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RESEARCH

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The importance of market signals in crop varietal development: lessons from *Komboka* rice variety

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Abstract

Growing high-yielding varieties is crucial for successful crop production and maximizing farmers' net returns. One such example is IR05N221, locally referred to as *Komboka* rice variety, which was released in Kenya in 2013. On the one hand, *Komboka* can bridge the gap in rice imports since yields of existing rice varieties do not meet the increasing rice consumption levels of the Kenyan population. On the other hand, it has taken about seven years for *Komboka* to be appreciated by farmers, necessitating the need to understand farmer preferences when it comes to adopting a new improved variety. We used a mixed-method study approach by combining quantitative and qualitative data collected regionally and locally in both rainfed and irrigated ecologies. When compared to most of the other rice varieties under evaluation, *Komboka* was high-yielding, early-maturing, and had moderate tolerance to diseases in both rainfed and irrigated ecologies. However, farmers at the regional level ranked *Komboka* either at the same or lower rank in terms of sensory attributes. At the local level, farmers predominantly grew older and more aromatic Basmati 370 rice variety for sale, as it fetched them more money, with preferences for both men and women rice farmers being the same. Despite *Komboka* being a high-yielding variety, Mwea rice farmers' perceptions and preferences for this improved variety were low. While *Komboka* was equally aromatic, the lack of a ready market dissuaded these farmers from widely preferring the new *Komboka* variety. We provide prerequisite information that can support the commercialization and promotion of the *Komboka* variety. We also show that widespread favourable perception of new varieties hinges on matching preferences between breeders' efforts for improved rice productivity with farmers' needs for market competitiveness in these new varieties.

Keywords: Improved rice varieties, Farmers' perceptions, *Komboka*, Basmati 370, Kenya, Mwea

Background

Rice (*Oryza sativa* L.) is an important food crop that contributes approximately 21% of the world's per capita caloric intake. Sub-Saharan Africa (SSA) produces 16 million tonnes of milled rice per year but consumes nearly double that amount at 30 million tonnes. In SSA, productivity averages 2.2 t/ha against the global average of 4.3 t/ha largely due to lack of improved high-yielding varieties as well as awareness about them and over-reliance on the informal seed sector because of the poor seed system (Fisheries and co-operatives. (MoALFC): Roadmap for rice seed development 2016–2026, In 2016). Moreover, 21 out of 39 rice-producing SSA countries import from 50 to 99% of their rice requirements, and very few of these countries have attained self-sufficiency in rice production (Uyeh et al. 2021). Although SSA is not among the top rice-producing regions, the crop is becoming increasingly important in terms of

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consumption and production in the region. SSA has abundant arable land resources with a congenial environment that can support a huge agricultural production expansion, including rice production. Moreover, rice is a commercial crop with considerable potential to improve rural livelihoods and generate income, especially for women and youth (And and Cooperatives,: National Rice Development Strategy-2 (2019–2030) 2020).

In Kenya, rice production dates back to 1907 when it was introduced by Europeans at the Coast (Ouma-Onyango 2014). Rice is the third most important cereal after maize and wheat, which is cultivated as a semi-subsistence crop mainly by smallholder farmers (Kega et al. 2015). The demand is increasing at an annual rate of 12% compared to wheat at 4% and maize at 1%, which had been the main staple foods. Rice per capita consumption in Kenya increased from 12.7 kg in 2008 to 20.6 kg in 2018. This has been attributed to changes in consumer preferences, population growth, urbanization and other lifestyle changes which stipulate the need for less fuel-consuming and rapid cooking methods (Atera et al. 2011). While Kenya's rice demand is increasing, with 730,000 tonnes recorded consumption in 2020/21, the current annual milled rice production has been recorded at 80,000 tonnes (USDA;: Rice Outlook;. 2021), which only meets 11% of the country's demand, with the rest being met through imports. Rice imports in Kenya amount to almost 89%, which is valued at USD 260,000,000 (And and Cooperatives,: National Rice Development Strategy-2 (2019–2030) 2020). Rice is imported to Kenya from several countries, especially Pakistan, India, Vietnam, Thailand, Egypt and Tanzania, which in turn causes strenuous pressure on foreign exchange and trade balance. Moreover, these massive rice imports have choked the economy of local rice farmers, including those in the Mwea region, which is the biggest grower and supplier of rice in Kenya. While many Kenyan rice consumers have a special preference for the expensive aromatic rice varieties such as Basmati (especially during special occasions), there are also many other consumers who prefer the cheapest rice in the market and whose demand is mainly met by imported rice (Aroma in rice has no nutritional value, but a marketing trait 2019). Although there is an over-reliance on the international market, self-sufficiency in local rice production is central to the Kenyan government's policy agenda on growth as articulated in the Big Four Agenda (2018–2022) and the Third Medium Term Plan (2018–2022) (Rice and Center: Kenya adopts 'Rice Sector Development Hub' approach to achieve rice self sufficiency 2020). The National Agriculture Investment Plan (NAIP 2019–2024) (National Agriculture Investment Plan: Investing In Kenya's Agricultural Sector Transformation Towards Sustainable Agricultural Transformation and Food Security In Kenya.In.;2019) seeks to accelerate Kenya's agricultural transformation towards a commercial and modern sector that sustainably supports the country's food and nutrition security and socio-economic development. Rice is categorized as one of the strategic crops for alleviating food insecurity in Kenya and a priority value chain in NAIP 2019–2024 (National Agriculture Investment Plan: Investing In Kenya's Agricultural Sector Transformation Towards Sustainable Agricultural Transformation and Food Security In Kenya.In.;2019). Self-sufficiency in rice production is also a component of saving funds, as these would be spent in purchasing other items that the country does not produce locally. The National Rice Development Strategy-II (NRDS-II, 2019–2030) (And and Cooperatives,: National Rice Development Strategy-2 (2019–2030) 2020) forecasts that in order for the country to reduce the import bill significantly and move towards self-sufficiency, the total domestic rice production must increase seven-fold and reduce the current importation volumes by at least 47% by 2030. The national rice research capacity is also getting stronger, given that it was not very active in Kenya until 2009 when the stakeholders started a rice varietal release system that did not exist before (Singh et al. 2013). Rice breeding activities in Kenya have expanded with the introduction of germplasm from different international research institutes, co-developing (with local research institutes) the varieties that are suitable for the agro-ecologies in Kenya, and releasing those varieties for dissemination. The International Rice Research Institute (IRRI) has been working hand-in-hand with National Agricultural Research and Extension System (NARES) partners to facilitate the varietal development and release process for rainfed lowland and irrigated ecologies in Kenya. Screening of improved materials on a large scale on-station as well as on-farm trials with the active participation of farmers and local extension workers have been the key to implementing a bottom-up approach, in addition to evaluating market preferences of these released varieties.

Besides lack of government-led interventions, limited extension services and lack of improved varieties, awareness of improved high-yielding varieties and over-reliance on informal seed systems are still being reported as major constraints for rice production in Kenya (Singh et al. 2013). Most farmers in Kenya continue to use cultivars released thirty or more years ago, or landraces selected generations ago which are low-yielding (2.5–3 t/ha), late-maturing (135–150 days) and many are susceptible to rice diseases prevailing in the country (Atlin et al. 2017; Atera et al. 2018). Although a number of rice varieties have been released in Kenya in the last two decades (Table 1) to raise productivity, most of them are not

Table 1 Key characteristics of rice varieties released in Kenya

Variety	Advantage	Disadvantage	Year released	Other details/Owner
IR05N221 (*Komboka*)	This is a medium slender shiny white grain variety, semi-aromatic, translucent (low chalkiness), high yield of up to 6.5–7 t/ha, many grains per panicle (195), medium feeder and responds well to nutrient, highly palatable(soft, separate and non-sticky grain texture when cooked, high tillering capacity of 30–35,high milling recovery at 68.34%,easy to thresh at 58% moderately tolerant to bacterial blight, Rice Yellow Mottle Virus (RYMV), brown spot, sheath rot and rice blast disease, tolerant to submergence, salinity and drought. Adapted to both rainfed lowland and irrigated ecosystems, intermediate plant height thus less susceptible to lodging, very uniform flowering and maturity with 100% exertion	It is not tolerant to cold and salt conditions	2013	Owned by KALRO (Kenya Agricultural and Livestock Research Organization) and IRRI (International Rice Research Centre) Medium maturity variety a range of 110–120 days at maximum height of 90–120 cm
Basmati 370 (NIBAM 11)	Aromatic, slender grains and translucent (soft separate and non-sticky grain texture upon cooking), High ratoonability, it is not a high feeder (high amount of Nitrogen leads to lodging)	Susceptible to blast and lodges	Late 1990s	Owned by NIA (National Irrigation Authority) Mean yield of 4.6 mt/ha hence comparatively higher yields than NIBAM 10. High ratoonability. Medium maturity variety a range of 120–130 days at maximum height of 120 cm
Basmati 217 (NIBAM 10)	Stronger aromatic than Basmati 370, slender shiny grains and translucent (separate when cooking), good milling ability, not a high feeder. Irrigated variety	Lodges and susceptible to blast	Early 1970's	Owned by NIA Mean yield is 4.5 mt/ha. Medium maturity variety a range of 115–120 days at maximum height of 120 cm
BW 196 (NIBAM 109)	High yielding, thick grains, Japonica grain type, non-aromatic, high tillering ability (up to 40 tillers) Tolerant to rice blast	High feeder and late maturing, susceptible to RYMV. Glutinous (sticky when cooked)	2010	Owned by NIA Short structured- 90 cm. Late maturing variety of 140–150 days. Mean yield of about 8 t/ha
Nerica 1(WAB450-I-B-P-38-HB)	Early maturing (95–100 days), Medium resistance to blast and RYMV, Suitable for upland conditions	Poor threshability	2008	Owned by KALRO Plant height: 90–100 cm, Tillers: 15–20, Yield: 4.5 t/ha
Nerica 4(WAB450-I-B-P-91-HB)	Maturity: 95–100 days, Non-aromatic Upland	Poor threshabiliy	2008	Owned by KALRO Plant height: 120 cm, Yield: 5 t/ha
Nerica 10 (WAB450-11–1-1-P41-HB)	Medium maturity, Non-aromatic, for upland ecology	Poor threshability	2008	Owned by KALRO Plant height: 100 CM, Days to maturity: 90–100 days, Yield: 6 t/ha
Nerica 11(WAB450-16-2-BL2-BL2-DV1)	Non-aromatic Resistant to blast For upland environment	Poor threshability	2008	Owned by KALRO Plant height: 105 cm, Maturity: 75–85 days, Yield: 7 t/ha

Table 1 (continued)

Variety	Advantage	Disadvantage	Year released	Other details/Owner
TXD 306 (SARO5)	This is a slender long shiny white grain variety, Aromatic, medium maturity variety, not a high feeder and responds well to nutrient, tillering capacity of 25–30, Non- sticky, Good milling abilty, White brown grains, Easy to thresh, moderately tolerant to Rice Yellow Mottle Virus and Rice Blast disease		2013	Owned by KALRO Mean yield of 4.5–6 t/ha. Medium maturity variety a range of 120–130 days at maximum height of 80–100 cm
Duorado precoce	Tolerant to blast, rice yellow mottle virus and bacterial leaf blight Can be grown in Upland ecologies Good cooking qualities	Late maturing and lodges	2013	
NIBAM 110 (ITA 310)	Slender long shiny white grain variety. Has basmati characteristics but no aroma. Medium feeder and responds well to nutrients. Tolerant to RYMV. Non sticky, good milling ability, easy threshability		2010	Owned by NIA Mean yield of 3–5 t/ha. It is a medium maturity variety a range of 120–130 days at maximum height of 95 cm
NIBAM 108 (IR2793-80-1)	Less amylose content than BW196 (translucent grains) but thick grains Resistant to blast and RYMV High yielding and high tillering	High feeder	2010	Plant height of about 80 cm. Non-aromatic. It is a late maturing variety of approximately 140–150 days. It yield ranges from is 8 t/ha
ARIZE TEJ GOLD	Long slender high quality grain, Slight-aromatic, High yielding yield is 7–8 mt/ha, Good milling ability, Non chaffy, Highly tolerant bacterial leaf blight and moderately tolerant to Rice Blast disease, Resistant to lodging, It is a medium feeder and responds well to nutrient,Palatable and non-sticky, High tillering capacity of 50, Easy to thresh**,** Recommended ecological altitude zone of between 15 and 1700 m adapted to rainfed lowland and irrigated ecosystems		2014	Hybrid rice developed by BAYER in India Mean yield of 7–8 t/ha. Medium maturing variety at 125–135 days (seed to seed). Good milling ability
ARIZE 6444 GOLD	This is a medium slender white grain variety. Slightly-aromatic. It mean yield is 7.5–9 mt/ha, Good milling ability, Non chaffy, Highly tolerant bacterial leaf blight and moderately tolerant to Rice Blast disease. It is a medium feeder and responds well to nutrient, Palatable and non-sticky, Easy to thresh, Slender grain shape, Recommended ecological altitude zone of between 15 and 1700 m adapted to rainfed lowland and irrigated ecosystems		2014	Hybrid rice seed developed by Bayer in India. This is medium slender white grain variety Mean yield is 7.5–9 t/ha. Medium maturity of 135–145 (seed to seed). Good milling ability

Table 1 (continued)

Variety	Advantage	Disadvantage	Year released	Other details/Owner
Mwea irrigated rice (MWIR 2)	Non-aromatic, high tillering capacity of 20–25. Good milling ability, moderate tolerant bacterial blight, Rice Yellow Mottle Virus and Rice Blast disease. Adapted to rainfed lowland and irrigated ecosystems	Late maturing	2013	Owned by KALRO Mean yield is 4–5 t/ha Matures in 135–140 days at maximum height of 90-100 cm
Mwea upland rice (MWUR4)	Suitable for Rainfed Upland High yield potential upto 9.0 t/ha. Tall and non-aromatic; Tolerant to blast		2013	Owned by KALRO
AT054	Slender long grains that are translucent. High tillering ability. Suitable for both lowland and upland ecologies. Hybrid. Moderately tolerant to blast		2010	Owned by Afritec Seeds Ltd Matures in 125 days
AT058(SC213)	Suitable for both lowland and upland ecologies. Hybrid. Moderately tolerant to blast			Owned by Afritec Seeds Ltd Matures in 120 days
AFEXH001	Suitable for both lowland and upland ecologies. Hybrid. Moderately tolerant to blast			Owned by Afritec Seeds Ltd Matures in 125 days
AFEXH004 (ATH741A)	Suitable for both lowland and upland ecologies. Hybrid. Moderately tolerant to blast			Owned by Afritec Seeds Ltd Matures in 118 days

Source(s)https://kephis.org/images/pdf files/UPDATED%202,020%20August%20NATIONAL%20VARIETY%20LIST1.pdf,https://www.kalro.org/sites/default/files/BBSRC-Varieties-Kenya-doc.pd being widely grown by farmers. Farmers adopt these varieties to varying degrees.

In Kenya, most middle-class consumers prefer aromatic rice varieties, which come at a premium market price. However, most lower-income households and local institutions with mass numbers consume imported rice as it is cheaper compared to the aromatic 'pure pishori' rice. For example, while the higher quality Mwea rice retails for a higher price of KES 140 to 200 (USD 1.2 to 1.8), Pakistan-imported rice retails at KES 100–120 (USD 0.9 to 1.1) (Mano et al. 2022). This gap for imported rice consumption can be filled by *Komboka*, which is high yielding (6.5 to 7.0 t/ha), semi-aromatic, medium slender and translucent grain with intermediate plant height which makes it resistant to lodging. Cultivation of high-yielding semi-aromatic *Komboka* can enhance food and nutrition security by increasing local rice production which will, in turn, contribute to a reduction of rice imports in the country. Its wide adaptability in both irrigated and rainfed lowland ecologies can lead to expansion in rice-growing areas that are currently not being cultivated. However, the rice seed replacement rate is very low and sometimes no data on seed access is available (Fisheries and co-operatives. (MoALFC),: Roadmap for rice seed development 2016–2026, In 2016).

Moreover, there is low private sector interest in rice seed production and marketing since *Komboka* is an inbred variety. Coupled with a limited human capacity to develop materials for pure seed production and other policy-related limitations, these key constraints need to be addressed for widespread preference for *Komboka* by the smallholder farmers. This paper discusses the factors that may be indicative of farmers' perception and preference for modern rice varieties, focusing on *Komboka* as a case study. It is hypothesized that farmers' perceptions of varietal quality could affect preferences for improved cultivars that may in turn bolster commercialization. Research has also shown that approaches that incorporate farmers' preferences for various characteristics of rice in breeding programs and extension strategies that are geared towards providing accurate information for efficient and timely revision of farmer perceptions are needed to raise the adoption rate of new varieties.This study contributes by showing how appropriate crop varieties can stimulate production growth in Kenya, a country that has an excellent environment for production of high-quality rice. Expanding the production acreage and diversifying the quality of rice through the introduction of new varieties is a potential solution to insufficiency and also a way of saving the foreign exchange for use in items that cannot be produced locally. Specifically, our study seeks to evaluate the factors affecting new rice varieties in Kenya, where we assessed the perceptions of both breeders and farmers on IR05N221, locally referred to as Komboka.

Methods

Study overview

The focus of this paper was to document farmers' perceptions and preferences for new varieties to support commercialization, with the case study of *Komboka* rice in East Africa. The release of *Komboka* involved multi-locational breeder trials in multiple East African countries. Here, we report the general cultivar performance based on major traits and qualities as assessed during the field evaluation by breeders, combined with farmers' perceptions derived from focus group discussions as well as in-depth interviews. The combined components were assembled in this study with a focus of highlighting the importance of integrating the biophysical and social aspects of varietal adoption in Africa. The approaches for each component are described in the subsequent sections below.

Data collection

This study combined quantitative data collected from regional yield trials during on-station evaluations of *Komboka* together with qualitative sensory evaluations and field day evaluations of the variety. The quantitative data collection is elaborated upon in the subsequent section on *Komboka* evaluation and release, followed by a description of the varietal release committee process in Kenya. Qualitative data collected both regionally and locally focused on agronomic and sensory evaluations (Paris 2011). Additionally, local farmers' perceptions by use of FGDs and in-depth interviews formed the basis of understanding farmers' preferences for *Komboka*, which is also elaborated upon in this section.

Komboka evaluation and release

Quantitative data collected on *Komboka* evaluation and release included days to 50% flowering, plant height, number of productive tillers per square metre, and grain yield. Plant height was recorded as an average from five randomly selected plants in the middle two rows. At maturity, net plots of 4.6 m × 0.6 m were harvested from where the yield was determined in each of the replicate plots. The rice samples were weighed and moisture content measured and adjusted to 14% moisture content. The major diseases of rice in Kenya consisting of leaf blast and Rice Yellow Mottle Virus (RYMV) were scored using the scale specified in the standard evaluation system of rice (IRRI 2014). Grain yield was expressed in tonnes per hectare (t/ha) after it had been adjusted to a moisture content not exceeding 14% and to the missing hills for each plot. Farmers ranked *Komboka* differently in terms of agronomic traits according to the IRRI Standard Evaluation Score (IRRI 2014).

Study sites, description of germplasm and experimental design

The trials were conducted in seven East and Southern African (ESA) countries, viz. Burundi, Tanzania, Uganda, Kenya, Rwanda, Malawi and Mozambique (Table 2). At regional level, 27 rice genotypes (including *Komboka*) consisting of fixed lines selected from IRRI's lowland breeding program, nominations from NARES partners and local checks were evaluated during the 2011/2012 period.

The experiments were designed in randomized complete block design with replications for each site. The plot size measured 5 m by 1.4 m. Genotypes were planted in eight rows with an intra spacing of 20 cm between the hills. Fertilizer application followed local recommendations. Field management followed normal agricultural practices of weeding and irrigation with the exception of fungicide and bactericide application which were as per country guidelines and recommendations. Harvesting was done by leaving the outer rows and columns as borders.

In Kenya, seven genotypes and three checks (Table 3) were transplanted in a 1.0 m × 5.0 m plot size at 20 cm × 20 cm spacing in 2012 in western (in Ahero, Bunyala and west Kano) Kenya as well as the eastern region, specifically in Mwea at Kenya Agricultural and Livestock Research Organization's (KALRO's) research station at Kirogo (Fig. 1). The trials were established in a randomized complete block design with three replications. Management practices (fertilizer application rate and frequency, time and method of planting) applied to the trials were those common at the specific localities. Hand weeding was done to keep trials weed-free.

Variety release committee process in Kenya

In Kenya, variety release and registration is governed by the 'The Seed and Plant Varieties Act, Cap 326' of the Laws of Kenya, which spells out clear guidelines on regulatory process of seed release, certification, and production. Variety release procedures are designed to evaluate and regulate the varieties of seed that can be produced and traded. Under this act, it's a perquisite for applicant (breeder or Seed Company) to submit request to the National Performance Trials (NPT) committee to conduct NPT and Distinctness Uniformity and Stability (DUS) tests. The test candidate material for release (Komboka) was evaluated alongside the selected national checks for performance and DUS tests under Sect. 9(2) or 9(3) of the Act for the purposes of release as per the set protocol. From the multi-sites evaluation report conducted by KEPHIS, a case of rice crop to be released as a new variety; it must be distinct from any known rice variety in respect to (i) specified characteristics (height, maturity duration, aroma, yield, adaptability to agro-ecological conditions, tolerance to biotic & abiotic stresses, grain type and cooking quality), (ii) uniformity in morphological appearance, (iii) physiological or other accepted characteristics, (iv) stability in its described performance after repeated reproduction. After these bare minimum requirements were met, *Komboka* variety was recommended for release by the National Variety Release Committee, Gazette and listed in the National Variety List.

For the case of *Komboka* in the same breath of the Seed Act, the law also provides for plant variety which has been officially released in any country within the regional economic blocks to which Kenya is a member can/would undergo performance trial for at least one season in similar agro-ecological zones. (Law 2016). In the case of *Komboka*, the variety was submitted for national variety testing and released after one season of evaluation in Kenya (Fig. 2); since it had followed the formal release process not only in Tanzania but also in Uganda and Burundi (Table 4).

However, in the period of 2013–2019 no deliberate efforts were made in popularizing the variety, regardless of its outstanding traits. Also, this was as a result of the poor seed system in the country, which impeded the availability of the *Komboka* seed to the farmers. Demo trials were done in Kenya in the period 2019–2020, in the efforts of creating awareness to the farmers. This informed the grounds of the field day where the interview was conducted to explore possible reasons why the variety was not being adopted.

Focus group discussions and in-depth interviews

Out of the total of 406 farmers participating in the 2020 field days, a subset of 76 farmers were selected to participate in a mixture of Focus Group Discussions (FGDs) and in-depth interviews. Both the FGD and in-depth interview participants were purposely selected from the overall participant pool of 406 farmers. FGD participants ranged from six to nine participants. For inclusion in the FGDs, the proposed participants met the following key criteria: (i) their experience as a rice farmer, based on number of rice growing years, (ii) their ability to communicate in Kiswahili and/or the local language, (iii) diversity in age, gender and region. Thus, the FGD participants were selected purposively according to the aforementioned criteria. Where the participants available were less than five, in-depth interviews were utilized as they offered richer insights to complement those obtained from the FGDs. In-depth

Table 2 Mean yields of rice genotypes under irrigated ecology in seven East and Southern African (ESA) Countries in 2011/2012

No	Genotypes	Kenya	Tanzania		Burundi	Rwanda		Uganda	Malawi	Mozambique		Mean yield (Kg/ha)
		Ahero	Bagamoyo	Dakawa	Burundi	Cyabanga	Cyili	Kibimba	Malawi	Chokwe	Umbeluzi	
1	SUPA BC	2311	3604	5957	7041	1582	1807	3066	5117	6304	7100	4389^{gh}
2	BKN/SUPA	1770	2445	5773	7418	3035	4848	3062	5681	5878	6660	4657^{fgh}
3	WAB189-B-B-B-HB	7836	1331	5840	4359	1138	7441	2228	3408	4435	5299	4331^{gh}
4	ROJOMENA 271/10	3824	2615	5003	7175	7228	11,509	4590	5461	3738	3781	5493^{cdef}
5	IR 80,482	6269	3358	8220	6425	6115	4064	5382	5534	6895	8558	6082^{abcd}
6	IR 77,080	6443	3354	8257	7794	8361	7136	4898	5960	6489	7516	6621^{ab}
7	HUA 565	2544	3140	6940	8530	6412	1970	4656	5330	5440	6563	5152^{cdefg}
8	FRX 78-12	2796	2570	5753	7608	1160	3368	4945	4513	5946	6930	4559^{fgh}
9	FRX 92-14	3247	3951	6970	7617	3386	2412	4483	4736	7122	6634	5056^{defg}
10	IR77713	7034	2788	8353	8722	8987	5189	5588	6248	6628	7859	6740^{ab}
11	IR79511	5402	3876	5260	8424	9298	8302	4656	4364	6965	8608	6515^{ab}
12	INTSINDAGIRA-BIGEGA	3118	3256	5300	6637	10,798	10,953	4570	4989	4935	6930	6149^{abc}
13	INTSINZI	6572	3237	8007	6704	8764	9648	5466	5232	5946	6930	6651^{ab}
14	RUMBUKA	6350	1375	3983	2521	7839	5755	1994	1000	3539	5648	4000^{h}
15	IR 05N221 (Komboka)	5913	3689	6563	7829	6709	6973	4346	5769	5882	7061	$6074^{\mathbf{abcd}}$
16	IR 03A262	4937	3642	8297	8824	7010	3263	3248	5086	6741	8121	5917^{bcde}
17	TXD 307	4651	3244	7543	6700	4670	3338	3370	4332	5892	6170	499^{1efgh}
18	IR 07A167	3085	3714	7060	3035	4429	2762	3004	4075	6401	7060	4463^{fgh}
19	IR 07A166	3385	3687	4493	8042	4284	2550	2975	5017	5460	7466	4736^{fgh}
20	IR 06A107	1993	3180	8693	8826	3982	5999	4266	4333	6641	5849	5376^{cdefg}
21	IR 09A136	6156	3759	9470	8500	8163	7794	4948	4976	8045	8136	6995^{a}
22	IR 03A550	2065	2891	7853	3947	2254	2073	4744	5611	5741	9183	4636^{fgh}
23	WITA 9	7003	3638	7500	5739	6128	2162	5145	5159	5942	6930	5535^{cdef}
24	K5	2786	4340	7873	6843	5601	4751	3665	5434	5029	6930	5325^{cdefg}
25	Regional check 5438		2718	7950	6721	7184	5237	5351	5101	5776	7431	5891^{bcde}
26	National check 6081		3623	6253	6815	6427	13,399	4903	5927	7108	5788	6632^{ab}
27	Local check	7660	3773	6237	8511	8061	9458	5435	5264	6056	6449	6690^{ab}
	Means of sites 4691		3215	6867	6937	5889	5710	4259	4950	5962	6948	5543
	$L.s.d_{(0.05)}$ site											741.8*
	$L.s.d_{(0.05)}$ designation											646*
	$L.s.d_{(0.05)}$ site × designation											2121.9*
	%C.v											23

* Significant at 0.05 and NS, not significant respectively; figures with super scripts that have the same letters are not significantly different

Table 3 Grain yield (t/ha) of genotypes under irrigated conditions during the 2011 wet season in different parts of Kenya

No.	Genotypes	Mwea	Ahero	Kirogo	Bunyala	West Kano	Mean
1	IR 05 N 221 (*Komboka*)	6.21	5.28a	5.52	4.72a	6.56a	6.26
2	IR 80,396-112-3-1-2	4.36	5.12a	4.89	4.20a	6.52a	5.02
3	NSIC RC 148	5.23	4.53b	4.42	4.49a	3.78b	4.69
4	[Y]IR 05 N 499	5.41	4.50b	**6.06**	4.08a	5.79a	5.17
5	IR 75,287-19-3-3-3	5.21	5.18a	5.26	2.63b	5.89a	4.83
6	[Y]IR 82,574-543-3-1	6.00	**5.43a**	5.68	**5.09a**	5.25b	4.79
7	IR 82,251-9-3-3-3	3.83	4.34b	5.43	4.63a	6.58a	4.96
8	TXD 307 check	5.24	4.35b	4.63	2.88b	6.39a	4.70
9	TXD 306 check	**6.67**	4.75a	5.00	2.58	**7.46a**	5.29
10	[@]Local check	4.81	3.20c	5.29	5.02a	5.08b	4.68
	Mean	5.30	4.67	5.22	4.04	5.92	
	LSD	2.80	0.84	1.50	1.41	2.06	
	CV (%)	27.9	9.6	15.3	18.6	18.42	
	F test	ns	***	ns	***		

F test: probability level; ***, ** and * significant at p = 0.01, 0.05, and 0.10; ns = not significant. LSD g refers to significant differences in genotypes

Means followed by the same letters are not significantly p < 0.01

[Y] refers to varieties under evaluation, that is, they were just tested but not yet released

Yields indicated in bold font highlight the top yielding varieties per location

[@] represents local checks per location, which are as follows: Mwea = Basmati 370, Ahero = IR 2793–80-1, Kirogo-Basmati 370, Bunyala = IR 2793–80-1, and, West Kano = IR 2793–80-1

interview participants were also purposely selected so as to add views of the few but resourceful lead farmers available on the day (who were also seed producers nominated and trained to produce rice seeds). Both the in-depth interviews and FGD sessions were conducted with separate men and women farmers. In total, 30 women and 46 men rice farmers were interviewed. The list and profile of these participants is detailed in Table 5. The sessions were conducted in each of the three field day sites, that is, Karaba, Tebere and Thiba areas (Fig. 1). In-depth interviews were conducted in two out of the three sites (Karaba and Tebere) where we encountered few but resourceful lead farmers. The sessions were conducted in either or both the national language (Swahili) and the local language(s). Balanced participation of respondents was ensured by drawing in quieter participants and providing them space to talk. After seeking consent orally, explaining the purpose and length of the interaction, the session commenced. The checklist guided the remainder of the discussion. The checklist questions captured basic socio-economic and demographic characteristics of the participants, as well as specific rice-trait questions. These questions were designed to elicit qualitative information underlying rice varietal preferences. The specific questions focused on: (i) rice varieties currently grown by farmers and why farmers liked them, (ii) qualities farmers needed in a new rice variety so as to replace old varieties and the most important traits that farmers valued in a rice variety, and why, (iii) how farmers judged a rice variety, (iv) what texture of rice meant to farmers, and specifically what kind of rice they liked, (v) whether farmers thought rice could help solve any nutrition problems, (vi) which colour of (milled) rice grain farmers liked, and why, (vii) how important was ease of threshability for farmers, and why. At the close of the discussion, the facilitator invited participants' questions, to which the team responded. The facilitator also summarized key take-home messages from the discussion.

Data analysis

Statistical analysis was conducted using GenStat statistical package version 12 (Payne et al. 2009). The means of yields were compared using LSD at alpha = 0.05 (Kwanchai and Arturo 1983).

Notes recorded during the farmer FGDs and in-depth interviews were transcribed after the sessions. To reveal insights on the liked and disliked characteristics in each of the rice varieties, a qualitative content analysis was conducted (Graneheim and Lundman 2004). Specifically, the qualitative data transcripts were reviewed, sorted and organized so as to identify and code recurring themes and concepts related to key issues identified by participants (Newing et al. 2011), using NVIVO version 12.6.0.

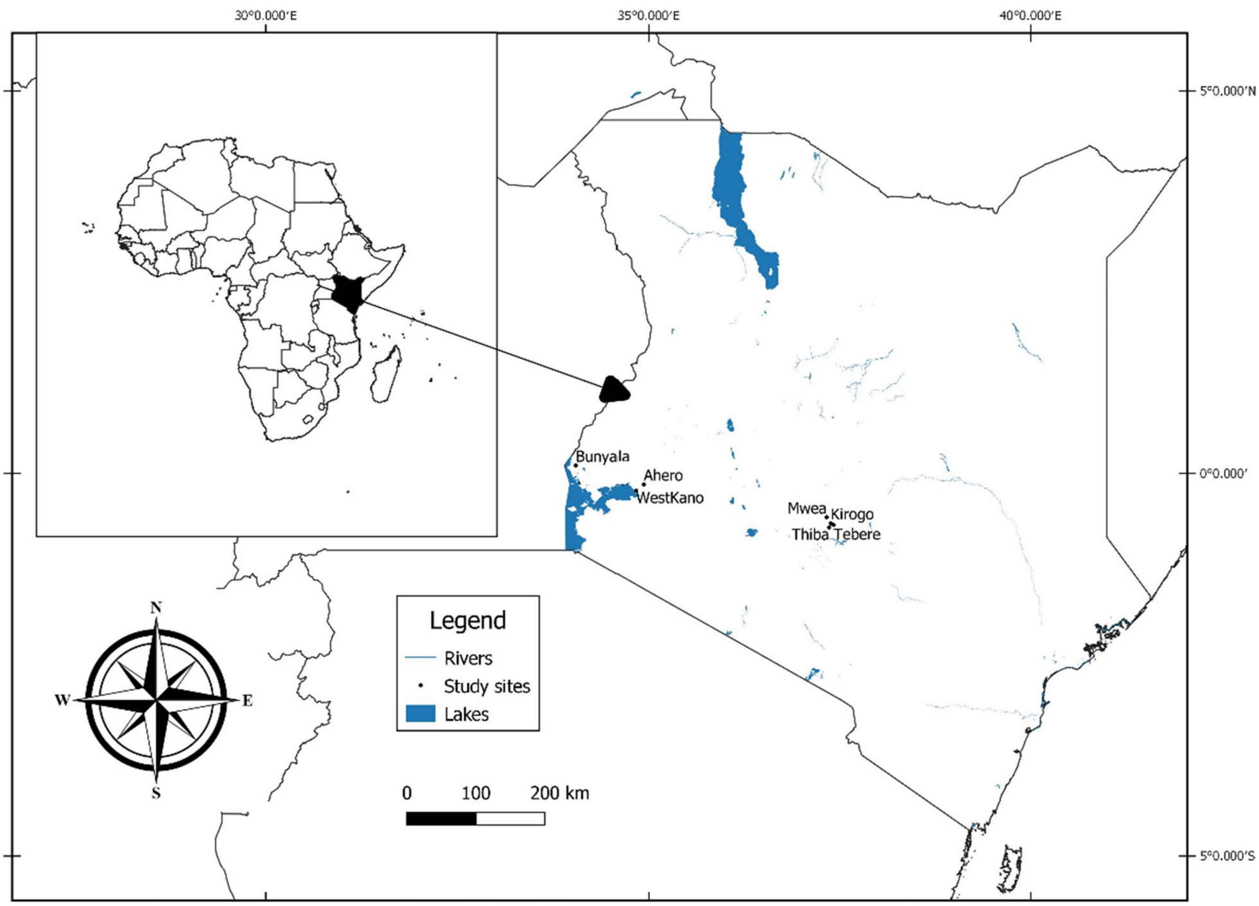

Fig. 1 Kenyan study sites for yield trials and FGDs as well as in-depth interviews (for the FGDs and in-depth interviews, these were specific to Mwea–in Thiba, Kirogo and Tebere areas)

Results

Performance of Komboka based on field evaluations

Tanzania, Uganda and Burundi, in 2013, 2014 and 2018, respectively (Table 4). Various other varieties were tested together with *Komboka* across multiple country sites in most cases. Researchers also listed their most liked *Komboka* traits, mostly pertaining to good performance in terms of disease tolerance, early maturity traits, moisture stress conditions as well as both rainfed and irrigation systems. While there were differences in yield performance for some countries depending on environmental factors, site-specific and overall yield performance of multiple varieties showed either higher or similar yield results for *Komboka*, ranging from 5.95 t/ha to 7.10 t/ha (Table 5).

Across five locations in Kenya during the wet season in 2011, *Komboka* had the highest overall mean yield when compared to nine other varieties cultivated under similar growing conditions under irrigated ecology. The most popular variety grown in irrigation schemes in Tanzania, TXD 306, which was released together with *Komboka* in Kenya, was the second best yielder in the five sites. In Mwea, while *Komboka's* yield (at 6.21 t/ha) surpassed that of Basmati 370 (yielding at 4.81 t/ha), *Komboka* was ranked second to the TXD 306 check variety. *Komboka* was also second-yielding at a different Mwea location (Kirogo) as well as in western Kenya (in Ahero and west Kano) and a distant third at Bunyala, also in western Kenya (Table 3). From the overall assessment, *Komboka* had good performance in low moisture stress conditions, and matured early. Furthermore, for natural infection by RYMV and blast, the cultivar had average disease scores of up to 3 in a 0–9 scale (where 0 signified no visible damage, while 9 represented greater than 75% damage of the leaf area by the disease). Thus, *Komboka* was moderately resistant to both diseases compared to other varieties tested across five sites in Kenya (Table 6). It should be noted that these trials did not have any artificial disease pressure enhancement, and the findings are subject to an error of inoculation escape.

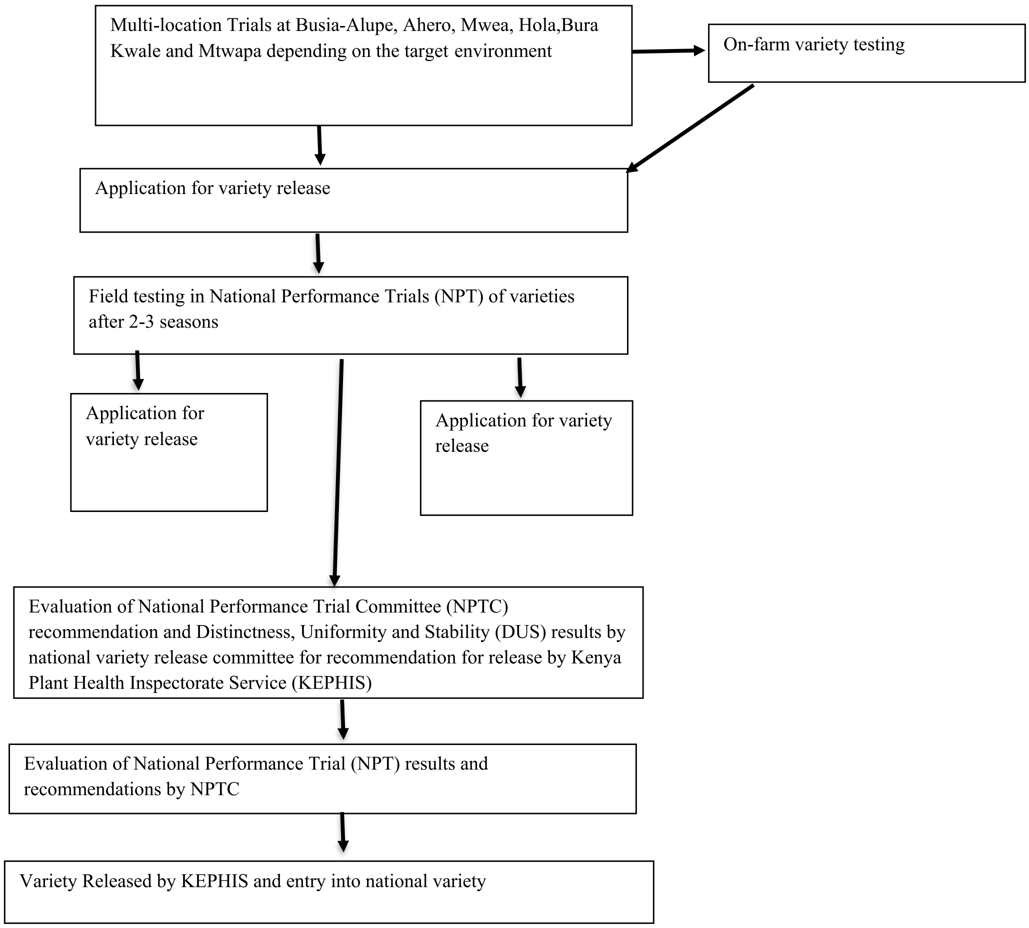

Fig. 2 Variety release system in Kenya

Farmer-preferred qualities of *Komboka*

Surveyed farmers noted that new varieties should have traits very close to Basmati 370 in terms of grain quality, but a little shorter in plant height, and not susceptible to lodging, which closely matched *Komboka* traits (Table 1). All (in-depth and FGD-interviewed) women and most men rice farmers cultivated Basmati 370, which was predominantly grown for commercial purposes. These farmers preferred growing this highly aromatic rice variety as it fetched them more money due to its premium quality. A few of both the men and women farmers grew NIBAM 109 (also referred to as BW 196, Table 1) for home consumption purposes on a small portion of their land. *Komboka*, the semi-aromatic rice variety that was being promoted during the field days, was only grown by one woman lead farmer. Nonetheless, a small percentage of the men farmers had also adopted *Komboka* cultivation since it was high yielding. The surveyed men farmers mentioned they could easily experiment with new rice varieties, such as *Komboka*, as they made most of the decisions on what to grow, unlike women farmers who needed to consult their spouses. While the rest of the women farmers were interested in growing *Komboka*, they mentioned that they needed to first observe the lead farmer's rice growing journey. This same woman lead farmer also grew AT054, a hybrid rice variety introduced in 2010 (Table 1), for which the seed marketing company, Afritec Seeds Ltd., not only provides farmers with seeds but also buys back the harvested produce, thus guaranteeing rice farmers a ready market. Unlike AT045, the women rice farmers' concern was lack of a ready rice market for the *Komboka* rice variety. This concern was also shared by the men farmers, who cited that market availability was a key determinant in the widespread adoption of any rice variety, as their aim was the profits they could generate. Among the men farmers, a rice variety with not only the main crop harvest but also an extra ratoon yield was also a determinant factor when adopting a

Table 4 Komboka-related characteristics during Participatory Varietal Selection (PVS) and sensory evaluations in Tanzania, Uganda and Burundi

Category	[1]Tanzania	[2]Uganda	[3]Burundi
Release year	2013	2014	2018
Number of varieties tested (including *Komboka*)	9	10	4
Study sites	Kyela (Mbeya district), Igunga (Tabora district) Ifakara (Morogoro district), Bagamoyo (Coast district), Dakawa (Morogoro district)	Namulonge Doho Olweny Kibimba Agoro	Gihanga
Farmers' matrix ranking for IR05N221	[a]2nd (1st was TXD 306, an improved local variety)	[b]1st	[c]2nd (after Musaruro/IR85260-148, and in same ranking as mugwiza)
Farmers' on-farm perceptions on agronomic traits of IR05N221	1st (at Kyela and Bagamoyo) 2nd (at Ifakara and Dakawa–1st was Supa at Ifakara site and IR05N499 at Dakawa site)	3rd (at Agoro) 1st, with other two varieties (at Olweny)	2nd (same ranking as *Mugwiza* rice variety)
Farmers' perceptions on sensory evaluation (cooking and eating grain characteristics)	Ranked 1st (in Dakawa) and 2nd (in Ifakara and Igunga) in terms of cooking and eating quality, with acceptable grain qualities, specifically soft cooking and good eating taste	Not applicable/unavailable	[d]4th/least ranking across the four criteria, but was most appreciated for its taste
Researchers' liked traits	Good performance in moisture stress conditions Early maturity Shows disease free characteristics under natural environments	Not applicable/unavailable	Suitable for rainfed and irrigated systems
Yield performance	Higher yields (15–30%) under rainfed lowland ecology than all the local checks tested At all sites, high yields. At Dakawa high yield performance (6.73 t/ha) when compared to local check, Supa (4.37 t/ha) but non-significant difference to improved local check, TXD 306 (7.20 t/ha)	Higher yields (15–30%) under rainfed lowland ecology than all the local checks tested Overall/ across all sites yield performance trials at 5.96 t/ha: In 2012: 2nd highest (after WITA-9) at 6.5 t/ha In 2013a: 3rd highest (after GSR0057 and K85) at 4.52 t/ha In 2013b: highest at 6.85 t/ha	Average yield in 2018 at Gihanga Research station at 7.1 t/ha: Non-significant difference with the check: Mugwiza (7.29 t/ha) and Komboka (7.10 t/ha)
Maturity period	Matures 7–14 days earlier than the most popular variety SARO 5 hence saving water and also avoiding the later stage drought	Matures 28–30 days earlier than K85 hence saving water and also avoiding the later stage drought	

[1] Application for National Performance Trials (NPTs) of IR05N221 and IR03A262 seed release in Tanzania 2012 by Agricultural Research Institute (ARI)–KATRIN by Rice Breeder Nkori J. M Kibanda

[2] Variety Release Application–Submission to the variety release committee for the release of five lowland rice varieties in 2o14 by National Agricultural Research Organization (NARO)

[3] Confirmation trial's report of Distinction, Homogeneity and Stability (DHS) and Agronomic and Technological Value (VAT) of three new rice varieties from IRRI-ESA at Gihanga station in 2018, National Office for Seed Control and Certification (ONCCS)

[a,b,c] The ranking among rice varieties was based on 11 traits: 1- high tillering, 2-plant height, 3-number of grains/panicle, 4-long and big panicle, 5- aromatic, 6- taste, 7-good milling quality, 8- ease to thresh, 9- lodging resistance, 10- time to maturity, 11-resistance to pests and diseases

[d] The four sensory criteria taken into account were: (i) paddy (visual)—Shape and size of the grain, no lesions on the grain (indication of diseases in the field) (ii) White rice (visual): shape and colour, broken rate, approximate milling recovery (iii) Cooked rice (visual): shape, size and colour of the cooked rice, volume increase after cooking, wet or dry after cooking (iv) Taste: aroma, smell, taste and flavour. The distribution of sensory preferences among samples was determined by use of frequency tables and the significant difference determined by chi square test

Table 5 List and profile of rice farmers participating in FGDs and in-depth interviews

Session code (coded as area-sex-group number)	2020 dates	Area	Participant number	Sex (M-male, F-Female)	Number of rice growing years	Farmer age bracket 1: 0–35 2: 35–50 3: 50+
KM1	18th Nov	Karaba	1	M	49	3
			2	M	25	2
			3	M	20	3
			4	M	47	3
			5	M	15	2
			6	M	40	3
*KM 2	18th Nov	Karaba	1	M	47	3
KM3	18th Nov	Karaba	1	M	5	2
			2	M	6	1
			3	M	15	3
			4	M	15	2
			5	M	4	1
			6	M	10	2
*KF1	18th Nov	Karaba	1	F	47	3
			2	F	47	3
			3	F	51	3
			4	F	51	3
*KF2	18th Nov	Karaba	1	F	5	2
			2	F	30	3
*KF3	18th Nov	Karaba	1	F	40	3
*TF1	19th Nov	Tebere	1	F	15	3
			2	F	33	3
			3	F	35	3
			4	F	60	3
*TF2	19th Nov	Tebere	1	F	6	1
			2	F	5	1
			3	F	20	2
			4	F	25	2
TM1	19th Nov	Tebere	1	M	35	3
			2	M	20	3
			3	M	19	3
			4	M	20	2
			5	M	25	3
			6	M	16	2
			7	M	20	3
			8	M	20	3
			9	M	25	2
TM2	19th Nov	Tebere	1	M	5	2
			2	M	10	3
			3	M	5	2
			4	M	7	2
			5	M	6	2
			6	M	15	3
			7	M	24	3
TM3	19th Nov	Tebere	1	M	20	2
			2	M	40	3

Table 5 (continued)

Session code (coded as area-sex-group number)	2020 dates	Area	Participant number	Sex (M-male, F-Female)	Number of rice growing years	Farmer age bracket 1: 0–35 2: 35–50 3: 50+
			3	M	25	3
			4	M	20	2
			5	M	10	3
			6	M	15	2
			7	M	10	2
			8	M	10	2
			9	M	20	2
THF1	20th Nov	Thiba	1	F	55	3
			2	F	5	1
			3	F	5	2
			4	F	10	2
			5	F	3	3
			6	F	53	3
			7	F	4	2
THF2	20th Nov	Thiba	1	F	2	1
			2	F	5	2
			3	F	10	2
			4	F	3	3
			5	F	2	3
			6	F	20	2
			7	F	2	2
			8	F	4	3
THM1	20th Nov	Thiba	1	M	20	3
			2	M	20	3
			3	M	30	3
			4	M	20	2
			5	M	10	3
			6	M	30	3
			7	M	15	2
			8	M	46	3

* In-depth interviews were utilized in Karaba (among both male and female farmers) as well as Tebere (for female farmers) as the participants available were less than five

new variety since ratoon yields increased farmers' profitability. The two most important rice qualities mentioned by all women rice farmers were the need for high yields and high market price. All participants preferred white-coloured rice grain as it was what they were accustomed to. Similarly, all participants had been using machines/tractors for rice threshing for the last 25 years, thus ease of threshing was not a point of concern in the area. Farmers' opinions tended to be homogenous the closer the farmers were located near the roads, as was the case in Mwea's Thiba field site (Fig. 1).

Discussion

Variation in yield trial results point to environmental differences

The present study aimed at identifying high-yielding lowland rice varieties for cultivation in Kenya by evaluating a set of 11 lowland rice varieties in different environments. The results showed that the variation in performance of the rice varieties could be attributed to a strong influence of environmental differences. Such variation may be due to differences in rainfall and soil texture across the different locations where the experiments were established. Indeed, the rice grain yield in clay soil

Table 6 Responses of genotypes to Rice Yellow Motor Virus (RYMV) and blast at different Kenyan locations in 2011

Genotype	Disease and location									
	RYMV					Blast				
	Mwea	Ahero	Kirogo	Bunyala	West kano	Mwea	Ahero	Kirogo	Bunyala	West Kano
IR 05 N 221 (Komboka)	1	1	1	3	1	0	0	0	0	0
IR 80,396,112-3-1-2	1	3	1	3	3	2	4	2	2	2
NSIC RC 148	1	3	1	3	3	1	4	5	1	3
IR 05 N 499	3	3	3	3	3	2	6	4	2	4
IR 75,287-19-3–3-3	3	5	3	5	5	6	6	4	4	4
IR 82,574-543-3-1	3	3	3	5	5	2	4	2	4	4
IR 82,251-9-3-3-3	1	9	5	7	5	4	6	4	1	3
TXD 307	1	7	5	7	5	5	5	3	2	3
TXD 306 (Check)	3	9	5	7	5	7	6	5	6	2
Local check	3	5	5	5	5	4	6	4	4	4

Details of blast and RYMV scores are detailed in the Standard Evaluation system for rice (SES) (Mano et al. 2022)

In brief, RYMV Score 1 represents high RYMV resistance, score 3 represents moderate RYMV resistance while scores 5,7 and 9 represent low RYMV resistance

Pertaining blast score scales, score 0 represents high blast resistance; scores 1 to 3 represent moderate blast resistance; scores 4 to 9 represent low to no blast resistance, affecting from less than 4% (score 4) to more than 75% leaf area (score 9)

@represents local checks per location, as follow: Mwea = Basmati 370, Ahero = IR 2793-80-1, Kiorogo = Basmati 370, Bunyala = IR 2793-80-1, and, west Kano = IR 2793-80-1

is known to be higher than that in sandy soil (Dou et al. 2016) and is closely correlated with total rainfall(Saito et al. 2006). The significant effect of genotype by environment (G × E) interaction reflected on the differential response of a given lowland rice variety in various environments. This difference in response demonstrated that, in addition to the strong effect of the environments, the G × E interaction had a remarkable effect on genotypic performance in different environments. The significant effect of G × E has been previously noted in rice (Sharifi et al. 2017) and several other crops. The relative contributions of G × E interaction effects for grain yield noted in this study were similar to those of another study evaluating 27 rice genotypes in four fields during three consecutive years in northern Ghana (Katsura et al. 2016). In our study, *Komboka* showed the highest mean grain yield, while the local checks had the lowest average grain yield. The grain yield performance of *Komboka* was higher than the national average grain yield of the national released varieties. *Komboka's* high performance could be explained by its earliness when compared to the other varieties which is an important aspect to consider because of the unpredictable rains observed in Kenya in the recent past. Farmers usually consider earliness as one of the most important criteria when selecting a variety to grow in Kenya. Reliable identification and release of rice genotypes based on the yield and stability index (Sarr et al. 2021) was successfully achieved in the case of *Komboka* in Kenya, Tanzania, Uganda and Burundi. *Komboka* was moderately resistant to blast disease, based on field evaluations. However, as disease pressure was not imposed on the variety (which is a standard procedure in hotspot disease screening), there is a need to further test the cultivar using artificial inoculation and/or at hotspots with conditions favourable for major diseases in the region.

Farmers look for more than yield-related rice traits

Komboka was introduced to Kenya from Tanzania. In Tanzania, *Komboka* was first introduced in 2009 and thereafter released in February 2013. In Kenya, *Komboka* was released in June 2013 (KEPHIS: Updated_2022_January_National_Variety_List. In. Kenya 2022) after its preliminary introduction and testing under multi-location trials in 2011, upon which one of the Kenyan NARES breeders requested seeds from one of Tanzania's national research centres–Tanzania Agricultural Research Institute in Morogoro region (TARI Katrin), for release under the East African Community agreement and KEPHIS guidelines on release of varieties that have been officially released in any country within the regional economic blocks to which Kenya is a member (Law 2016). While *Komboka* was introduced much earlier in Tanzania, it may not have picked up much probably due to Tanzanians' coastal cultural preference for tastier but low-yielding highly aromatic local rice varieties that not only do well in low mechanized and rainfed setups but also fetch premium prices, predominantly the local *Supa* rice variety (Kangile et al. 2018). In contrast, Kenyans, especially in non-coastal areas, may have less of a cultural heritage preference toward specific local aromatic rice varieties. More emphasis may be placed on varieties that have a more competitive market advantage, accelerating efforts by highly mechanized market-oriented farmers to generate more cash earnings. When compared to Tanzania, it is likely that *Komboka* could pick up much faster in Kenya due to its higher-yielding nature, suitability for both irrigated and rainfed ecologies and potential for mass market production, thus reducing the country's reliance on imports (Komboka and rice to double yield, boost food security 2020). While *Komboka* was released around the same time as TXD 306 in Kenya, the latter is yet to pick up in the country. This could be due to *Komboka's* higher-yielding trait. *Komboka*, meaning 'liberate' in Swahili, out-yielded TXD 306 by more than 15%. In Tanzania, however, the improved aromatic TXD 306 variety has picked up much faster probably because aroma is considered a must-have rice trait moreso in Tanzania, where a non-aromatic rice variety was not easily adopted by farmers (Singh et al. 2013). While the momentum for widespread adoption of *Komboka* in Kenya's Mwea region is currently slow, there is potential for *Komboka* to put in check cheap imports (Alliance for a Green Revolution in Africa (AGRA): Komboka rice to put in check cheap imports that thrive on the name of pishori variety 2021) thus reducing the huge import gap.

While *Komboka* is a high-yielding variety, this trait is not necessarily the most important trait for farmers. This finding is consistent with other studies that have shown that some high-yielding varieties do receive low ranking during farmers' evaluations (Burman et al. 2018). Moreover, it is becoming evident that breeders need to consider traits beyond yields in their breeding programs by incorporating end-user needs such as grain quality, shape, size, texture, fragrance and specific cooking quality traits (Custodio et al. 2016; Bairagi et al. 2020; Britwum et al. 2020). For example in Kenya, as in other east African countries, consumers prefer aromatic long grain rice, due to spillover of preferences from Asian imports (Kilimo Trust: Expanding Rice Markets In The East African Community,In., 2018. 2018).

Men and women market-oriented farmers prefer same rice traits

Our study finding on the similar preference for high-yielding and high marketability traits, for rice varieties meant for both home consumption and for sale among both men and women farmers, is consistent with those of previous studies. In maize systems in Zimbabwe, sex-disaggregated multiple innovative approaches were utilized, including identification of farmer preferences through variety trait preference ranking, revealing that the same four varieties were preferred by both genders, and for the same reasons (Setimela et al. 2017). In cassava systems in Nigeria, variety ranking by both men and women farmers was the same (Teeken et al. 2018). Intra-household surveys conducted among rice farmers in the Philippines revealed that wives' rice varietal preferences matched their husbands' preferences due to the wives' substantial involvement in post-harvest activities, despite the fact that husbands largely dominated decision making on varietal adoption (Maligalig et al. 2021). This could imply that some traits have the same level of importance across the gender divide, such as high yields and marketability.

Preferences of men and women rice farmers is also dependent on their predominant production orientation. Farmers are likely to have a diversity of prioritized rice trait preferences, starting with razor-sharp focus on economic traits for commercial-oriented producers, to a mix of agro-economic traits for producers-cum-consumers and an even broader set of agro-socio-economic selection criteria among risk-averse subsistence producers. The rice farmers in our study are commercial-oriented (rather than subsistence-oriented). When rice production is commercial, these market-oriented producers' preferences and choices are more aligned regardless of their gender, as they are more influenced by preferences of the end-users, who are consumers. As most farmer production goals are also profit-oriented, farmers consider attributes that interest consumers in their production decision-making process (Asante et al. 2013). In western Indo-Gangetic plains of India, a study among 69 commercial-oriented farmers in four peri-urban New Delhi villages was conducted to understand their rice preferences. Overall, basmati rice varieties were preferred in comparison to non-basmati varieties, where acceptance of a basmati rice variety was dependent on market demand and seed availability for adoption (as observed for Pusa Basmati 1 and Pusa Basmati 1509) (Sharma et al. 2017). In eastern India, FGDs among 70 rice farmers and qualitative interviews with other value chain actors showed that among the main preferred traits were high yields and profitability as reflected by price and market demand (Custodio et al. 2016). These findings corroborate with our study suggesting that commercial-oriented farmers may be most concerned with economically-driven rice traits.

Another aspect could be that the preferences of men and women farmers may be more similar when contrasted with those of farmers vis-à-vis other stakeholders, especially researchers. Combined results of multi-year evaluations of different rice varieties during different seasons by rice farmers in coastal Indian Sundarbans region, most of whom were producers-cum-consumers, showed similarities in both men and women farmers' preferences in most of the trials, suggesting that both genders had similar criteria for selection of rice varieties, while farmers' preferences were different from those of researchers (Burman et al. 2018).

The incorporation of qualitative farmer data obtained from FGDs and in-depth interviews to complement breeder-related yield trial and sensory evaluation results was useful in three ways. Firstly, it deepened the understanding of a coherent mosaic of diverse perspectives from both men and women farmers. Secondly, both separate men and women farmers supported each other in elaborating each other's perspectives where either gender provided explanations for trait preferences raised by the other gender. Thus, the use of both qualitative and quantitative methodologies generated more balanced views from both men and women farmers, as opposed to the sole use of either yield trial data or FGDs and in-depth interviews. Lastly, incorporation of more socially inclusive ways to collect data enables all voices to be heard so as to facilitate the co-creation of solutions that enable communities to move forward together. After all, rice is one of the major crops that has the potential to unite cultures (Burman et al. 2018). It is produced and consumed by both men and women from all walks of life where each gender has different roles and responsibilities (Okam et al. 2016). While documentation of both men and women farmers' perspectives in variety choices is needed, this is still insufficient for widespread varietal adoption. Among other systemic challenges, wider adoption of improved varieties remains a bottleneck due to absence of a ready market for farmers' produce (Kilimo Trust: Expanding Rice Markets In The East African Community,In., 2018. 2018).

Marketability is a key attribute for farmer uptake of new varieties

Despite the introduction of *Komboka*, Kenyan Mwea farmers' hesitancy in widely adopting this rice variety due to uncertainty of its marketability suggests that there is a need for breeders to consider market-oriented farmers' concerns when selecting new varieties, to accelerate new rice varietal and seed replacement efforts. Enhancing adoption, appropriate communication and awareness is key.To support this, field days continue to be conducted with an aim of promoting the variety and linking up the farmers to potential buyers such as the National Cereal Board (NCPB) and Mwea Rice Growers Multipurpose (MRGM) (Komboka rice variety takes spotlight in field day 2020). Also, through conducting on-farm trials, lead farmers have been selected and have helped in eliciting more insights to support the adoption of the variety. This is for example through social learning that makes it easier for other farmers to extrapolate the likely outcomes of the farm demonstrations to their own situations. These various approaches have established a significant increase in uptake as substantiated by the rising demand for the *Komboka* variety seed for planting from the KALRO seed unit (Government Launches High Producing Rice Variety). This is a good indication that the prior apprehension about the marketability is gradually fading away.

Neglecting market signals when developing new varieties can have dire consequences. In Mali, although many rice varieties had been developed, few had been adopted because researchers did not take into account farmers' preferences and perceptions on the varieties during the development process (Efisue et al. 2008). In Nepal, despite the release of new rice varieties, the majority of the farmers continued to cultivate old rice varieties, sometimes with an average age of 20 years post-variety release (Witcombe et al. 2017). Through other similar illustrations, more breeders have seen the importance of incorporating users' feedback, especially when some high-yielding varieties receive low ranking during farmers' evaluations (Worku et al. 2020). In our study, while *Komboka* received high scores, there was still hesitancy in its widespread cultivation due to uncertainty on its marketability upon harvest. Farmers in Mwea (Stephen Oduor: Kenya 2021) as well as Ahero (Joe 2019) have struggled with finding market for their surplus rice produce on several occasions.

Lack of market for improved rice varieties in Kenya is partly attributed to the low competitiveness and low productivity of domestic rice, due to cheap rice imports and high production costs of locally produced rice (Trust 2017). The influx of cheap imported rice from Asian countries as well as neighbouring Uganda and Tanzania into the country, which is sold at low prices (at around USD 0.3 per kg), knocks off demand for local rice varieties produced by farmers (sold at around USD 0.6 per Kg) (Mwangi 2020). Exacerbating the problem is the illegal practice of blending these cheaper imports with Mwea's pure aromatic basmati rice which is thereafter traded as (mixed) pishori variety at a much lower price than the original 'pure pishori' that Mwea is renowned for (Andae 2021). Nonetheless, if measures such as government policy restrictions on imports are put in place and implemented consistently (Atera et al. 2018), there still remains a significant market opportunity for improved new varieties that are attractive to both farmers and consumers such as *Komboka* to meet this increasing domestic rice demand. Another challenge faced by Kenyan rice farmers is the high cost of rice production, which if reduced can enhance local farmers' competitiveness with imported rice. For example, the National Irrigation Board manages the country's irrigation infrastructure system, which is mobilized by expensive diesel fuel (not gravity) thus necessitating farmers to pay higher costs for irrigating their farms. While plans have been underway to replace this expensive diesel system in various irrigation systems (Stephen Oduor: Kenya 2021; Alushula 2017; Gravity and to replace generators in Sh7.5bn Tana River irrigation project. 2021), it has unfortunately not been actualized as yet (Scheme and Inspection, 2020). While the Mwea irrigation scheme is deemed reasonably competitive and a model success case study (State declares Mwea Irrigation Scheme a success story 2021), this upper hand against imports could be further accentuated by introducing subsidies on some of the tradable inputs such as chemical fertilizers and herbicides so as to further cushion farmers and stabilize the market prices (Mugane 2010). Currently, the high un-competitiveness on price and quality of locally produced rice compared to that of imported rice coupled with the low production capacity is a handicap not only in Kenya but also in the wider East African Community region (Trust 2017), which needs a value chain approach to ameliorate the situation.

Conclusions

Our study evaluated a set of 11 rice varieties across five environments to assess their stability and productivity. Despite the variation for growth observed among rice genotypes, the 2013-introduced *Komboka* (IR05N221) was the most productive variety within each environment and the most stable and productive variety across environments, producing higher yield and better growth traits in both rainfed lowland and irrigated conditions. Concomitantly, surveyed farmers across the seven ESA countries ranked *Komboka* differently across 11 traits comprising of agronomic and sensory traits. In Kenya's Mwea area, a market-oriented irrigated rice production region, our study further revealed evidence on alignment of rice trait preferences among men and women rice farmers, with preference for the older late 1990s released- Basmati 370 rice variety, for its high marketability but lower yields (at 4.81 t/ha). While *Komboka* was even more high-yielding (at 6.21 t/ha), Mwea farmers' concerns hinged on uncertainty of the marketability of the new *Komboka* variety. Breeders and social scientists can use these data to define market segments and develop product concepts for varieties that can match to the farmer preferences and needs in these commercial-oriented market segments.

Two main methodological limitations and suggestions for improvement emerged, hinging on closing farmer-breeder gaps by optimizing opportunities to capture farmer-derived suggestions using methodologies that breeders already utilize, as well as working around realities of regional niche markets for different rice varieties. To increase chances for *Komboka* to be more widely adopted, sensory evaluations need to be layered with additional qualitative data, for example through discussions with farmers, so as to understand and implement farmers' perspectives on how rice traits in improved rice varieties could better cater to their needs. While FGDs and in-depth interviews were conducted to understand and popularize *Komboka's* adoption during the field days in Mwea area, the timing was late. Moreover, the small sample size available within the limited time further narrowed our ability to draw more robust qualitative conclusions from a more representative sample. While the composition of FGDs and in-depth interview participants entailed not only rice grain farmers but also lead farmers (who were also rice seed producers) from both genders, diverse age groups and rice growing years across the three areas, we were unable to involve consumers from different market segments (such as middle and low-income groups). To improve on this, especially in the context of multiple activities occurring simultaneously, ample time and prior logistical arrangements need to be set aside for FGD and in-depth participant recruitment. Where possible, taking the time to visit households in representative locations in the study areas, instead of simply relying on local contact persons and partners to mobilize participants on our behalf, facilitates directly expounding on the study objectives which may in turn enhance attendance of a diversity of stakeholder groups, besides producers. While the assistance of local partners is helpful, enlisting the support of these gate-keepers when recruiting participants unavoidably influences which social spaces are available and which are not. Nevertheless, it is suggested that small sample sizes are adequate (Cohen 1990), especially if the research aim is to explain phenomena rather than to estimate the statistical representativeness of data (Djurfeldt 2012). Thus, the FGDs provided a valuable opportunity to better understand this Kenyan hub rice market that is flooded with highly-aromatic Basmati 370 rice variety and a niche market where farmers produce for both rural and urban consumers who are already accustomed to its specialty quality attributes and are willing to travel long distances to procure the famed Mwea rice. Thus, Mwea farmers would be unwilling to gamble with uncertainty in consumer market acceptance that comes with new varieties, thus taking some of *Komboka's* superior attributes for granted. *Komboka* could be better appreciated and more widely adopted in areas where its resilience traits can outcompete local varieties currently in use, and coupled with its high-yielding traits, farmers would be more willing to seek out new markets in such areas, for example, the semi-arid Bura rice growing area in Taita-Taveta County in Coastal Kenya. It is heartening to note that this is already starting out, where KALRO will support Taita-Taveta county to triple its annual rice productivity (from 4644 t/ha to 12,000 t/ha, using *Komboka* rice variety (K24: Taita Taveta set to triple rice production in the county 2021). Overall, through the robust multiple replicate experimental design conducted regionally, this study has shown the immense potential that lies in the commercialization of *Komboka* variety which is climate-resilient and high-yielding so as to promote a profitable rice-based system and contribute to reducing Kenya's reliance on imports of rice and other food staples. This will significantly contribute to the country's rice development strategy, food and nutrition security, improved incomes and thus resilient households. Moreover, *Komboka* holds great potential to be introduced in varietal release pipeline in other countries as per the regional variety agreements to offer a greater varietal choice for farmers. The widespread adoption can further be accelerated when breeders take into account and address farmers' challenges, which will in turn enable rice farmers to use improved rice varieties which will in turn improve the overall rice production in SSA and decrease rice imports.

Recommendations

High-yielding, market-demanded rice varieties go hand in hand with high productivity levels as well as quality production, accessibility, and replacement of seeds. Concomitantly, enabling factors such as the ability of farmers to afford farm inputs, beneficial policies for farmers and seed producers, as well as good infrastructure, are also a prerequisite. In addition to the availability of *Komboka* rice variety in Kenya and other countries, we recommend:

1. Working with seed dealers to boost availability, accessibility and affordability of seeds of *Komboka* rice variety to smallholder farmers.
2. More demonstration and other popularization efforts to increase awareness about *Komboka* to all value chain stakeholders.
3. Value addition such as introduction of biofortified *Komboka* containing essential minerals such as zinc and iron, which will also bolster nutrition security among the burgeoning population consuming rice.
4. Strengthening the capacity of extension agents so that they are better equipped to enhance farmers' good agricultural management of the rice crop.
5. Conducting evaluations of *Komboka* to assess and optimize how it competes with imported rice varieties especially in terms of market and sensory attributes.
6. To enhance a better access of rice farmers to the local market, multiple strategies should be implemented. First, adoption of pre- and post-harvest technologies that would reduce the cost of rice production, including use of machines at different levels of the value chain. Second, creation of awareness among the farmers for the existence of alternative varieties that could be acceptable to farmers. This could be coupled with exhibitions and promotional activities by government extension agencies for alternative varieties of rice. Third, expansion of land under rice cultivation through provision of more water for irrigation—this is currently being implemented by expanding the local water dam. Increasing the land under rice production would attract more farmers and/or larger land sizes per individual growers and hence the farmers would enjoy some increased benefits of large scale production.

The aforementioned factors will enable provision of prerequisite information that can support commercialization and promotion of the new *Komboka* rice variety.

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Author contributions
Conceptualization: RMM, MN, AP, RM; methodology: RMM, MN, MLK, LC, JN, ON; software: MLK, RMM, MN, SM; validation: RMM, MN, MLK, LC, SM, JN, ON, SN, AP, RM; formal analysis: RMM, MN, ON; investigation: MN, MLK, LC, JN; visualization: RMM, MN, SM, AP; writing—original draft preparation: MN, RMM, MLK, LC; writing—review and editing: RMM, MN, MLK, LC, SM, JN, ON, SN, AP, RM; resources acquisition: RMM and AP. All authors read and approved the final manuscript.

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Availability of data and materials
Please see below link to the available data, including survey instruments and protocols: https://drive.google.com/drive/folders/1rXv2M3DcMjBB5PsDkQE579OiVgB7MuJl?usp=sharing

Declarations

Ethics approval and consent to participate
The authors obtained oral informed consent from each participant in the survey through a Yes/No procedure prior to beginning the interview. All participants were informed about the context of the study and the anonymous nature of the survey. Permission was sought from each respondent, and they openly and freely answered the questions asked.

Consent for publication
All authors read and approved the final manuscript for publication.

Competing interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The sponsors did not pay any role in the design, execution, interpretation, or writing of the study.

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