, 3–5, and 6–7. The intermediate ITs of 3–5 and 5–7 could have been due to APR genes. Spectrum 24 (unknown) consisted of “K. Korongo” with ITs of 0–3 and intermediate reactions (4–5, 4–6), which is an indication of APR genes.

Wheat genotypes “K. Korongo” and “K. Wren” have unknown APR gene(s) as the disease reaction and infection type were moderately resistant (Table 5). Genotypes postulated to have Yr1, Yr7, Yr9 (“K. Ibis,” “Kwale,” “NJBW2,” “Duma,” “K. Kingbird,” and “K. Tai”) exhibited low disease reactions in the field at Njoro and Eldoret ranging from 0–20%, while the genotypes with Yr2 (“1190120,” “K. Hawk12,” “Eagle10,” “K. Sunbird,” and “Robin”) had disease severity ranging from 10–50%. Genotype “K. Korongo” had a combination of unknown all stage resistance (ASR) and adult plant resistance (APR) due to moderately resistant to moderately susceptible (M) reactions observed in the field experiments (Table 5).
Table 5. Resistance response spectrum, postulated stripe rust (Yr) genes, and field resistance of twenty wheat genotypes to *Puccinia striiformis* across three environments.

| Genotype   | Pedigree/Accession name | Resistance Spectrum | Postulated Yr Genes | Yellow Rust Field Resistance of the Genotypes in Three Locations |
|------------|-------------------------|---------------------|---------------------|------------------------------------------------------------------|
|            |                         |                     |                     | Eldoret | Njoro | Mau Narok |
| 1190713    | Watkins                 | 22 Unknown          | 40MSS-50S           | 15MS-30S | 50S |
| 1190026    | Watkins                 | 15 Unknown          | 50MSS               | 20-35MSS | 65-80S |
| 1190034    | Watkins                 | 21 Unknown          | 0-10MSS             | 30-60S   | 5-25M  |
| 1190826    | Watkins                 | 20 Unknown          | 0-50MSS             | 30MSS    | 5MS-70S|
| 1190120    | Watkins                 | 1 None/Yr2          | 10-50S              | 30MSS-60S| 30MSS-75S|
| 1190524    | Watkins                 | 22 Unknown          | 50S                 | 25MSS-30S| 25MSS-35S|
| 1190527    | Watkins                 | 23 Unknown          | 50S                 | 15-20MSS | 5-20M  |
| 1190059    | Watkins                 | 12 Unknown          | 5S                  | 10MS-20MSS| 15MS-50S|
| K. Korongo | Emb16/CRBD//CBRD         | 24 Unknown          | 5-10M               | 0        | 5-20MR |
| Kwale      | Kinglet,Cm33089-W       | 25 Yr9, +           | TMS-5M              | 15-20MSS | 45-55S |
| K. Wren    | THELIN#2/TURUKU         | 24 Unknown          | 10MR                | 0-10MS   | 30-40S |
| Duma       | R674-AV/UP301/GLL/SX/PEW ‘S’/4/MAI ‘S’//PEW ‘S’-CM67245 | 18 Yr7, +           | 5-10MR              | 5-15MS   | 35MS-60S|
| NJBW2      | CM8181-12y-06PZ-4y-5m-0y-2AL-0AL-0M | 25 Yr9, +           | TMR-20M             | 5-20MSS  | 45-60S |
| K. Hawk12  | Equator-II/kenya-Ploughman | 1 None/Yr2          | TR-5MR              | 5-10MS   | 10-20MS|
| Eagle10    | Babax/Lr42/Babax*2/4/SN1/TRAP#1/3/KAUZ*2/TR | 1 None/Yr2          | 40-50S              | 10-15MS  | 5R     |
| K. Ibis    | Kwale/Duma             | 21 Yr1, +           | TMR-15M             | 0-10MS   | 10-30MS|
| K. Kingbird| TAM200/TUI/6/PVN/CAR422/ANA/5/BOW/CROW | 18 Yr7, +           | 0-10M               | 5-10MS   | 25-30MS|
| K. Sunbird | ND643/2*WBL1           | 1 None/Yr2          | 10MR                | 0-15MS   | 15-20M |
| K. Tai     | ND643/2*WBL1           | 19 Yr15, +          | TMR-5MR             | 0        | 20MS-50S|
| Robin      | Babax/Lr42/Babax*2/3/Turuku | 1 None/Yr2          | 15-20MS             | 0-10S    | 35S    |

Gene postulation was based on the resistance spectrum from the seedling results in Tables 3 and 4. Resistance genes of the genotypes were postulated by comparing resistance spectra of the genotype to twelve races with those of wheat genotypes possessing known Yr resistance genes (differential lines) [9]. R (resistant); MR (moderately resistant); MS (moderately susceptible); M (moderately resistant to moderately susceptible); S (susceptible). Disease severity was based on a modified Cobb scale [28].
4. Discussion

4.1. Confirmation of the Virulence Phenotype of the Twelve Yr Isolates and Response of the Differential Lines to the Isolates

The Pst isolates used had virulence for Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr8, Yr9, Yr10, Yr17, Yr25, Yr27, Yr32, YrAmb, and YrAstS, but were avirulent to Yr15 and YrSp. There was virulence for Yr1, Yr2, Yr6, Yr7, Yr8, Yr9, Yr17, and YrAstS on Pst isolated collected before the year 2000 and after the year 2000 in Kenya (unpublished data). Virulence for Yr17 has not been common in Kenya; however, most of the European pathotypes were virulent on Yr17; this could be due to the presence of Pst1 and Pst2 strains, which are also present in East Africa [29]. The varieties deployed in these countries, such as “Bill,” “Biscay,” and “Bandit” from Denmark and “Equinox” from England have been postulated to have Yr17 [16].

The difference in virulence for pre-2000 and post-2000 Danish isolates is due to the evolution of the new races, such as the “warrior” race, that was detected in Europe in 2011 infecting many wheat varieties and triticale (Triticosecale), where the isolate DK09/11SP used in this study belongs to the warrior race, which is virulent to Yr2, Yr6, Yr7, Yr8, and Yr10 [21]. From the results, we can group the isolates’ pathotypes into two different groups according to the regions of East Africa (Eritrea and Kenya) and Europe (Denmark, Sweden, and U.K.), which brings out the geographical distribution of Pst, and the Middle East and East African population were grouped together as Middle East-East African as they did not differ much from each other [29]. Pst1 and Pst2 were present in East Africa (Kenya) and the same strains were present in Europe in addition to the “warrior” race. This brings out the evolution and similarity in Pst strains, which has been observed in Europe (Denmark) and East Africa (Kenya and Ethiopia), both from different continents with common virulences for Yr2, Yr6, Yr7, and Yr8 [21,30,31]. Wheat genotypes with resistant genes Yr2, Yr6, and Yr7 have been extensively used in Kenya and the same virulence to these genes were also found in isolates obtained from Hungary and Canada [29]. The pathotypes from different countries shared common virulence but differed in the degree of their virulence due to differences in the aggressiveness of the races against the deployed resistant genes in the regions [32].

Gene pyramiding is effective in conditioning resistance as “CarstensV” with resistant genes (Yr32, Yr25) was resistant to more isolates than “TP981” (Yr25). The difference in resistance of Yr17 in “VpM1” and in “AvocetS” was the same as the resistance to Yr6 in the “Heines Kolben” and “AvocetS” background, which brings out the interaction of genes in different background conditioning differences in gene expression and resistance.

Virulence to Yr5 and Yr15 were not detected in this study. This is because Yr5 and Yr15 are resistant to a wide range of isolates of yellow rust from different geographical regions [26]. Therefore, these genes, in combination with other race non-specific genes, can be deployed in wheat breeding programs to condition resistance [27,30].

4.2. Wheat Genotypes and Resistance Responses to Stripe Rust Isolates Representing Distinct Races

The genotypes with a broad resistance spectrum possessed resistant genes, such as Yr4, Yr10, Yr15, Yr32, YrAmb, and YrSp, which are still effective. Among the Yr genes that could be present in the genotypes under study, Yr17 is still effective in Kenya. Several researchers have employed a gene postulation for identifying Yr genes in wheat genotypes. For instance, Sharma [17] reported Yr genes Yr2, Yr6, Yr8, Yr9, Yr10, Yr15, YrA, and YrSu in 52 advanced emmer wheat lines. Hovmøller [9] postulated Yr1, Yr2, Yr3, Yr4, Yr6, Yr9, Yr15, Yr17, Yr25, and Yr32 in 98 Danish wheat cultivars. In China, they have postulated several genes, such as Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr8, Yr9, Yr1, Yr20, Yr21, Yr22, Yr23, Yr24, Yr26, Yr27, Yr32, YrHV, YrSD, YrV23, YrRes, YrC591, YrCle, YrSel, and YrSdin at the seedling level in their wheat varieties [20,33].

Based on the multi-pathotype tests conducted, the wheat lines could have had different stripe rust resistance genes, with some similar to the tester lines and others being unknown. Yellow rust genes
Yr2, Yr7, Yr9, and Yr15 were postulated in the Kenyan line tested. “K. Korongo” and four Watkins lines (“1190713,” “1190026,” “1190826,” “11900034,” and “1190524”) did not match any spectra of the testers, indicating the presence of unknown resistance genes in these lines.

Stripe rust Yr1 gene was not postulated in the wheat lines tested in this study; however, the same gene was postulated in Chinese landraces “Zhengmai366,” “Xinmai208,” and “Luomai21”, and in cultivar “Buster” [9]. Gene Yr2 was postulated in several studies in Nepal, Europe, and China [17,27,33]. The stripe rust gene (Yr2) is no longer effective against the Yr pathotypes tested and it might be present in wheat varieties “1190120,” “K. Wren,” “K. Hawk12,” “K. Sunbird,” and “Robin,” which explains why these varieties were susceptible to most of the pathotypes used. This gene (Yr2) found in the differential line “Kalyansona” is no longer effective; therefore, the lines with a single Yr2 need to be improved by incorporating resistant genes such as Yr15, YrSP, Yr4, Yr10, and YrAmb to attain durable resistant.

Gene Yr6 was postulated in Australia wheat lines categorized under group six (YRG6) [28] and in wheat cultivars “Hunter,” “Lynx,” and “Rialto” [9]. In our study, no genotype was postulated to have Yr6. Gene Yr7 could be present in “Duma” and ‘K. Kingbird,” where this gene is linked to Sr9g in cultivar “Cadenza” and “Tonic” [34]. Gene Yr9 postulated in “Kwale” and “NJBW2” is pleotropic or linked to Sr31Lr26. However, virulence to Sr31 has been present in Kenya since the emergence of Sr31 virulence in Uganda [9]; therefore, the gene is ineffective and cannot be deployed in Kenyan wheat lines unless in combination with other resistant genes. Genotype “K. Tai” was postulated to have Yr15 plus other unknown genes. Yr15 is a T.-dicoccoides-derived stripe rust resistant gene with all stage resistance (ASR) located on chromosome 1BS [35] and was found in 25 wheat lines from Iran [20]. The genotypes that had an unknown gene postulated include all the Watkins lines except “1190120,” exhibiting more than 50S in either one of the locations tested, which is an indication of the lack of effective genes against the pathotypes present in that environment.

The effectiveness of stripe rust genes against the new Pst pathotypes is not clear and the genetic background plays a big role in this; hence, it is important to have a diverse germplasm for testing [36–38]. Yr15 and Yr65 are among the genes that are still effective, while Yr9 and Yr10 are among the ineffective genes [39].

5. Conclusions

Evaluation of Kenyan and Watkins lines with twelve races from Kenya, Eritrea, Denmark, Sweden, and U.K. indicated that race DK02d/12 from Denmark was more virulent on the genotypes than any other race except genotype “K. Tai,” which was resistant to these races and others; hence it is useful for breeding wheat cultivars with resistance to stripe rust. The twenty wheat genotypes that exhibited similar infection type responses as the tester lines could have had the same genes as the tester lines, but this needs further research to confirm the genes present.

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