Chapter 1

Wheat in Kenya: Past and Twenty-First Century Breeding

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Additional information is available at the end of the chapter

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Abstract

Plant breeders aim to improve crop varieties to benefit humankind. Since wheat was introduced in Kenya, numerous varieties have been released and cultivated to varying extents. Past genetic gains have been fragile due to various environmental challenges-mostly rust diseases, and unfavorable socio-economic national policy for the crop. The role and the contribution of wheat breeding to the success of the crop in Kenya for over a century is reviewed. It is considered that systematic exploitation of local and introduced genetic diversity has contributed to release of varieties with superior genetics over time, enhancing productivity from 1 ton/ha in the 1920's to approximately 3 tons/ha recently. Consistent rise in demand to about 1 million metric tons suggests that the national wheat breeding research program must be remodeled to leverage modern tools and best practices; to reconsider its target range of breeding environments in the wake of climate change; to entrench its engagement with the international wheat research programs; and to promote a culture of continuous mentorship. Here, cases are highlighted where the national program has moved in such positive directions to address the varietal needs of a crop that has fully integrated in the economy and the diets of many Kenyans.

Keywords: Kenya wheat, rust, breeding cycle, phenotyping, genomics

1. Introduction

Traditionally, wheat (*Triticum* spp.) is considered one of the several founder crops domesticated in the "Fertile Crescent" [1] and significantly contributed to "Neolithic Revolution" [2]. This is initially attributed to the cultivation of diploid (genome A^m, $2n = 14$) einkorn wheat (*Triticum monococcum*) and tetraploid (genomes BBAA, $2n = 28$) emmer wheat (*Triticum turgidum* spp. *dicoccoides*) around 10 millennia [3] Tanno and Willcox 2006 which triggered the evolution of human societies and the hallmark transition from hunting and gathering of food to agrarian lifestyles [4]. It is estimated that bread wheat (*Triticum aestivum* spp. *aestivum* L.), an allohexaploid (genomes AABBDD, $2n = 42$) hybrid of emmer wheat with goat grass (*Aegilops tauschii*, genome DD) [5], accounts for over 95% of all cultivated wheat. Instructively, since its emergence approximately 8000 years ago, this species is not only deemed among the most important cereal crops in global production that also includes rice (*Oryza sativa*) and maize (*Zea mays*) but also in its ecological range of cultivation, cultivar diversity, and the extent to which it has become inseparable to the cultures and religions of diverse societies worldwide [3].

In Kenya, wheat was introduced in the early twentieth century, while wheat breeding research through introduction, hybridization, and selection has been underway in the country [6] for over a century. Past achievements have led to the development of cultivars highly adaptable to the Kenya highlands with most commercial production practiced at altitudes above 1500 m. Diseases, especially rusts, have reduced wheat productivity in Kenya ever since the crop was first grown commercially in 1906 [7–11]. Devastating historical and current epidemics (**Figure 1**) including the highly virulent race *Ug99* of wheat stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Eriks) [12] and other related races [13] have reduced Kenya and regional countries to perennial net wheat grain importers. This is in the backdrop of increased consumption needs, estimated at more than 150% of local production [14].

Figure 1. Stem rust disease has been a key deterrent to Kenya's wheat productivity for nearly a century. A devastating epidemic of the disease caused major losses in fields planted to variety Robin in 2014.

1.1. Wheat growing conditions and a reflection of the origin and objectives of the national breeding program

Considering that a vast majority of Kenya's wheat production is accomplished in the medium-to-high-altitude zones, the uniqueness of the growing conditions and hence breeding objectives is encapsulated in Sir Rowland Biffen's 1926 address to a farmer's gathering following a tour of the Kenya wheat fields. As at that time, just as is today, Sir Biffen reflected that the growing conditions were characterized by a continuous growing period, where the crop is practically grown at any time of the year such that it is not uncommon to find within the same vicinity a field being prepared for sowing, while an adjacent one has a crop at tillering, booting, or even grain-filling growth stages [15]. Kenya unfortunately sits at the epicenter of wheat rust diseases where devastating epidemics of particularly stem and stripe rusts driven by rapid evolution of new races have been recurrent over the last century [16]. In his address, Biffen posed: "…I have never yet seen wheat so badly attacked by rusts as I have in this country. I have been impressed by the variety of the rust attacks and it soon became quite clear that the incidence of the rust on wheat was going to determine whether Kenya is ever to be a producing country…."

Dixon [6] traces the origin of bread wheat in Kenya initially to introductions of Australian germplasm at the beginning of the twentieth century followed by a gradual succession with a few Egyptian, Italian, and Canadian founder lines decades later. Moreover, development of breeding populations and variety release in 1930–1950 was largely based on crosses within that core diversity with relatively limited additions from contemporary international programs. But for a short stint during the late 1980s through early 1990s, during which period the national program devoted substantial resources to breeding for drought tolerance [17, 18] and insect pests [19], an overarching objective throughout the history of wheat in Kenya has been that for rust resistance.

Today the goal of the breeding program is to design cultivars that are high yielding, widely adapted, and resistant/tolerant to prevailing biotic and abiotic stresses, particularly rust diseases, drought, and Russian wheat aphid. Moreover, the breeding effort as a priority releases cultivars that are of good end user quality.

1.2. Remodeling the future of wheat breeding in Kenya

Through breeding efforts and better management practices, grain yield of wheat in Kenya has increased (**Figure 2**) from an average of 1.0 ton/ha during the 1920s to 3 tons/ha during the 2010s [20]. Yet, the demand for wheat grain through the last century has risen from an average of about 0.02 million metric tons in 1920 to about 1.0 million metric ton in 2014—a 50-fold increase.

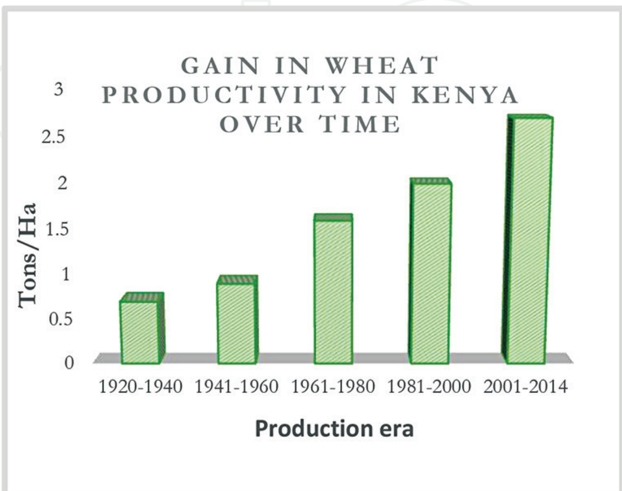

Figure 2. Significant gain in Kenya's wheat productivity since the earlier years of the crop is evident. Faster gain through a remodeled breeding scheme would be instrumental in achieving self-sufficiency.

Demand for bread and related food products in the country is expected to increase even further owing to changing diets that favor wheat-based diets over traditional food sources and generally due to increased human populations. Generally, crop researchers and more so breeders agree that improvement and selecting for high yields and yield stability as well as maintaining resistance to insect pests and disease pathogens are objective and priority traits for any crop [21], including wheat in Kenya; it behooves to consider that how breeding is implemented, and what goals are achieved, is a function of biological feasibility, consumer demand, and production economics [22]. Twenty-first century wheat breeding in Kenya must audit (e.g., [23]; **Table 1**) and systematically exploit the genetic diversity within its reach vis-à-vis the target growing environments, reevaluate what specific trait growers value most alongside traditional target traits, and importantly consider designing cultivars that are responsive to current and future management practices including zero tillage and irrigated environments.

	No. of marker	No. of alleles	Mean		
			MAF	PIC	H_e
Chromosome					
1A	510	1015	0.29	0.30	0.38
1B	358	716	0.27	0.29	0.36
1D	91	182	0.33	0.30	0.29
2A	325	650	0.31	0.30	0.39
2B	625	1250	0.28	0.30	0.37
2D	98	196	0.22	0.25	0.31
3A	390	780	0.26	0.28	0.35
3B	402	800	0.29	0.29	0.37
3D	33	66	0.25	0.27	0.34
4A	360	720	0.27	0.29	0.36
4B	159	318	0.27	0.29	0.37
4D	28	56	0.13	0.18	0.21
5A	408	812	0.28	0.30	0.38
5B	511	1017	0.30	0.30	0.38
5D	73	146	0.20	0.24	0.29
6A	417	834	0.26	0.28	0.36
6B	403	802	0.30	0.31	0.39
6D	52	104	0.27	0.27	0.34
7A	397	794	0.27	0.29	0.36
7B	279	558	0.31	0.30	0.39
7D	43	86	0.28	0.27	0.35

	No. of marker	No. of alleles	Mean		
			MAF	PIC	H_e
Genome					
A	2807	5605	0.28	0.29	0.37
B	2737	5461	0.29	0.30	0.38
D	418	836	0.24	0.26	0.32

Table 1. Number of markers and alleles, minor allele frequency (MAF), polymorphism information content (PIC) and expected heterozygosity (H_e) averaged across 5962 mapped SNP loci in an East African enriched set of 297 wheat lines.

Like any typical breeding program and for its success, the implementation of wheat improvement must be approached as both an art and a science. Conceptually current and future wheat breeders must be guided by a range of both subjective and objective judgments in the design and implementation of the program and in deciding which parents to cross, which selection methods to use, which progenies to keep, and which cultivars to release [24]. The latter implies that the Kenyan wheat program might in future explore development of hybrid wheat besides pure lines. That consistently the breeding program must maintain a sufficient return on investment in people, money, and time and generate benefits in the most efficient way. Routine self-audit on what genetic gain is made per unit time and cost and in every cycle of breeding would be a healthy practice moving into the future. The latter consideration of a routine self-audit would provide a major paradigm shift from the current situation where in general no empirical assessment of genetic progress is purposely done in the program.

1.3. The need for enhanced collaborations

From a wider perspective, research collaborations between African scientists and foreign agencies have been known to yield important results [25] in addressing a myriad of agricultural problems in the continent. The success of the Kenyan wheat breeding program can significantly be attributed to close networks that have been created with the wheat community globally. These collaborations that extend back to the beginning of the twentieth century revolve around sharing germplasm and information as well as in training (**Figure 3**). For instance, beginning mid-1950s, there was a major shift in the national program in which event breeders reasoned that continued under performance and attack of wheat crops by rust diseases was partly due to low genetic diversity of cultivated material. During this decade, breeders at the national program devoted systematic effort to introduce a new gene pool comprising of cultivars identified from the International Spring Wheat Nursery initiated in 1950 by B. B. Bayles and R. A. Rodenhiser of United States Department of Agriculture-Agricultural Research Services (USDA-ARS) as well as screening nurseries emanating from Food and Agriculture Organization [6].

Beginning mid-1960s, the national program increasingly utilized germplasm developed at CIMMYT culminating in the release of many superior cultivars that were not only shorter in height but were resistant to stem rust and had a significant yield advantage [23]. The collaboration with CIMMYT has today gone full cycle. The shuttle breeding program (**Figure 4**) in which crosses made at CIMMYT are tested for stem rust in the global rust phenotyping platform at

Njoro-Kenya, for stripe rust resistance, leaf rust resistance, and heat tolerance at Toluca, El Batan, and Ciudad Obregon, respectively, is a case study of how future collaborations should be modeled.

Figure 3. Breeding effort must address training for future breeders. In this image, students participate in selection of rust-resistant plants at the KALRO-Njoro rust phenotyping facility.

An example at the regional level that might generate significant gain and progress for the wheat breeding program and hence the crop's success is envisioned in the recent dialogue about an "opened seed space." The rationale is to align seed laws as well as harmonize seed trade regulations across countries in the COMESA region. The outcome is that superior cultivars released under similar growing conditions in the pertinent countries will not necessarily be subjected to lengthy testing in Kenya, and benefits in their adoption and use should accrue immediately. At the national level, expedient production and distribution of seed of released cultivars need to be strengthened through both private-public and public-public partnerships. Neighboring countries could also be co-opted in varietal maintenance and initial seed increases so that each country need not maintain every variety it uses [26].

1.4. Breeding wheat for nontraditional environments

Wheat breeding in Kenya will continue to play a key role in the coordinated need and effort for increased food production. In the background of current yield trends, predicted population growth, and pressure on the environment, traits relating to yield stability and sustainability should be a major focus of plant breeding efforts [27]. These traits include durable disease resistance, abiotic stress tolerance, and nutrient and water-use efficiency [28–30]. Designing and developing cultivars that are adaptable to marginal lands, conservation agriculture, irrigated conditions, etc., is likely to be a key driver of the future of wheat breeding in Kenya. In this context, consideration needs to be prioritized for cultivars that are resilient to climate change, well aware that this phenomenon negatively impacts economies largely based on rain-fed agriculture [23], the traditional source for Kenya's wheat. Rigorous and inclusive wheat research that also involves multifaceted technological approaches in various frontiers beyond conventional breeding is paramount.

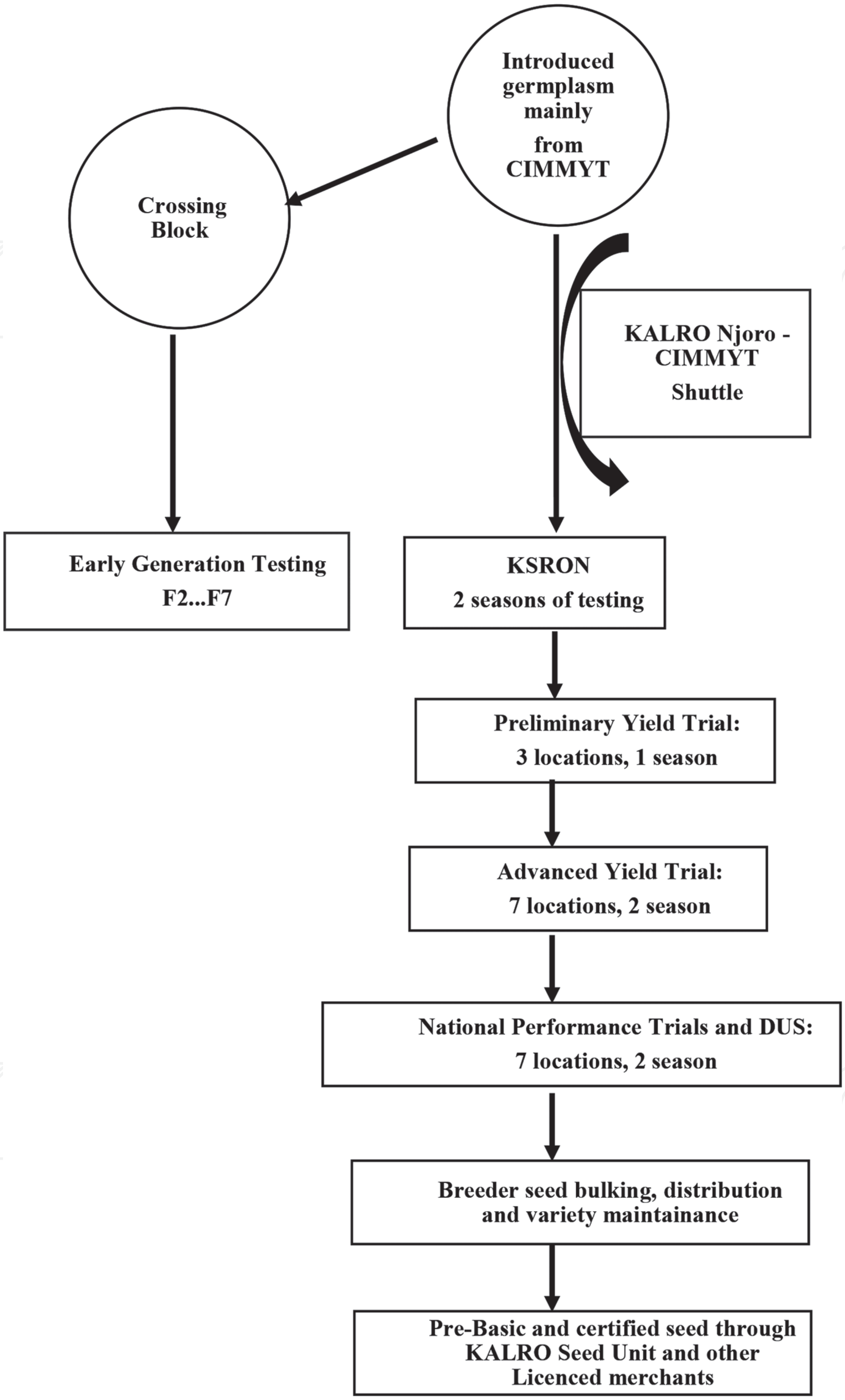

Figure 4. Kenya wheat breeding scheme has lately incorporated systematic germplasm sharing between KALRO-Njoro and CIMMYT through a shuttling program. Benefits from breeding effort can also be fast tracked through incorporation of biotechnology.

1.5. Leveraging modern breeding tools and best practices

Modern plant breeding increasingly utilizes innovations that promise greater efficiencies over current breeding methods. A key approach has been the utilization of biotechnology in many breeding programs globally. While the Kenya breeding program prides success in releasing cultivars through conventional selection methods, DNA-based marker-assisted selection (MAS) still largely underutilized might expedite development of desired cultivars if well implemented. MAS is applicable in four main areas that wheat breeders in Kenya often encounter: for efficient detection and selection of a small number of traits that are difficult to manage via phenotype and usually characterized with low penetrance and/or complex inheritance, for the retention of recessive alleles in backcrossing pedigrees, for the pyramiding of disease-resistance genes, and for aiding in the choice of parents in crossing, to ensure minimal levels of duplication [31]. However, just as this author posits, wheat breeding will continue to be mostly characterized by selection in the breeding plots, rather than detection in the microtiter plots per se.

Since selection in the breeding plots has traditionally been based on phenotyping, success in the future for the Kenya wheat breeding program must be inbuilt on robust phenotyping platforms. The objective of modern phenotyping is to increase the accuracy, precision, and throughput of phenotypic estimation at all levels of biological organization while reducing costs and minimizing labor through automation, remote sensing, improved data integration, and experimental design [32]. Hence robust phenotyping assays for the nation program with the objective of reducing inefficiencies in development and release of superior cultivars would immensely benefit from investments in infrastructure and human capacities in biometrics in plant breeding.

The bigger picture is in utilizing methodologies that combine accurate phenotyping and sufficient genotyping in modeling gene discovery and introgression in breeding populations. Recently, the national program collaborating with other researchers has implemented both biparental and association mapping works for rust resistance genes (e.g., [23, 33, 34]). Such effort will contribute to faster cultivar development.

2. Conclusion

The wheat breeding program in Kenya has become of age. Ever since the first crosses were made in the 1910s leading to the release of cultivar *Equator* in 1920 and subsequently over 130 other cultivars (**Table 2**), measurably genetic gain has been made. However, recent trends both in the country's production and consumption landscapes necessitate that for wheat to continue to play its rightful roles as a food crop for an increasing Kenyan population, breeding efforts must not only be enhanced but such should be systematic and guided by international best practices for it to create novelty and stimulate industry. Lastly, there is optimism that a large potential for enhancing wheat productivity through breeding, and of course management avails for Kenya especially if synergies among local, regional, and international collaborations are enriched.

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Variety name/code	Breeder	Year of release	Variety name/ code	Breeder[a]	Year of release	Variety name/ code	Breeder	Year of release
1061.K.1	NBS	*Unknown*	Kenya8	NBS	*Unknown*	Lenana	NBS	1963
1061.K.4	NBS	*Unknown*	KenyaB-256-G	NBS	*Unknown*	Menco	NBS	1963
1200.M	NBS	*Unknown*	Kenya cheetah	NBS	*Unknown*	Fanfare	NBS	1964
291J.1.I.1	NBS	*Unknown*	KenyaFL.1.158	NBS	*Unknown*	Fury	NBS	1964
BF236C1L	NBS	*Unknown*	Equator	NBS	1920	Gem	NBS	1964
EgyptianNa95	NBS	*Unknown*	Kenya Governor	NBS	1925	Kenya Hunter	NBS	1964
FLIKenya9	NBS	*Unknown*	Kenya	NBS	1929	Kenya Plume	NBS	1965
H441	NBS	*Unknown*	Kenya Standard	NBS	1930	Bailey	NBS	1966
K-360-H	NBS	*Unknown*	Kenya Plowman	NBS	1950	Bonny	NBS	1966
Kenya 291 J.1.I.1	NBS	*Unknown*	338AA1A2	NBS	1951	Bounty	NBS	1966
Kenya-117A	NBS	*Unknown*	Kenya-184-P	NBS	1951	Brewster	NBS	1966
Kenya117C	NBS	*Unknown*	Kenya Farmer	NBS	1954	Kenya civet	NBS	1966
Kenya-122	NBS	*Unknown*	Kenya-362-B-1A	NBS	1956	Kenya Grange	NBS	1966
Kenya-131	NBS	*Unknown*	321BT11B1	NBS	1960	Kenya Jay	NBS	1966
Kenya155	NBS	*Unknown*	Africa Mayo	NBS	1960	Kenya Kudu	NBS	1966
Kenya-294-B-2A-3	NBS	*Unknown*	Equator1	NBS	1960	Kenya Leopard	NBS	1966
Kenya-318.O.3B.2	NBS	*Unknown*	Kentana Yaqui	NBS	1960	Goblet	NBS	1967
Kenya-318-AJ-4A-1	NBS	*Unknown*	Kenya-5	NBS	1960	Mentor	NBS	1967
Kenya-358-AC	NBS	*Unknown*	Kenya-1	NBS	1961	Beacon-Ken	NBS	1968
Kenya501	NBS	*Unknown*	Kenya Mamba	NBS	1962	1010AM2 (L)	NBS	1969
Kenya-58	NBS	*Unknown*	Catcher	NBS	1963	1010F3SEL.13C	NBS	1969
Kenya-6297-2	NBS	*Unknown*	Fronthatch	NBS	1963	1010F3SEL.4	NBS	1969
Kenya6820	NBS	*Unknown*	Gabrino	NBS	1963	1010F3SEL.7	NBS	1969
Kenya7	NBS	*Unknown*	Kenya page	NBS	1963	1012B.1 (L)	NBS	1969
1016.P.2	NBS	1969	Kenya Kanga	NBS	1977	Njoro BW1	KARI	2001
1016P.1	NBS	1969	Kenya Kifaru	NBS	1977	Njoro BWII	KARI	2001
1076.D.7	NBS	1969	Kenya Ngiri	NBS	1979	KS-Simba	KSC	2007
688F4SEL3	NBS	1969	Kenya Nyangumi	NBS	1979	KS-Chui	KSC	2008
690F4SEL.D.1	NBS	1969	Kenya Paa	KARI	1981	Kenya Ibis	KARI	2008

Variety name/code	Breeder	Year of release	Variety name/ code	Breeder[a]	Year of release	Variety name/ code	Breeder	Year of release
Kenya Sungura	NBS	1969	Kenya Kanga	NBS	1977	Robin	KARI	2011
Kenya Swara	NBS	1972	Kenya Kifaru	NBS	1977	Eagle10	KARI	2011
Kenya Nyati	NBS	1973	Kenya Ngiri	NBS	1979	Kenya Hawk 12	KARI	2012
Kenya Mbweha	NBS	1974	Kenya Nyangumi	NBS	1979	Kenya Tai	KARI	2012
Kenya Nungu	NBS	1975	Kenya Zabadi	NBS	1979	Kenya SunBird	KARI	2012
Kenya Nyoka	NBS	1975	Kenya Paa	KARI	1981	Kenya Wren	KARI	2012
Kenya Paka	NBS	1975	Kenya Popo	KARI	1982	Kenya Korongo	KARI	2012
Kenya Tembo	KARI	1975	Kenya Nyumbu	KARI	1982	Kenya Kingbird	KARI	2012
Kenya Kongoni	KARI	1975	Kenya Tumbili	KARI	1984	KS-Kanga	KSC	2013
Kenya Fahari	KARI	1977	Kwale	KARI	1987	KS Nyota	KSC	2013
Kenya Kanga	NBS	1977	Mbuni	KARI	1987	Eldo Baraka	UoE	2014
Kenya Kifaru	NBS	1977	Kenya Chiriku	KARI	1989	Eldo Mavuno	UoE	2014
Kenya Ngiri	NBS	1979	Pasa	KARI	1989	Kenya Hornbill	KALRO	2016
Kenya Nyangumi	NBS	1979	Duma	KARI	1998	Kenya Peacock	KALRO	2016
Kenya Zabadi	NBS	1979	Mbega	KARI	1998	Kenya Songbird	KALRO	2016
Kenya Paa	KARI	1981	Chozi	KARI	1998	Kenya Pelican	KALRO	2016
Kenya Popo	KARI	1982	Ngamia	KARI	1998	Kenya Falcon	KALRO	2016
Kenya Nyumbu	KARI	1982	Kenya Heroe	KARI	1999	Kenya Deer	KALRO	2016
Kenya Tumbili	KARI	1984	Kenya Yombi	KARI	1999	Kenya Weaverbird	KALRO	2016
Kwale	KARI	1987	KSMwamba	KSC	2001			

[a]Breeder refers to institution under which the variety was developed and is maintained: NBS, national breeding station. Now defunct; KARI, Kenya agricultural research institute. Now defunct; KALRO, Kenya agricultural and livestock research organization; KSC, Kenya seed company; and UoE, University of Eldoret.

Table 2. List of bread wheat varieties for commercialization in Kenya over a century of crop improvement.

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