Chapter

Past, Current and Future of Wheat Diseases in Kenya

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Abstract

Wheat (*Triticum aestivum* L.) is an important cereal and is among the crops that contribute significantly to food security in Kenya. However, wheat diseases are among the biotic factors that affect wheat production. Considerable progress has been made to control wheat diseases through host plant resistance breeding and chemical applications. Frequent changes in the pathogens population still present a major challenge to achieving durable resistance. Disease surveillance and monitoring of the pathogens have revealed the changes in virulence across the region, justifying the need to develop and deploy more efficient and sustainable strategies to manage the diseases. Understanding the genetic variability and composition of the diseases is important for variety release with appropriate resistance gene combinations for sustainable disease management. This review highlights the prevalence, distribution of wheat diseases, host plant resistance in the key wheat-growing regions of Kenya, and future prospects in Kenya.

Keywords: wheat, diseases, challenges, control strategies

1. Introduction

Wheat (*Triticum aestivum* L) is the second most important cereal crop in Kenya after maize and is produced mainly under rainfed conditions on 0.4% of the arable land [1, 2]. The crop has greater potential in the country where it is grown in Agro-ecological zones: UH2-UH3; LH2-LH3) [3]. Annual estimated area under production is 150,000 hectares [4] with a production of 320,000MT in 2019 compared to local consumption of 2,450,000MT [5]. The national demand for wheat and wheat consumption is on the increase, partly due to the high population growth, increased urbanization, and changing diet [6, 7]. The local wheat production has not been able to meet this demand leading to the importation of large quantities to fill the gap between supply and demand [8]. However, this is unlikely to be satisfied partly due to pre-harvest sprouting, lodging, losses caused by re-emerging diseases, insect pests, intermittent droughts [6, 9], inadequate seed systems, and poor crop practices under resource-constrained small scale farming conditions. The crop grows in a considerably wide range of altitudes in the country, maturing between 90–145 days depending on the location and cultivars.

There are various wheat diseases such as fungal, which include stem or black rust, caused by *Puccinia graminis* f. sp. *tritici* Erikss and Henning (*Pgt*), yellow/stripe rust,

caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*), leaf/brown rust caused by *Puccinia triticina* (*Pt*) and Fusarium caused by *Gibberella zeae* that infect wheat in Kenya. Other diseases include Septoria leaf and glume blotch caused by *S. tritici* and *S. nodorum*, respectively Spot blotch (*Bipolaris sorokiniana*), Loose smut (*Ustilago tritici*), Take All (*Gaeumannomyces graminis* var. *tritici*) and a viral disease, Barley Yellow Dwarf, causal agent Barley Yellow Dwarf Virus (BYDV) [10].

1.1 Wheat rust diseases in Kenya

Among the wheat diseases, rusts have become the most destructive diseases of wheat in Kenya resulting in yield losses of up to 100% in susceptible cultivars [10, 11]. Breeders have been breeding for wheat rust resistance, since 1908, but up to date, there is no permanent solution to the rust diseases as the pathogens keep on evolving rendering the resistant cultivars ineffective [12]. Since the beginning of the wheat breeding program in Kenya in the 1900s, until early 1980s, stem rust was the most serious disease of the three wheat rusts and therefore was given a high research priority by the breeding program. Consequently, many resistant wheat cultivars were developed and the disease seemed to have been controlled. It was until between 1985 and 1988 that trace amounts of the disease were observed in the experimental plots in Njoro; in 1996, it was recorded in some commercial cultivars in Mau-Narok and Molo, and in the year 2000 all the cultivars had become susceptible [10, 12].

Stem or black rust of wheat, caused by *Pgt* is known historically for causing severe losses to wheat production and was the most feared disease in various countries where wheat is grown [13]. The common host is wheat with other small grain cereals, durum wheat (*Triticum durum*), barley (*Hordeum vulgare* L), Rye (*Secale cereael* L.), oats (*Avena fatua* L.), wild barley, goatgrass and forage grasses [14]. Although the disease has been under control through widespread use of resistant cultivars, the re-emergence of a new virulent race, Ug99 [15] first keyed to pathotype TTKS [16] using the North American nomenclature [17] and later as TTKSK after a fifth set of differentials was adapted to further expand the characterization [18]. Prior to the official reporting of the new race, trace amounts of the disease were observed in experimental plots in Njoro between 1985 and 1988, in 1996 the disease was recorded in some commercial cultivars in Mau-Narok and Molo (high altitude areas) in 1996 and in 2000 all the cultivars had become susceptible [10, 12]. This Ug99 race group has evolved and is now composed of 15 races in 14 countries [19–21] with 12 variants (TTKSK, TTKST, TTTSK, PTKSK, PTKST, TTKTT, TTKTK, TTHSK, PTKTK, TTHST, TTKTT+, TTHTT) present in Kenya reversing the gains made by breeders, posing a new and significant threat to wheat production in the Eastern Africa region [16]. In the year 2016, race TKTTF (Digalu race) was genotyped in Kenya for the first time. A new variant TTKTT+ with additional virulence on *Sr*8155B1 was detected in 2019 and another new variant, TTHTT detected in Kenya in 2020 [22]. This is an indication that Ug99 race group is spreading faster specifically, in the areas where close to one billion people reside and the majority of this population consumes wheat and its products [23].

Wheat yellow or stripe rust, caused by *Pst*, is one of the key economical diseases of wheat worldwide [24, 25]. In Kenya, it occurred as early as 1908 and is prevalent in the Rift valley region [12, 26, 27]. Since then it has become a major threat every year as no commercial cultivar is resistant [28, 29]. Serious attacks of the pathogen occur annually and newly introduced resistant cultivars lose their resistance within a short time.

Stripe rust to limits wheat production by affecting the yield and quality of kernels as it develops at an early crop stage when temperatures are favorable for rust development [30]. Stripe rust destroys leaves at jointing to booting growth stages. Consequently, infection of stripe rust on wheat reduces photosynthetic area as early as tillering and jointing stages of development. Stripe rust epidemic has occurred in more than 60 countries in every continent causing yield losses of up to 100% in susceptible cultivars [31]. In East Africa, Kenya, and Ethiopia the epidemics caused yield loss of 67–100% in the year 2010 [25]. In Kenya, wheat is grown throughout the year in different agro-ecological zones, and this increases the concentration of the urediniospores in the air making it difficult to control the disease in susceptible varieties [12, 16]. Yield losses of up to 80% have been estimated but some fields with susceptible cultivars go up to 100% [10, 25].

Stripe rust is a global problem evolving into different races, either from their wild ancestor or their host through introductions [32]. In Kenya and Ethiopia *Yr9* and *Yr27* based cultivars broke down due to evolution of virulent stripe rust races to these genes resulting to yield losses of up to 40% in commercial cultivars like Paa that carried *Yr9* gene [12, 33]. Stripe rust race 134 with virulence for *Yr7*, *6*, *9+* genes were present in Ethiopia, Kenya, Syria, and Yemen [34]. Thirteen races with virulence corresponding to stripe rust resistance genes *Yr1*, *Yr2*, *Yr3*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17*, *Yr25*, *Yr27,* and *Avocet S* are present in wheat-growing regions of Kenya [35], these races belong to either strain *Pst1* or *Pst2* which might have been present much earlier than 1982 and 1970.

Wheat leaf rust caused by *Pt* is the most common and widely distributed of the three wheat rusts and occurs in more regions than stem rust and stripe rust [36, 37]. Leaf rust mostly infects wheat in low to medium altitude wheat-growing areas of Kenya [38, 39]. The earliest epidemics of this rust were reported in Kenya as early as 1908 [26]; therefore, it is considered to be among the major three wheat rusts (stem, yellow and leaf) responsible for depressing crop yields drastically depending on the cultivar because of its high frequency and widespread occurrence. Yield losses attributed to leaf rust have been reported to range from 5–16% on average, and up to 40% in epidemic years [40]. Yield losses are usually the result of lower kernel weights and decreased number of kernels as the pathogen may kill wheat seedlings by elevating respiration rate, reducing photosynthetic area on the leaf surfaces, and lessening translocation of carbohydrates [41]. In Kenya, the disease appears sporadically and has not been a problem for the past 20 years, but it has recently emerged in the wheat fields, and experimental plots, including the Kenya Agricultural and Livestock Research Organization (KALRO), Njoro international screening nursery with severity of over 50% [42]. One of the recent studies [43] reported a high reduction in grain yield and kernel weight in some of the Kenyan wheat cultivars.

Highly effective durable resistance to leaf rust has been difficult to achieve due to the high degree of virulence variation in the *Pt* population and the rapid selection of races with virulence to effective *Lr* genes in wheat genotypes [44]. This high degree of specificity has made durable rust resistance in wheat difficult to achieve because the virulence of leaf rust against wheat resistance genes is highly diverse resulting in the existence of many different pathogenic races [37]. For instance, the novel race BBG/BN and its variant BBG/BP overcame the resistance of widely adapted durum cultivars in northwestern Mexico. In Kenya, leaf rust samples collected from wheat-growing areas were found to have virulence for leaf rust resistance genes *Lr*1, *Lr*2b, *Lr*3, *Lr*9, *Lr*11, *Lr*12, *Lr*14a, *Lr*14b, *Lr*18, *Lr*20, Lr22a, *Lr*23, *Lr*24, *Lr*26, and *Lr27*. The race for an isolate collected from Ololulung'a, Narok in the South Rift region was designated as LBBTN [45].

1.2 Other wheat diseases in Kenya

Fusarium diseases, mainly Fusarium head blight of wheat (FHB), also called head scab, are caused mainly by the fungus *Gibberella zeae* (also known as *Fusarium graminearum),* periodically causes significant yield losses and reduced grain quality. *Gibberella zeae* also produces mycotoxins [46]. All Kenya wheat cultivars are susceptible to Fusarium infection [47]. Studies done in Kenya show that the prevalence of FHB and yield loss due to FHB varies from trace to 100% [47, 48].

Septoria diseases are caused by *S. tritici* and *S. nodorum* [49]. Yield losses attributed to heavy incidences of *S. tritici* and *S. nodorum* have been reported to range from 31–53% resulting in shriveled kernels [49]. The occurrence of Septoria diseases in the wheat-growing areas of Kenya is sporadic and severe infection leading to shriveled grain is observed (Wanyera, Personal observation). Some of the foliar fungicides recommended for the control of rust diseases in wheat have been observed to reduce Septoria disease infection when applied at the right time. These foliar fungicides include: (*azoxystrobin* 200 g/L+ *tebuconazole* 300 g/L (Stamina 500 SC); *benzovindiflupy* 30 g/L + *azoxystrobin*114G/L + *propiconazole* 132 g/L (Elatus Arc 265.14 SE); *difenaconazole* 125 g/L + *azoxystrobin*200g/L (Token 325 SC); (trifloxystrobin250g/Kg/L + *tebuconazole* 500 g/Kg (Shadow 750 WG).

Spot blotch caused by *Bipolaris sorokiniana* (Sacc) Shoemaker, perfect stage *Cochliobolus sativus* (S.Ito & Kurib) also causes black point, root rot, and crown rot in wheat. It is known to occur worldwide in warmer environments and is a serious constraint in wheat production in India, Bangladesh, and Nepal [50]. It is also a serious problem on barley. The disease can attack all parts of the wheat plant (seed, roots, shoots and leaves) causing seed-rot, seedling emergence, reduced yield affecting end-use quality of the harvested grain [51, 52]. *Bipolaris* sp. is known to reduce seed viability in wheat and also causes a significant reduction in seed quality and flour [53]. Yield loss estimates of 15–25% and 30% have been reported [54] and on barley in Canada [55].

The sudden upsurge of *Bipolari*s sp. in certain areas of the country has been associated with acid soils. It is estimated that 30% of the soil in the wheat-growing areas is acidic. High infection has been recorded on wheat cultivars Ngamia in Uasin Gishu county (North Rift) and Kenya Nyangumi in Rongai areas of Nakuru county (Central Rift) (Wanyera, Personal observation).

The highland areas of wheat production in Kenya: Molo, Mau Narok (Central Rift), Eldoret and Endebess (North Rift) have a pH of 4.3–5.5 [56]. All wheat cultivars grown in these areas have shown susceptibility to the pathogen but no direct screening has been done. Aluminum toxicity in acid soils has been documented as the primary factor in the reduction of the crop yields [56]. Seed borne nature of the disease has been reported in wheat cultivars in Kenya [57, 58], and studies on disease management revealed that the pathogen can be reduced by the use of seed treatment fungicides [59]. Biological control methods have also been reported [60, 61].

Loose smut caused by *Ustilago tritici* is seed-borne and common in the wheat-growing areas of the world. Infection occurs during flowering through wind-borne spores. In Kenya, the disease occurs rarely and is mostly observed in recycled wheat seeds.

Take All (*Gaeumannomyces graminis* var. *tritici*) is soil and debri-borne, detected mostly in fields that are continuously cultivated with cereals. Both Loose smut and Take All are well managed through use of certified seed, cultural control, and seed treatment fungicides. Some of the recommended seed treatment fungicides are:

prothioconazole 100 g/L (Redigo FS100), *difenoconazole*92g/L + *metalaxyl-M* 23 g/L (Dividend Extreme 115 FS), and *azoxystrobin* 141.4 g/L+ *propiconazole*122.4 g/L (Quilt Excel 263.5 SE) [6].

Apart from fungal diseases, another disease that threatens wheat production in Kenya is the Barley Yellow Dwarf Virus (BYDV), which is an important virus disease of cereals globally and has a wide host range that includes wheat, barley, oats, triticale, and over 150 grass species [51]. The disease was first reported in Kenya in 1984 and causes serious damage in barley, wheat, and oats and estimated losses range from 16.5–54.7% [62, 63]. Cereal aphids are vectors of the barley yellow dwarf and five strains have been known to occur in Kenya: RPV (*Rhopalosiphumpadi*), RMV (*R. maidis*), MAV (*Sitobionavenae*), SGV (*Schizaphis graminum*), and PAV (*R. padi*, *S. avenae* [63]. Outbreaks are frequent, and management practices require use of seed dressing insecticides: Gaucho 350FS (*Imidacloprid*), Cruiser 350FS (*Thiamethoxam*), Redigo Deter 350FS (*Clothianidin + prothioconazole*), Celest Top 312FS (*Thiamethoxam* + fludioxonil +difenoconozole, and (ii) foliar-applied insecticides (Karate Zeon (*Lambda-cyhalothrin*), Bulldock star 262.5EC (*Betacyfluthrin + Chlorpyrifos*), Thunder OD 145 (*Imidacloprid + Betacyfluthrin*), Keshet 2.5EC (*Deltamethrin*),Twigathoate 40EC (*Dimethoate*), Nurelle D 50/505 EC (*Cypermethrin + Chlorpyrifos*), Alphadime (*Alpha-cypermethrin + Dimethoate*), Cyclone 505EC (*Cypermethrin + Chlorpyrifos*), and Pirimor 50WG (*Pirimicarb*) [6, 64, 65].

Under favorable environmental conditions, infection of the wheat crop with these diseases can reduce quantity and quality of the grain. Disease surveillance is an epidemiological practice by which the spread is monitored to establish patterns of progression and is key in identifying new diseases and races which can be used in risk assessment and resistance breeding. This review highlights the prevalence, distribution of wheat diseases, host plant resistance in the key wheat-growing regions, and future prospects in Kenya.

1.3 Distribution of diseases in wheat-growing regions of Kenya

Surveys were conducted in the farmer fields in the major wheat-growing regions (Central Rift, South Rift, North Rift, and Mount (Mt) Kenya from 2011 to 2019. The objective was to determine the prevalence and distribution of the wheat diseases and host plant resistance in these regions. Farms were randomly picked along the routes, stopping at every 3 to 5 kilometers. Crops were observed for disease symptoms. An International Standardized survey form was used to keep the records on disease incidence and severity, cultivar grown, production area, and growth stage [66], also any other data that was useful. The Global positioning system (GPS) tool was used to collect precise information on latitude, longitude, and elevation of the sampled farms. Stem, yellow, and leaf rust severities were taken using modified Cobb scale, 0–100% where; 0- immune and 100- susceptible [67]. The host plant response to infection was scored as resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible(S) [68]. Incidence and severity of other diseases observed during the surveys were also taken using recommended scales. Septoria diseases were assessed using 0–9 scale [49], where 0 = Free from infection and 9 = Very susceptible/severe infection. Similarly, barley yellow dwarf virus was assessed on a scale of 0–9 [69], where 0 = no symptoms and 9 = full symptom expression, and the Fusarium disease score rating system was 0–5 [70]. **Tables 1** and **2** show the occurrence (percent infection and severity & plant response) of the diseases in all the wheat-growing regions. Rust diseases are common in the wheat fields and stem rust is widespread in all the regions.

Year	Region	No. of sampled farms	Sr % Infection (%)	Sr % severity and plant response	Yr infection (%)	Yr % severity and plant response	Lr Infection (%)	Lr% severity (%)
2011	Central Rift	62	70.9	0-100S	17.7	TR -60S	17.7	TR-40S
	South Rift	125	68.8	TR-100S	6.4	TR- 20S	17.7	TR-20S
	North Rift	73	48.3	TR-90S	10.9	TR- 20S	10.9	TR-20S
	Mt. Kenya region	67	68.0	TR- 60S	10.4	0 - 40S	13.4	TR-20S
	Total/ Mean	**327**	**63.9**		**11.3**		**14.9**	
2012	Central Rift	67	65.7	TR-80S	4.5	5-50S	11.9	5-30S
	South Rift	71	5.6	TR-20S	—	—	—	—
	North Rift	101	26.7	TR-70S	5.9	5-70S	3.9	10-50S
	Mt. Kenya region	39	58.9	TR-50S	5.1%	5-60S	2.6	30S
	Total/ Mean	**278**	**39.2**		**3.9**		**4.6**	
2013	Central Rift	97	71.0	TR-70S	8.3	TR-50S	6.7	TR-50S
	South Rift	104	68.3	TR-100S	3.8	10S–30S	5.8	TR-50S
	North Rift	78	33.3	TR-70S	10.3	TR-50S	6.5	TR-50S
	Mt. Kenya region	54	25.9	TR-60S	7.4	10S–30S	0	0
	Total/ Mean	**333**	**49.6**		**7.5**		**4.8**	
2014	Central Rift	92	82.5	TR-80S	6.2	TR -50S	6.2	10S–50S
	South Rift	79	72.2	TR-80S	8.9	TR- 60S	—	—
	North Rift	95	55.8	TR-80S	6.3	TR- 40S	5.3	0 - 40S
	Mt. Kenya region	71	57.7	TR- 60S	15.5	5S - 60S	1.4	0-40S
	Total/ Mean	**342**	**67.05**		**4.0**		**4.0**	
2015	Central Rift	66	54.54	TR-80S	5.8	5S–40S	1.5	0-30S
	South Rift	101	35.6	TR-60S	—	—	—	—
	North Rift	106	75.5	TR-50S	8.5	TR-40S	1.9	TR-30S
	Mt. Kenya region	63	71.4	TR-60S	—	—	—	—
	Total/ Mean	**336**	**59.26**		**3.58**		**0.85**	
2016	Central Rift	60	88.3	TR-80S	16.7	TR-60S	3.3	30S–50S
	South Rift	81	76.5	TR-70S	4.9	TR-10S	1.2	0-50S
	North Rift	98	72.4	TR-80S	13.3	TR-40S	10.2	TR-50S
	Mt. Kenya region	61	80.3	TR-90S	1.6	TR	—	—

Year	Region	No. of sampled farms	Sr % Infection (%)	Sr % severity and plant response	Yr infection (%)	Yr % severity and plant response	Lr Infection (%)	Lr% severity (%)
	Total/ Mean	**300**	**79.38**		**9.13**		**3.68**	
2017	Central Rift	54	87.03	TR-70S	8.9	0 -30S	—	—
	South Rift	79	69.2	TR-100S	3.79	TR- 10S	—	—
	North Rift	78	64.1	TR-60S	8.97	TR- 30S	24.4	TR-40S
	Mt. Kenya region	38	44.1	TR- 30S	10.5	TR - 40S	—	—
	Total/ Mean	**249**	**66.11**		**8.04**		**6.10**	
2018	Central Rift	64	74.0	5-50S	10.0	5-60S	10.0	TR-30S
	South Rift	85	42.2	5-70S	3.3	10S–30S	1.1	TR-40S
	North Rift	89	25.84	5-80S	19.1	5S–60S	24.35	5S–70S
	Mt. Kenya region	62	47.9	5-40S	2.81	10S–30S	—	—
	Total/ Mean	**300**	**47.78**		**8.80**		**4.0**	
2019	Central Rift	56	82.2	TR-50S	2.2	0-40S	—	—
	South Rift	87	83.13	TR-80S	1.2	TR	—	—
	North Rift	101	22.77	TR-40S	7.92	TR-40S	4.95	TR-20S
	Mt. Kenya region	46	63.04	TR-50S	10.86	15S–60S	6.5	5S–30S
	Total/ Mean	**290**	**62.79**		**5.62**		**2.86**	

Sr = Stem rust; Yr = Yellow rust; Lr = Leaf rust; TR- trace; S = susceptible; – = no disease observed.

Table 1.
Occurrence of wheat rust diseases in the commercial fields in year 2011–2019.

This explains the importance of stem rust, Ug99 race group, since its detection in Uganda and spread to the wheat-growing areas of Kenya, throughout eastern Africa, Yemen, Sudan, Iran, Zimbabwe, Tanzania, South Africa, Mozambique, Zimbabwe, and Iraq [15, 16, 22]. The prediction for the rust diseases to spread towards North Africa, Middle East, Asia and beyond, raises serious concerns of major epidemics that could destroy the world's wheat crop [19].

Yellow rust, which was first described in 1777, and attacked wheat in Kenya as early as 1908 [26], was observed in low incidences but high severities across all the regions (**Table 1**). The disease is also a major threat as no cultivar is resistant [28, 29]. Newly introduced resistant varieties lose their resistance within a short time and farmers are forced to spray to save on yields. Serious attacks of the pathogen occur annually and the disease severity increases with altitude [33]. Serious epidemics also occur in the lower latitudes areas. All the wheat-growing areas are prone to disease in low medium and high altitudes areas.

In Kenya, leaf rust has been sporadic and has not been a problem for the past 20 years, but it has recently emerged in the wheat fields (**Table 1**), and experimental

Year	Region	No of sampled farms	Disease incidence (%)		
			***Septoria* diseases**	***Fusarium* sp**	**BYDV**
2011	Central Rift	62	16.1	9.6	0
	South Rift	125	4	1.6	0.8
	North Rift	73	27.4	12.3	0
	Mt. Kenya	67	1.5	0	0
2012	Central Rift	67	42.8	8.9	16.4
	South Rift	71	46.5	2.8	0
	North Rift	101	41.8	0.9	0.9
	Mt. Kenya	39	17.9	2.7	0
2013	Central Rift	97	8.2	6.2	2.1
	South Rift	104	14.4	0.9	0.9
	North Rift	78	28.2	0	0
	Mt. Kenya	54	45.3	1.9	0

Table 2.
Occurrence of Septoria *diseases,* Fusarium *sp. and Barley yellow dwarf virus (BYDV) in commercial wheat field year 2011, 2012, and 2013.*

plots, including the international screening nursery with a severity of over 50%. Our cultivars are now at risk given the fact that virulences and new races have been identified in Njoro and also South Rift, Ololulung'a areas (data not shown).

The growing of wheat in diverse agro-ecological zones throughout the year [71, 72] in Kenya creates a significant pool of airborne urediniospores, which coupled with favorable climatic conditions and the presence of host plants, favors rapid build up of inoculum and the occurrence of epidemics. This implies that there is a shift in races present each year, which affects different cultivars of wheat. There is continuous attack, due to the presence of wheat crops throughout the year. The breakdown in resistance could also be attributed to mutations [24]. It is, therefore, a problem to reduce the disease infection in susceptible cultivars and also not possible to grow a profitable crop of wheat without the application of fungicides [10, 16]. Septoria diseases, Fusarium spp., Barley yellow dwarf virus are also becoming more prevalent in the commercial fields (**Table 2**), year 2011 to 2013. Disease incidence varied from year to year depending on the chemical/spray applied. Data for the occurrence of these diseases from 2014 to 2019 was not shown because it was similar as shown in **Table 2**.

1.4 Wheat breeding in Kenya

Conventional breeding, which includes testing genotypes in different environments to determine the adaptability of the varieties has been used largely in Kenyan wheat breeding programs to identify resistant varieties [72]. Crop improvement by traditional methods, involves collection, hybridization, and inbreeding that has been practiced since the beginning of 20th Century. However, it has now been realized that these methods are insufficient to make further breakthroughs or cope with the increasing demand for improvement in crop varieties [73]. Some of the limitations of conventional breeding include the exhaustion of the gene pool, low response to biotic and abiotic stress of the introduced materials, and low combining ability, especially

with complex characters. In Kenya, diverse agro-ecological zones and favorable environs highly contribute to the emergence of new races. The cultivars grown are at high risk of being infected with diseases, therefore, it is necessary to identify and incorporate genes that confer durable resistance to contain major epidemics [74, 75]. There are various strategies employed to control these diseases in wheat. These include incorporation of genetic resistance into susceptible wheat genotypes, crop management plus use of fungicides. Despite the fact that it takes a long-time, breeding for durable resistance remains to be a cost-effective strategy of minimizing loss due to wheat diseases [76]. Therefore, host resistance is the primary tool to protect wheat crops from wheat fungal rust diseases and other biotic stresses [77]. Breeding for vertical (qualitative) resistance based on major genes and horizontal (quantitative) influenced by several minor genes for wheat disease resistance has been going on in Kenya since wheat introduction in the 19th century. However, due to pathogen evolution, most of the genotypes with qualitative and quantitative resistance become susceptible to the new races, especially wheat rusts pathogens. For instance, wheat cultivars Robin and Eagle 10 released in Kenya as resistant varieties in 2009 and 2010 were overcome by Ug99 variant *Sr*Tmp [78, 79]. Durable resistance by selecting resistant wheat varieties has been going on in Kenya for the past decades, most of the varieties released with resistant genes are now ineffective against the evolving wheat rusts pathogens (**Table 3**).

Kenyan wheat cultivars Robin, NjoroBW2, KS Mwamba, Kwale, Kenya Korongo, Robin, Eagle 10, Kenya Black Hawk 12 (**Tables 3** and **4**), and Kenya Seed Company cultivars were grown by most farmers in the wheat-growing regions of Kenya.

In 2011, KS Mwamba occupied the largest area in Central and South Rift (50.4%), North Rift (45.2%), and in Mount Kenya region 33.8% (**Table 3**). In 2012, the area planted with NjoroBW2 increased: 34.3%, 39.4%, 60.4%, while it decreased for KS Mwamba, 14.9%, 15.5%, and 28.7% in Central, South, and North Rift, respectively (**Table 3**). Cultivar Kwale was highly grown in Central Rift (20.9%), Mt. Kenya (23.1%), and South Rift (20.2%) in 2013. For the cultivars released in 2010 with adult plant resistance (APR) to the wheat stem rust race *Ug99*, Robin occupied 20.6% in Central Rift, 22.2% in Mt. Kenya, 7.7% in North Rift (2013). Cultivar Eagle 10 occupied 1.6% in Mt. Kenya region and 0.9% in South Rift. Mixed and other unknown

No	Variety	Region and variety area planted (%)											
		Central Rift			South Rift			North Rift			Mt.Kenya		
		2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
1	NjoroBW2	30.4	34.3	24.7	29.6	39.4	42.3	49.0	60.4	57.7	26.2	—	—
2	KS Mwamba	50.4	14.9	12.3	50.4	15.5	20.2	45.2	28.7	26.9	33.8	25.6	25.9
3	Kwale	14.0	20.9	14.4	14.4	9.9	20.2	4.1	1.9	5.1	6.2	23.1	11.4
4	Robin	—	7.5	20.6	—	1.4	—	—	—	7.7	—	—	22.2
5	Mixed	3.2	8.9	10.3	—	—	1.9	1.3	5.9	1.3	—	17.9	7.4
6	Eagle10	1.6	—	—	—	1.4	0.9		—	—	—	—	1.6
7	Others	0.4	13.5	17.7	5.6	32.4	14.5	0.4	3.1	1.3	33.8	33.1	31.5

-cultivar not planted.

Table 3.
Commonly grown cultivars in the key wheat-growing regions in the year 2011–2013.

Commercial Name	Pedigree	Yield potential tons/Ha	Days to Maturity	Year of release	Resistant status
Robin	BABAX/LR42//BABAX*2/3/TUKURU	8.1	110–120	2009	Overcome by TTKTT race in 2014
Eagle10	EMB16/CBRD//CBRD	6.5	100–110	2010	Good resistance to stem rust (Ug99 strain).
Kenya Wren	THELIN#2/TUKURU	8.5	120–130	2012	APR to both yellow and stem rust diseases.
Kenya Tai	ND643/2*WBLLI	6.5	100–110	2012	Resistant to both stem rust and yellow rust.
Kenya Sunbird	ND643/2*WBLLI	6.5	100–110	2012	Resistance to stem rust,
Kenya Korongo	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3KAUZ*2/TRAP//KAUZ	8.5	120–130	2012	Overcome by TTKTT race in 2014
Kenya Kingbird	TAM-200/TUI/6/PAVON-76//CAR-422/ANAHUAC-75/5/BOBWHITE/CROW//BUCKBUCK/PAVON-76/3/YECORA-70/4/TRAP-1	6.0	90–110	2012	Developed for Adult plant resistance to both stem rust and yellow rust.
Black Hawk12	URES/JUN//KAUZ/3/BABAX/4/TILHI	8.0	120–130	2012	Overcome by TTKTT race in 2014
Kenya Hornbill	PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1	7.5	110–120	2016	High APR to yellow rust and moderate resistance to stem rust.
Kenya Deer	PBW343*2/KUKUNA*2//YANAC	7.8	100–110	2016	High adult plant resistance to stem rust and yellow.
Kenya Weaverbird	PRINIA/3/ALTAR84/AE. SQ //2*OPATA/4/CHEN/AEGILOPS SQUARROSA(TAUS)//BCN/3/BAV92	8.0	110–120	2016	High APR to stem rust.
Kenya Peacock	QUAIU/3/PGO/SERI/BAV92		120–130	2016	High APR to both stem and yellow rusts.
Kenya Falcon	KSW/5/2*ATLAR 84/AE. SQUARROSA (221)//3*BORL95/3/URES/JUN/KAUZ/4/WBLL1	8.0	100–115	2016	Excellent seedling and APR to stem rust. Highly resistant to yellow rust
Kenya Songbird	KSW/5/2*ALTAR 84/AE. SQUARROSA (221)//3*BORL95/3/URES/JUN/KAUZ/4/WBLL1	8.2	110–120	2016	_

Commercial Name	Pedigree	Yield potential tons/Ha	Days to Maturity	Year of release	Resistant status
Kenya Pelican	KSW/5/2*ALTAR84 /AE. AQUARROSA (221)//3*BORL95/3/URES/JUN/KAUZ/4/WBLL1	8.5	120–130	2016	High APR to stem rust.
Kenya Jacana	KSW/SAUAL//SAUAL/3/REEDLING #1	6.5–8.0	110–130 Days	2019	Moderately resistant to original Ug99 races. In warmer weather, susceptible to race "TTKTT"
Kenya Kasuko	KSW/SAUAL//SAUAL/3/REEDLING #1	7.0–8.0	110–120 Days	2019	Moderately resistant to original Ug99 races. In warmer weather, susceptible to race "TTKTT"

APR = adult plant resistant.
Source: http://wheatatlas.org/country/varieties/KEN/0?AspxAutoDetectCookieSupport=1.

Table 4.
Current wheat varieties released in Kenya, their yield potential and resistant attributes.

cultivars were common across the regions and this could be due to the high cost of certified seed.

In 2014, cultivar Robin was highest in Central Rift (43.3%), South Rift (41.8%), and Mt. Kenya region (43.7%) while cultivar NjoroBW2 was highest in North Rift (64.2%), Central Rift (15.5%), Mt. Kenya (12.7%), and South Rift (8.9%). KS Mwamba was highest in North Rift (16.4%), Central Rift (15.5%), South Rift (11.4%), and Mount Kenya (9.9%). The area under cultivar Kwale was highest in Central Rift (10.3%), followed by South Rift and Mt. Kenya region (7.6% and 7.0%), respectively. The area under cultivar Eagle 10 was only noted in South Rift 18.9% and overall occupied only 4.4% across the region. Mixed and other unknown cultivars were common in Mt. Kenya region: Kenya Ibis occupied 1.2%, Duma (0.6%), mixed cultivars (1.8%).

In 2015, the area planted with NjoroBW2 increased in North Rift from 63.2% in 2014 to 70.6% in 2015 cultivar Robin increased in Mt. Kenya region (66.7%) as opposed to 2014 (43.7%), but decreased in Central Rift from to 21.2%. The area under production in North Rift increased from to 16.5% and decreased in South Rift from 35.6%. Cultivar Eagle 10 was only observed in South Rift (20.8%) of the sampled fields. Cultivars Kenya Wren and Kenya Hawk12 were observed only in the South Rift (1.9%).

The area planted on NjoroBW2 decreased in North Rift to 64.3% Mt. Kenya 49.2% in 2016. Cultivar Eagle 10 was only grown in South Rift (9.9%) and in North Rift (2.0%) of the sampled fields. Cultivars Kenya Wren was grown in South Rift (2.5%) and North Rift (1.0%) while Kenya Hawk12 was grown in the South Rift (6.2%). Kenya Korongo was grown in South Rift (8.3%) and North Rift (1.0%).

In 2017, cultivar NjoroBW2 was popular in North Rift (69.2%), Central Rift (40.7%), and South Rift (32.9%). Robin was popular in Mt. Kenya region (32.4%), followed by South Rift (20.3%), Central Rift (10.7%), and North Rift (7.7%). Kenya Korongo was only popular in the Central Rift (27.8%). Kwale was popular in Central Rift (7.4%), South Rift (6.3%), and Mt. Kenya (5.3%) area under production of the sampled fields. Cultivar NjoroBW2 occupied the largest area in North Rift (69.2%) and Central Rift (40.7%). Cultivar Eagle 10 was recorded in South Rift (13.9%), Central Rift (1.9%), and in North Rift (1.3%) of the sampled fields. While variety Duma was popular in Mt. Kenya region (42.1%) area under production of the sampled fields. Kenya Wren was grown in Central Rift 1.9.3%), South Rift (1.3%), and North Rift (1.0%) while Kenya Black Hawk12 was grown in South Rift (6.2%) and North Rift (1.3%). Kingbird was only grown in South Rift (2.5%) and North Rift (1.3%) area under production of the sampled fields.

In 2018, cultivar NjoroBW2 was popular in all the regions: North Rift (70.8%), Central Rift (44.0%), South Rift (34.4%), and Mt. Kenya region (14.08%). Robin was grown in North Rift (16.0%), Mt. Kenya (14.6%), Central Rift (12.0%), and South Rift (11.8). Kenya Korongo was only popular in the Mt. Kenya region (36.6%) while Kwale was grown in Central Rift (8.0%) and South Rift (4.7%). Variety Eagle 10 was only popular in South Rift (14.0%) area under production of the sampled fields. The area under production of variety Eagle 10 remained the same in the South Rift as the previous year. Kenya Wren was only grown in South Rift (3.5%), Kenya Black Hawk12 was grown in North Rift (2.5%). while Kingbird was grown in South Rift (1.2%) and North Rift (1.3%).

In 2019 cultivar NjoroBW2 was popular in Mt. Kenya (43.5%). North Rift (42.5%), Central Rift (39.28%), South Rift (31.0%). Kenya Korongo was grown in Mt. Kenya (23.9%), Central Rift (16.0%), South Rift (11.5%), and North Rift (7.92%). Cultivar Robin was popular in the Mt. Kenya (23.9%), South Rift (13.8%), and Central Rift (5.4%). Kwale was grown in North Rift (9.9.0%), South Rift (8.0%), Mt. Kenya

(6.5%), Central Rift (5.4%) area under production of the sampled fields. Cultivar Eagle 10 was only popular in South Rift (14.9%) and Central Rift (7.1%) area under production of the sampled fields. The Kenya Seed Company cultivars were more popular in the North Rift (24.8%) area under production of the sampled fields.

Over fifty percent of the previously released varieties (**Table 4**) are now susceptible to the Ug99 race. Robin, Kenya Black Hawk12, Kenya Korongo, Kenya Jacana, and Kenya Kasuko are susceptible to Ug99 races (TTKTK and TTKTT) that were detected on Robin with virulence to *Sr*Tmp and virulence to *Sr*24, respectively. The resistance in Kwale and other genotypes like Kenya Plume (not included) is due to adult plant resistance (APR) genes and others associated with variable levels of disease symptoms, which show recessive inheritance and is expressed primarily during the APR which has been deployed in a breeding program in Kenya [80]. Stem rust resistance gene *Sr2* is an APR gene present in some of the Kenyan genotypes such as Kwale, Kenya Swara, Kenya Nyangumi, and Kenya Popo together with other APR genes condition resistance to stem rust [11, 81].

There is a long history of wheat breeding in Kenya as early as 1908, however, the use of molecular breeding tools is very limited thereby hampering the rate of genetic gains achieved. As such, the national breeding program has depended on introductions of wheat lines from international wheat breeding programs including CIMMYT and ICARDA. Understanding the composition and diversity of fungal wheat disease resistance in Kenya wheat germplasm is important for defining breeding strategies and prioritizing trait targets for wheat improvement [82].

Biotechnological approaches in wheat breeding such as double haploid (DH) and mutational breeding have been used to speed up breeding by complementing conventional breeding [72]. DH which shortens the breeding period by a single cycle has been used in Kenya to produce varieties such as K. Ibis. Mutation breeding brings about genetic variation and accelerates the outcome of variety release has been applied at KARLO, Njoro to release varieties NjoroBW2 and K. Heroe by irradiation using gamma rays [72, 83]. Conventional method of gene pyramiding is time-consuming, hence, the incorporation of molecular breeding is efficient in breeding for biotic and abiotic stresses in wheat for quick release of resistant varieties. The use of molecular markers enhances phenotypic selection because it makes it more efficient, effective, reliable, and cost-effective compared to conventional plant breeding, hence improving the latter [84]. There has been some concern about the incorporation of DNA marker technology in many plant-breeding institutions and most institutions can now develop their own markers [85, 86]. Molecular markers such as SSR, AFLP, and KASP markers have been developed to evaluate genotypes for biotic stresses such as diseases in Kenyan varieties [7, 82, 87].

1.5 Control of wheat diseases in Kenya

Other than host plant resistance, cultural and chemical methods have been used to control wheat diseases in Kenya. Cultural control techniques such as growing resistant genotypes, late planting, reduced irrigation, avoidance of excessive nitrogen use, and elimination of volunteer and grass plants can reduce stripe rust severities as they limit exposure time to inoculum [25]. Altering planting date and separating the vulnerable crop from the pathogen in either time or space controls certain airborne disseminated pathogens of wheat [88]. Although the cultural techniques are used, they are either not profitable, conflict with conservation farming, or reduce yield potential [89]. Genetic resistance combined with chemical treatments, although expensive to the

poor resource farmers may often be very effective in controlling wheat diseases [90]. Some of the fungicides used by farmers in Kenya are listed in **Table 5**. The application of seed treatment chemicals such as *triadimenol* (sterol biosynthesis inhibitors) and *carboxin* (respiratory inhibitors) and the use of moderately resistant cultivars is effective in controlling wheat diseases as it provides the most efficient use of fungicides at the lowest rates [91, 92]. Reduced chemical applications could also minimize the potential development of resistance to the chemicals [90]. Although wheat diseases have been controlled by timely use of effective chemicals, the cost of chemicals and their application creates a huge burden for growers. In Kenya, large-scale farmers are the only ones who can afford to spray chemicals, but it costs about $ 8 million annually [10]. Fungicides can be used to control fungal diseases, but they cause environmental hazards and lead to fungicide tolerant strains [25]. Re-emergence of new virulent races has reversed the gains made by breeders, posing a new and significant threat to wheat breeding in Kenya [16]. Resistance in the commercial wheat cultivars in Kenya, including those released in the last decade, has been overcome by the new races making it impossible to grow a profitable crop of wheat without the use of fungicides [10, 90].

During surveys, we noted that farmers who sprayed following the right recommendations of fungicides in **Table 5** had good yields compared to those who did not spray or sprayed without following the proper recommendations hence losing the crop to the disease. Majority of the farmers sprayed the fungicides to reduce/suppress disease infections, particularly the rusts, but some sprayed farms were noted to have high disease infections. These are farms that either had been sprayed late or the timing/ chemical concentrations were not right.

1.6 Future of breeding for wheat diseases resistance in Kenya

Despite the occurrence of wheat diseases in Kenya, information on the genetic basis of the diseases and wheat cultivars is limited. Molecular genetic markers have been advanced from phenotypic and protein-based markers to DNA sequence polymorphism, this accelerates the process of plant breeding when coupled with conventional breeding [93]. Since many traits valued by plant breeders are complex and polygenic, it is essential to involve the deliberate combination of various genomic regions from many different individuals in the development of an adapted elite variety [94]. Sequencing polymorphism markers are important in identifying genetic diversity in cultivated and wild genotypes, the source of novel genomic regions, alleles, and traits [95].

In crops, marker-assisted selection (MAS) has been made efficient by designation of markers associated with economic importance, for instance, disease resistance (wheat rust), response to abiotic stress and seed quality [96, 97]. The use of molecular markers enhances phenotypic selection because it makes it more efficient, effective, reliable, and cost-effective compared to conventional plant breeding hence improving the latter [84]. There has been some concern about the incorporation of DNA marker technology in many plant-breeding institutions but most institutions can now develop their own markers [85, 86].

In genetic studies of wheat, genetic markers such as amplified fragment length polymorphism (AFLP), restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), simple sequence repeat (SSR), and single nucleotide polymorphism (SNP) have been used but they are limited in their own ways [98]. These limitations are being overcome by improving already available techniques to form next-generation sequencing (NGS) [98]. With next-generation

No	Chemical name	Common name	Rate L/ha
1	*trifloxystrobin* 100gL+ *tebuconazole* 200 g/Ll	Nativo 300SC	1.0
2	*prothioconazole* 125gL + *tebuconazole* 125gLl	Prosaro 250EC	1.0
3	*epoxiconazole* 250 g/L	Twiga Epox [GF]	1.0
4	*tebuconazole* 200 g/L	Fezan 250 EW [GF]	1.0
5	*picoxystrobin* 200 g/L + *cyproconazole* 80 g/L	Acanto Plus	1.0
6	*epoxiconazole* 62.5 g/L + *pyraclostrobin* 62.5 g/L	Abacus SE	1.0
7	*epoxiconazole* 18 g/L + *thiophanate methyl* 310 g/L	Rexduo SE	1.0
8	*metconazole* 27.5 g/L+ *epoxiconazole* 37.5 g/L + 200 g/L *picoxystrobin* + 80 g/L *cyproconazole*	Osiris EC	1.0
9	*propiconazole* 62.5 g/L+ *chlorothalonil* 375 g/L + *cyproconazole* 50 g/L	Cherokee 487.5 SE	1.0
10	*propiconazole* 250 g/L + *cyproconazole* 60 g/L	Menara 410EC	0.5
11	*tebuconazole* 430 g/L	Tebulis 430 SC	0.5
12	*tebuconazole* 200 g/L + *azoxystrobin* 200 g/L	Azimut SC	1.0
13	*bixafen* 75 g/L + *prothioconazole* 100 g/L + *tebuconazole*100g/L	Skyway Xpro 275 EC	1.2
14	*propiconazole* 150 g/L + *difeconazole* 150 g/L	Atlas 300EC	1.0
15	*propiconazole* 172.4 g/L + *azoxystrobin* 141.1 g/L	Quilt Excel 265 SE	1.25
16	*epoxiconazole* 187 g/L + *thiophanate methyl* 310 g/L	Swing Xtra 497 SC	1.0
17	*monopotassium phosphate* 43% + *dipotassiumphosphate* 19%	Fosphite Liquid	4.0
18	*azoxystrobin* 80 g/L+ *chlorothalonil* 400 g/L	Amizoc 480 EC	1.8
19	*bixafen* 50 g/L+ *tebuconazole* 166 g/L	Zantara 216 EC	1.0
20	*fluxapyroxad* 41.6 g/L + *epoxiconazole* 41.6 g/L + *pyraclostrobin* 66.60 g/L	Ceriax 149.8 EC	1.0
21	*azoxystrobin* 200 g/L+ *tebuconazole* 300 g/L	Stamina 500SC	0.9
22	*difenaconazole* 125 g/L + *azoxystrobin*200g/L	Token 325 SC	0.75
23	*benzovindiflupy* 30 g/L + *azoxystrobin*114G/L + *propiconazole* 132 g/L	Elatus Arc 265.14 SE	1.0
24	*tebuconazole/tridimenol*	Silvacur 375 EC	1.0
25	*tebuconazole*	Folicur 250 EC	1.0
26	(*trifloxystrobin* 250g/Kg/L + *tebuconazole* 500 g/Kg))	Shadow 750 WG SC	400 g

** Can control Fusarium Head Blight (FHB) when spayed at flowering** Can control Fusarium Head Blight (FHB) and Septoria diseases GF- Generic fungicide.*

Table 5.
Recommended fungicides for control/reduction of foliar wheat diseases in Kenya.

sequencing (NGS) technologies, SNP markers have been discovered in wheat, which is a good choice due to their abundance in the genome as they are distributed across all the wheat chromosomes [99]. These technologies offer easier means to map

polymorphic genetic loci and identify genes for important traits [98]. Microsatellite markers have been used to determine the genetic diversity of wheat stem rust races in Kenya ([100]; Wanyera, unpublished data).

1.6.1 Single nucleotide polymorphism (SNP) markers

Single nucleotide variations in genome sequences of individuals of a population are known as SNPs. They result when DNA sequence differs by a single base and are the most abundant molecular markers in the genome [101]. SNPs and flanking sequences are found by library construction and sequencing or through the screening of readily available sequence databases [102]. Genotyping methods, including DNA chips, allele-specific PCR, and primer extension approaches based on SNPs, are particularly attractive for their high data throughput and for suitability for automation [103]. They are used for a wide range of purposes, including rapid identification of crop cultivars and construction of ultra-high-density genetic maps [103, 104]. SNPs markers have been used in wheat in identifying resistance genes for stripe rust *Yr5*, leaf rust *Lr16*, stem rust *Sr6*, the waxy starch gene Wx-D, and Karnal bunt resistance among others [105–107].

1.6.2 Kompetitive allele specific PCR (KASP) markers

Application of modern marker-assisted breeding approaches can help accelerate variety development efforts, single nucleotide polymorphisms (SNPs) markers have emerged as powerful tools for many genetic applications mainly due to their low assay cost, high abundance, co-dominant inheritance, high-throughput, and ease of use [101]. Numerous genotyping platforms have therefore been developed for SNP genotyping [108, 109] including KASP (Kompetitive Allele Specific PCR) which is a gel-free and fluorescent-based genotyping platform. KASP is fast emerging as a global benchmark in SNP genotyping [110, 111] developed and validated 70 KASP assays for functional genes controlling economically important traits such as plant height, disease resistance, yield, and quality in bread wheat. KASP markers have been used to determine alleles for important agronomic traits in wheat in East Africa, Kenya, and Ethiopia [82].

1.6.3 Use of sequence-characterized-amplified region (SCAR)

The application of molecular markers in different epidemiological studies is crucial in developing strain-specific markers such as Sequence-characterized-amplified-region (SCAR) markers [112]. The SCAR markers are codominant, while others are dominant single locus which allows for quick and easy PCR amplification-based detection and hence used in the studies of pathogens [113]. The SCAR markers are efficient in testing large samples and useful in tracing the origin and spread of microbial pathogens with the ability for long-distance disposal and invasion like yellow rust [114]. SCAR markers SCAR1265 and SCAR1400 were developed in wheat to identify powdery mildew (*B. graminis*) gene *Pm21,* which was located on 6AL/6Vs same locus for gene *Yr26* [115]. Species-specific sequence-characterized-amplified-region (SCAR) markers have been used to characterize stripe rust races in Kenya [35].

2. Conclusion

There are high disease incidences and severity of wheat diseases particularly wheat rusts in the farmers' fields, which is attributed to the use of highly susceptible wheat cultivars and also climate change contributing to emerging of new diseases. For example, the evolution and spread of Ug99 race group and additional races like Digalu race (TKTTF) are spreading very fast causing epidemics subjecting the wheat germplasm to vulnerability.

Other wheat diseases such as *Septoria* and *Fusarium* although sporadic are also a major concern in the wheat-growing regions in the country. The increase in the spread of these diseases is largely due to the widespread of cultivars that are highly susceptible. The favorable climatic conditions and additional costs of fungicides qualify the diseases as damaging with a strong impact on wheat production. Varieties with adequate resistance are now being released and continued monitoring of disease virulences throughout the country is necessary to detect shifts in the pathogen population as early as possible and therefore to effect an appropriate breeding strategy. Effective genetic control of the diseases using the state of the art molecular techniques will require a coordinated effort, including race monitoring, collection, and characterization of sources of resistance and resistance breeding.

In Kenya, different research groups consisting of plant breeders, plant pathologists, agronomists, international partners, and farmers are working towards achieving host plant resistance and ways to combat wheat diseases in order to achieve high yields and contribute to food security.

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