Chapter

Irrigated and Rain-Fed Lowland Rice Breeding in Uganda: A Review

Jimmy Lamo, David Ochan, Desta Abebe,
Zelalem Zewdu Ayalew, Anna Mlaki and Cyprien Ndikuryayo

Abstract

Since introduction of rice into Uganda in 1904, improvement of the irrigated and rain-fed lowland types was undertaken to address a number of production and quality constraints in three consecutive and overlapping phases. The initial phase was achieved through evaluation of introduction, selection of promising lines and subsequent release of the selected lines for production by the farmers. In the second phase, genetic potential of traits and characteristics of interest were analyzed and used to guide selection of suitable parents for hybridization and the third phase employed genotyping approach in screening and selection of the parental lines and the segregating populations to enhance the breeding efficiency for the traits of importance. Simultaneously, the key production constraints addressed included resistance to rice yellow mottle virus (RYMV), rice blast, bacterial leaf blight and narrow leaf spot diseases as well as submergence tolerance and cold tolerance. The quality traits considered for the improvement alongside the grain yield parameters were the grain aroma, amylose content, shape and size. These interventions have resulted into release and wide adoption of seven rice varieties in Uganda besides several breeding lines which have informally diffused into different major rice production agro-ecology. Subsequently, it can be concluded that a substantially strong and functional breeding platform for rice in Uganda has been established.

Keywords: evaluation, genotyping, grain quality and yield, hybridization, inbred lines and variety release

1. Introduction

Uganda is a tropical country that lies astride equator, but with modified climatic conditions due to large water bodies and high peaked mountains. The altitude varies from 614 to 5,111 metres above sea level (masl) with much of the rice production areas falling within an altitude ranging from 1,000 to 1,400 masl. The least and the highest recorded temperature within the rice production agro-ecology is 8°C and 38°C, respectively, whereas on the basis of the average for the entire country, lowest temperatures range between 10°C and 17°C and highest from 23°C-25°C. The annual rainfall intensity in Uganda varies from 600 mm to 2,500 mm with much of the country receiving between 900 mm and 1,800 mm of rainfall. Owing to the diversity in the climatic conditions, rice production ecologies in Uganda are classified into three broad categories of rain-fed upland, irrigated and rain-fed lowland production areas. The total land area suitable for rain-fed upland rice production constitutes an estimated 70% of the arable land in Uganda and are mostly located within Upper Nile basin in the Northern region and Albert basin in Western Uganda [1]. The area is classified into four zones on the basis of availability of water for production and proximity to critical services for rice production, namely Upper Nile basin, Albert basin, Victoria basin and Kyoga basin. The upper Nile basin drains an area of 48,911 sq. km^2 comprising Albert Nile (21,234 sq. km^2) and Aswa catchment. The Albert basin covers 21,875 sq. km^2 with 4.5% of the area being permanent wetlands and 3.5% seasonal/ temporary wetlands while Victoria zone covers 30, 880 sq. km^2 and Kyoga zone covering 137,500 sq. km^2. Overall, a total of 239,166 sq. km^2 catchment basin suitable for rice production is located in Uganda. Of the Uganda's 241,500 sq. km^2 catchment area, 15% is open water and 3% represent permanent wetland area while 9.4% comprise the seasonal wetland area. In essence, therefore, much of the Uganda's land surface is collectively suitable for rain-fed and irrigated rice production.

Rice was introduced to Uganda in the early 1900's, but the exact year remains contradicting as the different years of 1904 [2] and 1910 [3] were reported. In addition, other authors believed that rice was already introduced into the country by end of the 1870's, the time when the Arab community grew rice for their consumption [4]. However, it was believed that rice was first introduced in milled form for consumption by European administrators and Indian businessmen as well as Indian rail construction workers, the 'coolies' who built the railway line then referred to as the 'Iron Snake', from Mombasa to Uganda. Subsequently, small observation and minimal fields were latter established during the period from 1904 to 1940 by Swahili and Indian staff and Church Missionary Society (CMS) staff [2]. In the year 1921, rice was already recognized and reported as one of the food crops produced and promoted in the country [5]. Rice production was promoted further during the World War II in 1939–1945 to provide food to soldiers. Progressively, a successful irrigated rice trial was launched in central Uganda [2] and by 1940's, commercial production of rain-fed lowland rice in the country had increased [2, 6]. Later, during the 1950's, the Uganda government developed further interest in rice and potential for irrigated rice farming. Subsequently, two irrigation schemes of Kibimba and Doho were developed in the 1970's in Eastern Uganda and later on a third rice irrigation scheme was constructed at Olweny swamp in Northern Uganda.

Given the relatively many decades of rice cultivation of the introduced rice crop and with expanding acreage under production, a long-standing draw back to irrigated and lowland rice production of pests and diseases were reported [2, 3, 6–9]. In most cases, some of the then existing varieties were dropped due to susceptibility to insect pests and diseases [7]. With this background constraints threatening rice yield, the rice breeding program was inevitably established to identify and incorporate broad-spectrum and durable resistance (BSDR). The initial stage was to identify the genetic donors for the targeted traits for the improvement through characterization and conservation of germplasm collections. This was followed by development of segregating populations and selection of genotypes possessing the desirable traits and identify candidate rice genes contributing towards BSDR through co-localization with resistance to different stress genes. The new lines generated were then advanced through anther culture technique and modified Rapid Generation Advance (RGA) technique, for which the anther culture technique has proved useful in improvement of selection efficiency for yield and other traits of low heritability. In addition, the doubled haploid lines developed from the RGA have been associated more with additive genetic variance component compared to the conventional F_2 and F_3 generations as the dominance variance component is eliminated in double haploid technology, implying higher irritability of these economic traits in rice [10]. It was reported that in the case of F_3 and F_4, both additive and dominance gene effects contribute to phenotypic differences between individuals, which tends to mask the expression of the desired traits [11] whereas variation in doubled haploid progeny is only due to some environmental effects.

The elite breeding lines were then evaluated in replicated yield trials and multilocation testing to identify promising lines for onwards evaluations on-farm and testing in National Trials following the National Variety Release guidelines and subsequently the promising lines basing on the key preferred production and quality attributes are nominated to the National Variety Release Committee of Uganda for approval and release as new rice varieties.

Key attributes of preferred rice for production are highlighted below:

1. Agronomic traits: This target breeding for high yielding and preferred plant type such as high yielding rice exhibiting 20% yield increase compared to the existing rain-fed lowland and irrigated rice varieties, but with plant height ranging from 90 to 110 cm and maturity period of between 90 and 135 days after planting.

2. Biotic stress: The focus in regards to the abiotic stress has been development of new climate resilient varieties tolerant to abiotic stresses such as drought, iron toxicity, low nitrogen (high nitrogen use efficiency), submergence and cold stresses.

3. Biotic stress: Among the biotic stresses, efforts were directed to develop varieties resistant to currently important and emerging insect pests and diseases. Major pests include stem borers (*Scripophaga* sp., *Chilo* sp., *Diopsis* sp), African rice gall midge (*Orseolia oryzae*), leaf hopper (*Cnaphalocrosis medinalis*), grain sucking insects such as rice bugs (*Nezara viridula*, *Leptocorsia sp* and *Nephotettix spp*), root feeding insects including Rood weevil (*Lissorhoptrus oryzophilus*) and whorl maggot (*Hydellia* sp); while major diseases include rice leaf blast (*Magnaporthe oryzae*), panicle blast, bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*). bacterial leaf streak, rice yellow mottle virus, sheath blight, sheath rot, narrow leaf spot and brown leaf spot diseases.

4. Grain quality: Development of rice with quality attributes preferably with low amylose content for diabetic and elderly persons of less than 20%, noodles (>29%), high milling recovery (>65%) and preferred cooking quality of non-sticky and aroma characteristics. Preference for aromatic, non-sticky, whole grain and white rice grains traits are also commonly preferred by most rice consumers in Uganda [7, 12]. In terms of size, medium and long grains are preferred in the country as well as rice with intermediate amylose and intermediate gelatinization temperature desired.

5. Physiological characteristics: This involves breeding for moderate threshability (non-shattering and tight grain attachment) as detailed in an earlier study conducted in Uganda [reference].

6. Produce quality breeder and foundation seed. This is one of the prescribed roles of a breeder to ensure availability of quality seeds in the right quantity either directly or through the agro-input dealers to the farming communities.

2. Evaluation and deployment of rice varieties

2.1 Introduction of rice varieties to Uganda

Irrigated and rain-fed lowland rice varieties were introduced into Uganda in two phases namely, first from 1921 to 1970 and second during 1971–2020. In the first phase, a total of eight irrigated and rain-fed lowland rice varieties, specifically Jaggery, Cakala, Matama, Kawemba, Kigaire, Seena, SUPA LOCAL and Bungala were introduced and grown (**Table 1**). On the basis of aroma, all the eight rice cultivars except Bungala were aromatic types.

In the second phase covering the period from 1971 to 2020, six released varieties and up to 70 unreleased but informally released rice varieties were commonly being grown by the farming communities. The 70 informally released varieties are classified into two different groups according to their generations. The first are called the K-series of rice introduced from China under technical assistance program, while the second are introductions from major breeding centers detailed in **Table 1**. Both groups are modern varieties with high-yielding capacity and tolerance for various biotic and abiotic field stress conditions. The K-series is an acronym of Kibimba lines, named so probably due to the series being grown then in the Kibimba government rice irrigation scheme. Fortunately, most of the K- series had a desirable combination of intermediate amylose content and intermediate gelatinization temperature and a notable variety is IR64, which has been widely accepted as a high-quality rice. Later, however, there were several devastating stresses that undermined the importance of these varieties for which reasons more introductions from other centres were requested and received. The major breeding centers that provided rice germplasm to Uganda include Africa Ricer Center (AfricaRice), International Rice Research Institute (IRRI), International Centre for Tropical Agriculture (CIAT), Colombia, Tanzania Agricultural Research Organization (TARO), Nigeria, Crop Research Institute (CRI) Ghana, Yunnan Agricultural University, Kunming, China and Chinese Academy of Agricultural Sciences (CAAS), China. Overall, the germplasm received include the following specie of *Oryza sativa*, generations involving crosses between *O. sativa* and *O. glaberrima*, *Oryza barthi* x *O. sativa* crosses, and *O. sativa* x *O. longistaminata* crosses.

2.2 Screening introduction, genetic studies and hybridization

2.2.1 Rice diseases

Rice yellow mottle virus (RYMV) disease is apparently the most serious disease of rice under irrigated and rain-fed lowland conditions in Uganda. In order to identify lines with resistance to RYMV disease, 934 rice lines were screened in the years 2015, 2016, 17 and 2018. These list excluded IR 64, K 34, K 38, K 85 and KOMBOKA (susceptible control), Gigante from AfricaRice (resistant check), Namche 2, NERICA 4 (MET P71), NERICA 8 (MET P72) and WITA 9 (local resistant check) that were included in each set [20, 21]. Each line was sown in the field at high plant population of 10 grams in a land area measuring 20 cm x 20 cm in size. Mechanical inoculations were carried out on seedlings (10 plants test line) at 3 weeks post germination as described by Thouvenel and Fauquet [22]. Symptom appearance was monitored on daily basis to assess the stage of disease initiation and thereafter, disease severity was scored using a scale of 1 (no symptoms) to 9 (severe symptoms) [23, 24] at 45 days post-inoculation (DPI). Of the 934 lines evaluated, a total of 54 either highly resistant or just resistant were identified (**Table 2**). Majority of the RYMV resistant lines were crosses with Tongil

S/N	Variety	Designation	Origin	Time started growing	Key Preferred trait	Reference
1	Jaggery	Unknown	Tanzania	1921	Aromatic	[13]
2	Cakala,	Unknown	Tanzania	1921	Aromatic	[2]
3	Matama,	Unknown	Tanzania	1921	Aromatic	[2]
4	Kawemba,	Unknown	Tanzania	1921	Aromatic	[2]
5	Kigaire	Unknown	Tanzania	1921	Aromatic	[2]
6	Seena	Unknown	Tanzania	1921	Aromatic	[2]
7	SUPA LOCAL	Supa v 88	Tanzania	1970	Aromatic	[13]
8	Bungala	Unknown	Tanzania	1970	Non- aromatic	[13]
9	Congo	Unknown	Tanzania	1972	Aromatic	[13]
10	Kaiso	Unknown	Tanzania	1972	Aromatic	[13]
11	K-12	Unknown	Tanzania	1972	Non- aromatic	[13]
12	K-23	Unknown	Tanzania	1972	Non- aromatic	[13]
13	K-34	Unknown	Tanzania	1972	Non- aromatic	[13]
14	K-38	Unknown	Tanzania	1972	Non- aromatic	[13]
15	K-85	Unknown	Tanzania	1972	Non- aromatic	[13]
16	K-98	Unknown	Tanzania	1972	Non- aromatic	[13]
17	K-264	Unknown	Tanzania	1972	Non- aromatic	[13]
18	Benenego	Unknown	Tanzania	1972	Aromatic	[14]
19	Supa America	Unknown	Tanzania	1972	Aromatic	[14]
20	Bulemeezi	Unknown	Tanzania	1972	Aromatic	[15, 16]
21	Kyabukooli	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
22	Pakistan	Unknown	Tanzania	1972	Aromatic	[15, 16]

S/N	Variety	Designation	Origin	Time started growing	Key Preferred trait	Reference
23	Maisombira	Unknown	Tanzania	1972	Aromatic	[15, 16]
24	Abenego	Unknown	Tanzania	1972	Aromatic	[15, 16]
25	Namahumbo	Unknown	Tanzania	1972	Aromatic	[15, 16]
26	Sebagala	Unknown	Tanzania	1972	Aromatic	[15, 16]
27	Vietnam	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
28	Supa china	Unknown	Tanzania	1972	Aromatic	[15, 16]
29	Gabon	Unknown	Tanzania	1972	Aromatic	[15, 16]
30	Namala	Unknown	Tanzania	1972	Aromatic	[15, 16]
31	Kaki	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
32	Kibimba	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
33	Kabonge	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
34	Kibuyu	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
35	NASSAN	Unknown	Tanzania	1972	Non- aromatic	[15, 16]
36	Nylon	Unknown	Tanzania	1972	Aromatic	[15, 16]
37	Basmati 370	Unknown	Tanzania	1972	Aromatic	[15, 16]
38	SIENNA	Unknown	Tanzania	1972	Aromatic	[13, 17]
39	TXD 306	Unknown	Tanzania	1972	Aromatic	[13, 17]
40	Pishori	Unknown	Tanzania	1972	Aromatic	[17, 18]
41	ITA 335	Unknown	Tanzania	1972	Aromatic	[15, 16]
42	TOX 6	Unknown	Tanzania	1972	Aromatic	[13]
43	TOX 4	Unknown	Tanzania	2001	Non- aromatic	[13]
44	TOX 5	Unknown	Tanzania	2001	Non- aromatic	[13]

S/N	Variety	Designation	Origin	Time started growing	Key Preferred trait	Reference
45	TOX 9	Unknown	Tanzania	2001	Non- aromatic	[13]
46	WITA 6	Unknown	Tanzania	2001	Non- aromatic	[13]
47	WITA 7	Unknown	Tanzania	2001	Non- aromatic	[13]
48	WAB 450	Unknown	Tanzania	2002	Non- aromatic	[13]
49	WAB 189	Unknown	Tanzania	2002	Aromatic	[13]
50	Kilombero	Unknown	Tanzania	2005	Aromatic	[13]
51	Kenya	Unknown	Tanzania	1980	Aromatic	[13]
52	MET 3	ART35-114-1-6N-2	AfricaRice	2019	Aromatic	[19]
53	MET 4	ART34-146-1-8N-1	AfricaRice	2019	Aromatic	[19]
54	MET 6	ART35-49-1-4N-1	AfricaRice	2019	Aromatic	[19]
55	MET 12	ART34-88-1-2-B-1	AfricaRice	2019	Aromatic	[19]
56	MET 13	ART34-113-3-2-B-1	AfricaRice	2019	Aromatic	[19]
57	MET 14	ART34-256-3-1-B-2	AfricaRice	2019	Aromatic	[19]
58	MET 16	ART35-272-1-2-B-1	AfricaRice	2019	Aromatic	[19]
59	MET 40	ART27-190-1-4-2-1-1-3	AfricaRice	2019	Aromatic	[19]
60	SUPA 1	Unknown	IRRI	2017	Aromatic	[19]
61	SUPA 2	Unknown	IRRI	2017	Aromatic	[19]
62	SUPA 3	Unknown	IRRI	2017	Aromatic	[19]
63	SUPA 4	Unknown	IRRI	2017	Aromatic	[19]
64	SUPA 5	Unknown	IRRI	2017	Aromatic	[19]
65	SUPA 6	Unknown	IRRI	2017	Aromatic	[19]
66	SUPA 1052	Unknown	IRRI	2017	Aromatic	[19]

S/N	Variety	Designation	Origin	Time started growing	Key Preferred trait	Reference
67	SUPA 1024	Unknown	IRRI	2017	Aromatic	[19]
68	PR 26	Unknown	China	2018	Non- aromatic	[19]
69	PR 27	Unknown	China	2018	Aromatic	[19]
70	PR 101	Unknown	China	2018	Aromatic	[19]
71	ARU 1189	Unknown	AfricaRice	2017	Aromatic	[19]
72	ARU 1190	Unknown	AfricaRice	2017	Aromatic	[19]
73	ARU 1191	Unknown	AfricaRice	2017	Aromatic	[19]
74	AGRA 41	AGRA-CRI-UPL-3-4	Ghana	2017	Aromatic	[19]
75	AGRA 55	AGRA-CRI-UPL-4-4	Ghana	2017	Aromatic	[19]
76	AGRA 60	AGRA-CRI-UPL-4-13	Ghana	2017	Aromatic	[19]
77	AGRA 78	AGRA-CRI-UPL-2-1	Ghana	2017	Aromatic	[19]
78	Yasmin aromatic	Unknown	Egypt	2017	Aromatic	[19]

Table 1.
Rice varieties grown in Uganda.

No	Genotype	Designation	Reaction	Breeding centre	Reference
1	ARC-1	ARC36-2-1-2	HR	AfricaRice	[25]
2	ARC-2	ARC36-4-EP-2	HR	AfricaRice	[25]
3	ARC-3	ARC39-145-P-3	HR	AfricaRice	[25]
4	ARC-4	ARC39-145-P-2	HR	AfricaRice	[25]
5	ARC-5	ARS126-3-B-1-2	HR	AfricaRice	[25]
6	ARS126-3-B-1-2	ARS126-3-B-1-2	HR	AfricaRice	[25]
7	IRL 2 (GP 54)	IRL 2 (GP 54)	R	AfricaRice	[25]
8	IRL 4 (69 GP 54)]	IRL 4 (69 GP 54)]	R	AfricaRice	[25]
9	Gigante	Gigante	HR	AfricaRice	[25]
10	ARICA-5/NamChe1	WAB95-B-B-40-HB (ARICA 5)	HR	AfricaRice	[25]
11	Tog5672	Tog5672	HR	AfricaRice	[25]
12	Tog5674	Tog5674	HR	AfricaRice	[25]
13	Tog5681	Tog5681	HR	AfricaRice	[25]
14	MET14	ART34-256-3-1-B-2	HR	AfricaRice	[19]; [25]
15	NamChe2	NM7-8-2-B-P-2-1	HR	AfricaRice	[25, 26]
16	MET3	ART35-114-1-6N-2	HR	AfricaRice	[25, 26]
17	MET8	ART35-100-1-7D-1	HR	AfricaRice	[25, 26]
18	MET12	ART34-88-1-2-B-1	HR	AfricaRice	[25, 26]
19	MET13	ART34-113-3-2-B-1	HR	AfricaRice	[25, 26]
20	MET16	ART35-272-1-2-B-1	HR	AfricaRice	[25, 26]
21	MET35	ART27-58-3-2-2-1	HR	AfricaRice	[25, 26]
22	MET44	PCT-11\0\0\2,Bo\2\1>404-1-1-1-1-M	R	AfricaRice	[25, 26]
23	MET50	PCT-11\0\0\2,Bo\2\1>82-3-1-1-3-2-M	R	AfricaRice	[25, 26]
24	MET60	PCT-4\0\0\1>295-2-3-1-3-3-M	R	AfricaRice	[25, 26]
25	MET66	PCT-4\SA\1\1,SA\2\1>746-1-1-4-1-3-M	R	AfricaRice	[25, 26]
26	MET70	PCT-4\SA\5\1>1754-5-1-5-3-1-M	R	AfricaRice	[25, 26]
27	Nerica8		R	AfricaRice	[25, 26]
28	IR61979-138-1-3-2-3		R	AfricaRice	[26]
29	SR33859-HB3324-133	SR33859-HB3324-133	HR	AfricaRice	[26]
30	NM 15-1	R33701-HB3330-78 X SR33859-HB3324-133	R	AfricaRice	[26]
31	NM 15-2	FAROX 521-357-H1 X SR33701-HB3330-78	HR	AfricaRice	[26]

No	Genotype	Designation	Reaction	Breeding centre	Reference
32	NM 15-3	NamChe-2/ SR33705-HB3381-62	HR	AfricaRice	[26]
33	NM 15-4	NamChe-5/ SR33705-HB3381-62	HR	AfricaRice	[26]
34	NM 15-5	ARC36-2-P-2/ SR33705-HB3381-62	HR	AfricaRice	[26]
35	NM 15-6	32610A X NERICA-4	HR	AfricaRice	[26]
36	NM 15-7	326104 X NamChe-5	HR	AfricaRice	[26]
37	NM 15-8	326104 X NERICA-1	HR	AfricaRice	[26]
38	SR34034-HB3471-10	HB4052/Ungwang	HR	AfricaRice	[26]
39	SR34034-HB3471-23	HB4052/Ungwang	HR	AfricaRice	[26]
40	SR34034-HB3471-24	HB4052/Ungwang	HR	AfricaRice	[26]
41	SR34555-HB3472-18	HB4055/Hopum	HR	AfricaRice	[26]
42	SR34039-HB3366-64	HB4055/MS11	HR	AfricaRice	[26]
43	SR34042-HB3475-6	HB4057/Japonica 1	HR	AfricaRice	[26]
44	SR34035-HB3477-61	HB4057/Ungwang	HR	AfricaRice	[26]
45	SR34035-HB3477-96	HB4057/Ungwang	HR	AfricaRice	[26]
46	SR33705-HB3381-62	Hwaseong/ IR84421-4-47-B-1-3	HR	AfricaRice	[26]
47	SR33705-HB3381-113	Hwaseong/ IR84421-4-47-B-1-3	HR	AfricaRice	[26]
48	SR33703-HB3482-8	Ilpum/IR84421-4-47-B-1-3	HR	AfricaRice	[26]
49	SR34040-HB3367-55	Japonica 1/HB4052	HR	AfricaRice	[26]
50	SR34038-HB3420-35	MS11/HB4052	HR	AfricaRice	[26]
51	SR34038-HB3420-38	MS11/HB4052	HR	AfricaRice	[26]
52	SR34038-HB3420-56	MS11/HB4052	HR	AfricaRice	[26]
53	SR33859-HB3324-93	Samgwang/ Yeongdeok53	HR	AfricaRice	[26]
54	SR33859-HB3324-133	Samgwang/ Yeongdeok53	HR	AfricaRice	[26]
55	SR33701-HB3330-78	Odae/Borami	HR	AfricaRice	[26]
56	CN127	D20-ARS-22-B	HR	AfricaRice	[26]
57	AR38	ARS887-9-1-4-4	HR	AfricaRice	[26]
58	LW21	CSR36	HR	AfricaRice	[26]
59	RF96	IR 97071-24-1-1-2	HR	AfricaRice	[26]

Table 2.
Rice genotypes resistant to RYMV.

rice types in their background developed under Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI) rice collaborative research.

In 2018, another set of 112 germplasm was screened for rice yellow mottle virus disease (RYMVD) resistance. The germplasm comprised of *O. barthi* interspecific lines generated from crosses between *Oryza sativa* L. and *O. barthi.* These breeding lines were selected for their high yield potential, resistance to diseases and other desirable culinary qualities. Seventeen promising genotypes were identified, among which six comprising of [ARS126–3-B-1-2 (11), ARC36–2-P-2 (2), ARC39–145-P-2 (5), Gigante, IRL 2 (GP 54) and IRL 4 (69 GP 54)] were highly resistant to RYMV disease. List of the 11 resistant lines for RYM derived from *O. barthi* crosses are shown in **Table 2**.

In 2019, a total of 307 lines including the 247 KAFACI lines were introduced into East African Regional Rice Research and Training centre at NaCRRI, Namulonge-Uganda and each of the introduced seed samples were divided into three parts. The first part was planted using a single row plots in the screen house at NaCRRI. Each row had 10 cm spacing with 15 hills and the rows were. Spaced 15 cm apart. A prepared RYMV inoculate was used to inoculate 5 plants in each row following procedure described by [22]. Symptom appearance was monitored on daily basis to assess the stage of disease initiation. Also, symptom expression post inoculation (DPI), severity on weekly intervals from 21 DPI, through 28 DPI, 35 DPI and 42 DPI were collected. We also took record of plant height for inoculated and non-inoculated plants and the percentage reduction for each of the lines were calculated The results revealed that 3 lines ofIR64/rymv1-2, IR64/rymv1-3 and IR64/RYMV3 showed severity score of 1 on score 1-9; 14 lines showed severity score of 3. These 7 lines are; SR34574-HB3565-284, ARS1958-1, SR34574-HB3565-285, SR34574-HB3565-290, HR32068F1-4-20-1-6-3-2, HR32068F1-4-20-1-6-4-2 and HR32068F1-4-20-1-6-4-3, which were also found to exhibit resistance to all other diseases assessed, namely rice blast, BB, sheath rot and narrow leaf brown spot. A total of 39 lines showed severity score of 5 while up to 57 lines showed reduction in plant height by at most 30%. Further analysis based on a rating scale for Susceptible (7-9), Medium resistance (4-6) and Resistance (0-3) indicated line, namely, HB4057, rymv1-2, rymv1-3, RYMV3, Hannam, NamChe-2 and Ungwang as the resistant donors.

In respect to bacterial leaf blight (BLB) disease, a total of 18 isogenic lines developed for BLB disease were screened in three hotspot areas of Namulonge-Wakiso, Olweny-Lira and Kibimba- Bugiri districts in Uganda. The results revealed IRBB21 (Xa 21) as the most resistant line in all the three locations followed by IRBB8 [27], implying that lines with these genes could be used to pyramid for multiple stress resistance in our breeding programme.

In another study, 32 lines were screened for resistance to BLB and six other lines, namely, CT 12, WITA 132 x NERICA 14, NERICA 10, NERICA 4 and NERICA 1 were reported resistant to BLB [27]. These four lines could be donor parents in breeding for BB resistance as currently, several rice lines have shown resistance to leaf bacterial blight (**Table 3**).

Rice blast disease has been mentioned in several articles as a major constraint in rice production in Uganda [2, 3, 5, 6]. Accordingly, 450 lines were progressively screened in 2014, 2015, 2016, 2017, 2018 and 2020 for sources of resistance to the rice blast disease. In 2014, a total of 50 lines introduced from South Korea though the KAFACI were screened alongside a resistant (IR-64) and a susceptible (NERICA 1) checks. These were the breeding population from a cross of an African cultivated rice, *Oryza glaberrima* of Niger Delta origin and Milyang 23, a Tongil-type Korean rice variety and a total of 29 lines were resistant to rice blast [26] (**Table 4**).

No	Genotype	Designation	Reaction	Source
1	IRBB21	Xa 21	HR	NaCRRI
2	CT 12	Unknown	HR	NaCRRI
3	NERICA 1	WAB 450-1-B-P-38-HB	HR	NaCRRI
4	NERICA 4	WAB 450 IBP91HB.	HR	NaCRRI
5	NERICA 10	WAB 450-11-1-1P41-HB	HR	NaCRRI
6	WITA 132 x NERICA 14	Unknown	HR	NaCRRI

Key: HR = high resistance; NaCRRI = National Crops Resources research Institute, Namulonge - Uganda. Source; Lussewa et al. [27].

Table 3.
Lines resistant to bacterial leaf blight disease.

Another set of 46 rice genotypes introduced from South Korea though the KAFACI were screened for resistance to rice blast under screen house condition and in the field at NaCRRI Uganda in the year 2015 [28]. The screening exercise involved infecting and selecting the infected rice plants and by observing the symptoms on the leaves based on the rice blast identification guide. Data on leaf blast severity, lesion size, area under disease progress curve (AUDPC) for leaf blast severity and lesion size, panicle blast and yield were collected on five randomly selected plants in the field and on three plants in the screenhouse from each plot according to the standard evaluation system of rice [24]. Results revealed that genotypes SR33859-HB3324-133, SR33859-HB3324-93 and SR33701-HB3330-78 were highly resistance to rice blast and had good performance for yield [28] (**Table 4**).

In a related study aimed at understanding transmission of genes for resistance to rice blast, it was found that both additive and non-additive effects contributed to transmission of resistance genes for rice blast disease to the progenies. The inheritance of rice blast resistance has been indicated to be mainly controlled by additive gene effects, besides a small influence of a non-additive effects [28].

In an effort to combat brown spot disease caused by *Biplaris oryzae* pathogen, a total of 100 lines were screened for resistance to rice brown spot in 2017 and 2018 at Namulonge. The results showed that 18 lines were rated as highly resistant, 52 resistant, 27 moderately resistant and three lines including the checks were susceptible [29]. The list of the highly resistant lines recommended for further breeding work is presented in **Table 5**.

Further studies where F_2 progenies from the crosses involving parents with distinct phenotypic classes of brown spot revealed information of segregation ratios for the different crosses. In particular, crosses TXD 306 × NERICA 4, NERICA 1 × NERICA 4, NERICA 4 × NERICA 1 and E 22 × PAK conformed to the 3:1 ratio, suggesting the presence of at least one gene showing dominance [30].

Another study conducted to identify lines resistant to bacterial leaf streak (BLS) identified three lines of NERICA 1, NERICA 6 and IURON 2015-1 as highly resistant to the pathogen causing bacterial leaf streak [31].

2.2.2 Insect pests

A study was also conducted to identify rice lines resistant to African rice gall midge (AfRGM) and 20 rice genotypes with diverse breeding background were evaluated for the resistance to AfRGM under controlled conditions in a screen house and under the field conditions at NaCRRI, Namulonge - Uganda [32]. Infestation was done in accordance with the method use by Ogah [33] where 3 females and 2

No	Genotype	Designation	Reaction	Breeding centre	Reference
1	MET3	ART35-114-1-6N-2	R	AfricaRice	[26]
2	MET8	ART35-100-1-7D-1	R	AfricaRice	[26]
3	MET12	ART34-88-1-2-B-1	R	AfricaRice	[26]
4	MET13	ART34-113-3-2-B-1	R	AfricaRice	[26]
5	MET16	ART35-272-1-2-B-1	R	AfricaRice	[26]
6	MET35	ART27-58-3-2-2-1	R	AfricaRice	[26]
7	MET44	PCT-11\0\0\2,Bo\2\1>404-1-1-1-1-1-M	R	AfricaRice	[26]
8	MET50	PCT-11\0\0\2,Bo\2\1>82-3-1-1-3-2-M	R	AfricaRice	[26]
9	MET60	PCT-4\0\0\1>295-2-3-1-3-3-M	R	AfricaRice	[26]
10	MET66	PCT-4\SA\1\1,SA\2\1>746-1-1-4-1-3-M	R	AfricaRice	[26]
11	MET70	PCT-4\SA\5\1>1754-5-1-5-3-1-M	R	AfricaRice	[26]
12	Nerica8		R	AfricaRice	[26]
13	SR34034-HB3471-10	HB4052/Ungwang	R	KAFACI	[26]
14	SR34034-HB3471-23	HB4052/Ungwang	R	KAFACI	[26]
15	SR34034-HB3471-24	HB4052/Ungwang	R	KAFACI	[26]
16	SR34555-HB3472-18	HB4055/Hopum	R	KAFACI	[26]
17	SR34039-HB3366-64	HB4055/MS11	R	KAFACI	[26]
18	SR34042-HB3475-6	HB4057/Japonica 1	R	KAFACI	[26]
19	SR34035-HB3477-61	HB4057/Ungwang	R	KAFACI	[26]
20	SR34035-HB3477-96	HB4057/Ungwang	R	KAFACI	[26]
21	SR33705-HB3381-62	Hwaseong/IR84421-4-47-B-1-3	R	KAFACI	[26]
22	SR33705-HB3381-113	Hwaseong/IR84421-4-47-B-1-3	R	KAFACI	[26]
23	SR33703-HB3482-8	Ilpum/IR84421-4-47-B-1-3	R	KAFACI	[26]
24	SR34040-HB3367-55	Japonica 1/HB4052	R	KAFACI	[26]
25	SR34038-HB3420-35	MS11/HB4052	R	KAFACI	[26]
26	SR34038-HB3420-38	MS11/HB4052	R	KAFACI	[26]
27	SR34038-HB3420-56	MS11/HB4052	R	KAFACI	[26]
28	SR33859-HB3324-93	Samgwang/Yeongdeok53	R	KAFACI	[26]
29	SR33859-HB3324-133	Samgwang/Yeongdeok53	R	KAFACI	[26]
30	SR-133,	SR33859-HB3324-133,		KAFACI	[28]
31	SR-93	SR33859-HB3324-93		KAFACI	[28]
32	SR-80	SR33701-HB3330-80		KAFACI	[28]

Table 4.
Lines resistant to rice blast.

male of AfRGM were released in each cage. A total of 180 females and 120 males of gall midge was used. Genotypes MET P-7 and NERICA 6, NERICA 4 and NERICA 1 consistently exhibited high tolerance to AfRGM. The most desirable (high negative)

No	Genotype	Designation	Reaction	Source
1	NM-22-1	NamChe-2/SR33705- HB3381-62	HR	NaCRRI
2	NM-22-2	NamChe-5/SR33705- HB3381-62	HR	NaCRRI
3	NM-22-3	ARC36-2-P-2/SR33705- HB3381-62	HR	NaCRRI
4	E22	NM7-22- 11- B-P-1-1 (WAB 450-1-BL1-136-HB /WAB 450-B-136-HB)	HR	NaCRRI
5	NERICA 10		HR	AfricaRice
6	NERICA 4	WAB450-1-B-P-91-HB	HR	AfricaRice
7	E1	NM7-22- 14- B-P-1-5	HR	NaCRRI
8	E11	NM7-1- 9- B-P-1-1	HR	NaCRRI
9	P27H4	NM7-27- 5- B-P-1-2	HR	NaCRRI
10	E186	NM7-186- 8- B-P-1-3	HR	NaCRRI
11	E51	NM7-51- 9- B-P-1-4	HR	NaCRRI
12	P8H13	NM7-8- 9- B-P-1-5	HR	NaCRRI
13	E123	NM7-123- 10- B-P-1-6	HR	NaCRRI
14	E3	NM7-3- 9- B-P-1-7	HR	NaCRRI
15	E104	NM7-104- 16- B-P-1-8	HR	NaCRRI
16	E99	NM7-99- 14- B-P-1-9	HR	NaCRRI
17	E16	NM7-16- 12- B-P-1-7	HR	NaCRRI
18	E135	NM7-135- 11- B-P-1-9	HR	NaCRRI
19	E8	NM7-8- 11- B-P-1-12	HR	NaCRRI
20	P26H6	NM7-26- 11- B-P-1-9	HR	NaCRRI
21	P27H3	NM7-27- 11- B-P-1-12	HR	NaCRRI
22	P3R1	NM7-3- 11- B-P-1-4	HR	NaCRRI
23	P55H7	NM7-55- 11- B-P-1-6	HR	NaCRRI

Source: Marco et al. [29].

Table 5.
List of rice lines resistant to brown spot.

SCA effects were observed in the crosses from NERICA 6 X E 22, NERICA 1 X K 85, NERICA 1 X KOMBOKA and NERICA 4 X KOMBOKA. Low (desirable) GCA values were witnessed in the case of genotypes of NERICA 6, NERICA 1, NERICA 4 and MET P-7, indicating the importance of the parents in contributing resistance towards AfRGM in rice.

In another study to identify sources of resistance to stalk-eyed fly pest (*D. longicornis*) in rice plants, four out of eight lines namely, NERICA 4, TXD 306, K 85 and NM7-22-11-B-P-1-1, showed high resistance to stalk eyed fly upon screening on-station at Namulonge in 2015 [34]. These four-high resistant (HR) lines were crossed with moderately susceptible lines NERICA 1, NERICA 6, Namche 2 and PAKISTAN in a North Carolina II mating design to determine their combing abilities for the insect pest resistance. The results showed that NERICA 4 and K 85 were good general combiners for resistance to the pest. The crosses Pakistan × TXD 306 and NERICA 1× NM7-22-11-B-P-1-1 were identified as promising lines for advancement. Further analysis revealed that the stalk-eyed fly in rice seems to be controlled both by additive and non-additive genes, thus selection at early generations (F_1 and F_2) would not be effective. Therefore, selection can be appropriately delayed to a later generations, between F_4 and F_6. Advancement of selected breeding lines (Pakistan × TXD 306 and NERICA 1× NM7-22-11-B-P-1-1) is, therefore, recommended for further evaluation for resistance to the stalk-eyed fly in later generations [34]. The parental lines NERICA 4 and K 85 are recommended as good general combiners and could be used as the donor parents in the breeding programme for the pest.

2.2.3 Abiotic stresses

Further, an investigation aimed at identifying rice lines with tolerance to cold was conducted and 41 lines at panicle initiation growth stage were subjected to controlled environmental condition of 17°C for 30 days prior to screening and the results revealed three lines, namely, Yunertian, Yunkeng and Zhongeng to exhibit tolerance to cold stress. Furthermore, a study was carried out to determine mode of transmission of genes resistance to cold stress and the crosses from Agoro x Zhongeng, TXD x Zhongeng, 1189 x Zhongeng, 1052 x Zhongeng, TXD x Yunertian and 1189 x Rumbuka presented high and positive specific combining ability (SCA) effect to cold stress at seedling stage indicating that the crosses could be used in selection of cold tolerant lines.

Submergence is a salient yield decimating factor in rice partly because water control and field level under irrigated and rain-fed conditions is weak. In order to address this challenge, a total of 29 rice genotypes were screened for submergence tolerance. Of these, six genotypes namely, *O. barthi* interspecific lines which were obtained from a cross of *O. barthi* and *O. sativa*, where *O. glaberrima* is a monocarpic annual derived from *O. barthi*. Two are released varieties (Namche 5, Namche 2) and six are candidate lines for release (ARS 126-3-B-1-2, ARU1189, ARU1190, ARU1191, E20 and E22) are potential candidate varieties for rain-fed lowland condition [35]. Evaluation of submergence tolerant rice genotypes following the IRRI standard protocol revealed a significant difference in seedling height assessed immediately after submergence stress. The genotypes were screened by submerging 14 days old seedling at 100 cm water depth for 14 days and another set at 45 cm water depth for 14 days following IRRI standard protocols. The study revealed four rice genotypes of Swarna, IRRI SUPA 3, KOMBOKA and SUPA 5 to be tolerant to submergence at 45 cm water depth for 10 days, with at least 85% survival rates. While varieties Swarna, SUPA 5, IRRI SUPA 3, KOMBOKA Mahsuri and IR 64 showed stable survival rate at both water depths with ≥75% survival rates.

2.2.4 Grain quality

Aroma in rice is a trait of high economic importance, thus are highly valued by consumers and thus commanding higher prices compared to the non-aromatic genotypes. However, the popular global varieties, namely, Basmati of India and Pakistan origins could not be adopted in Uganda because they succumbed to multiple biotic stresses rendering them not suitable for production in Uganda. In response to this challenge, the rice breeding program in Uganda, therefore, have employed two intervention strategies. The first was to screen all rice germplasm for aroma and initiate breeding program for improvement of aroma characteristics and through cooking and leaf sample testing, 39 aromatic rice varieties were identified (**Table 6**). In the second study, screening was conducted based on 2-acetyl-1-pyrroline (2-AP) concentration and the genotypes MET 3, SUPA 1052, Namche 1, ART-4 and BASMATI 370 exhibited not only high, but also stable 2-AP levels. These

S/N	Genotype	Designation	Reaction	Breeding centre	Reference
1	AGRA 41	AGRA-CRI-UPL-3-4	Aromatic	CRI, Ghana	[19]
2	AGRA 55	AGRA-CRI-UPL-4-4	Aromatic	CRI, Ghana	[19]
3	AGRA 60	AGRA-CRI-UPL-4-13	Aromatic	CRI, Ghana	[19]
4	AGRA 78	AGRA-CRI-UPL-2-1	Aromatic	CRI, Ghana	[19]
5	ART 4	ART15-22-10-8-1-B-2-2	Aromatic	AfricaRice, Nigeria	[19]
6	ART 7	ART15-17-7-8-1-1-1-B-1-1	Aromatic	AfricaRice, Nigeria	[19]
7	ART 10	ART15-21-2-4-1-B-1-B-1-1	Aromatic	AfricaRice, Nigeria	[19]
8	Basmati 370	Unknown	Aromatic	India	[19]
9	Komboka	IR 05N 221	Aromatic	IRRI, Philippines	[19, 36]
10	MET 3	ART35-114-1-6N-2	Aromatic	AfricaRice, Nigeria	[19]
11	MET 4	ART34-146-1-8N-1	Aromatic	AfricaRice, Nigeria	[19]
12	MET 6	ART35-49-1-4N-1	Aromatic	AfricaRice, Nigeria	[19]
13	MET 12	ART34-88-1-2-B-1	Aromatic	AfricaRice, Nigeria	[19]
14	MET 13	ART34-113-3-2-B-1	Aromatic	AfricaRice, Nigeria	[19]
15	MET 14	ART34-256-3-1-B-2	Aromatic	AfricaRice, Nigeria	[19]
16	MET 16	ART35-272-1-2-B-1	Aromatic	AfricaRice, Nigeria	[19]
17	MET 40	ART27-190-1-4-2-1-1-3	Aromatic	AfricaRice, Nigeria	[19]
18	NERICA 10	WAB 450-11-1-1-P41-HB	Aromatic	WARDA/Africa Rice	[19]
19	Sande	O. barthi interspecific lines	Aromatic	AfricaRice, Nigeria	[19]
20	Supa 3	IR 97011-7-7-3-1-B	Aromatic	IRRI, Philippines	[19]
21	Supa 5	IR 97011-16-2-4-B	Aromatic	IRRI, Philippines	[19]
22	Supa 6	IR 9712-4-1-2-1-1	Aromatic	IRRI, Philippines	[19]
23	Supa 1052	SUPA V88*2/ IR09F154	Aromatic	AfricaRice, Nigeria	[19]
24	Yasmin aromatic	Unknown	Aromatic	Egypt	[19]
25	GSR-1	GSR IR1- 5-S14-S2-Y1	Aromatic	IRRI, Philippines	[19]
26	GSR-2	GSR IR1- 4-D3-Y1-Y1	Aromatic	IRRI, Philippines	[19]
27	GSR-3	GSR IR1- 4-D6-LI2-LI1	Aromatic	IRRI, Philippines	[19]
28	GSR-4	GSR IR1- 3-D7-LI1-S2	Aromatic	IRRI, Philippines	[19]
29	GSR-5	GSR IR1- 4-D3-LI1-LI1	Aromatic	IRRI, Philippines	[19]
30	GSR-5	GSR IR1- 3-S13-Y1-S1	Aromatic	IRRI, Philippines	[19]
31	NM 19-12-13-1	ARC36-2-P-2/Komboka	Aromatic	NARO, Uganda	[19]
32	NM 19-12-13-1	ARS126-3-B-1- 2/Komboka	Aromatic	NARO, Uganda	[19]
33	NM 19-12-13-1	SR33705-HB3381- 62/ Komboka	Aromatic	NARO, Uganda	[19]
34	NM 19-12-13-1	NamChe-2/Komboka	Aromatic	NARO, Uganda	[19]
35	NM 19-12-13-1	NamChe-5/Komboka	Aromatic	NARO, Uganda	[19]
36	Supa local	SUPA V88	Aromatic	Tanzania	[37]
38	TXD-306	TXD-306	Aromatic	Tanzania	[37]
39	Pishori	Pishori	Aromatic	Tanzania	[18]
40	GSR1	GSR IR1- 5-S14-S2-Y1	Aromatic	IRRI/CAAS	
41	GSR2	GSR IR1- 4-D3-Y1-Y1	Aromatic	IRRI/CAAS	

S/N	Genotype	Designation	Reaction	Breeding centre	Reference
42	GSR3	GSR IR1- 4-D6-LI2-LI1	Aromatic	IRRI/CAAS	
43	GSR4	GSR IR1- 3-D7-LI1-S2	Aromatic	IRRI/CAAS	
44	GSR5	GSR IR1- 4-D3-LI1-LI1	Aromatic	IRRI/CAAS	
45	GSR6	GSR IR1- 3-S13-Y1-S1	Aromatic	IRRI/CAAS	
46	GSR7	NM7-8-2-B-P-11-6	Aromatic	IRRI/CAAS	
47	GSR8	IR 83683-63-3-1-2-1	Aromatic	IRRI/CAAS	

Table 6.
Rice lines showing aroma characteristics.

parents identified with strong aroma characteristics could be used in the subsequent breeding program for aroma characteristics.

Amylose level influences grain cooking quality and therefore rice with high amylose content are not preferred, for example in Uganda, rice with intermediate amylose level ranging from 15–22% are the commonly grown varieties. Therefore, in a bid to maintain preferred amylose content within the Uganda's rice collections, a study was under taken to screen 60 lines for amylose content for two seasons in 2018 [38]. Of the 60 lines screened, seven lines consistently were of intermediate amylose content (AC), namely Namche 1 (21.84%), P62H17 (20.86%), Namche 1 (21.84%), Namche 2 (16.74%), Namche 3 (14.64%), Namche 5 (22.77%) and ARU 1190 (27.86%) in both environments. A study to understand the mode of transmission of genes for amylose content revealed that six crosses, namely, 1052 x Suparica, 326104 x NERICA 4, 1052 x Namche 2, Namche 2 x Namche 3, Namche 1 x NERICA 4 and Namche 3 x NERICA 4 with significant ($P \leq 0.05$) negative SCA effects indicating that there was reduced AC% in the crosses whereas the remaining seven crosses with positive significant SCA effects for amylose content indicated increase in the AC% of the progenies in these crosses.

2.3 Variety release

In light of the challenges of rice production and increasing demand for climate smart agriculture, varieties that are tolerant to known biotic and abiotic stresses were developed and released in Uganda (**Table 7**). Overall, 7 rainfed lowland rice varieties were released in addition to existing local rice varieties. Of the 7 varieties 2 were aromatic and 5 non-aromatic varieties [14, 39].

2.4 Current focus

This information will guide selection of parents to use in rice improvement in the country. In the development of improved rice varieties, core sets of population are critical. Identified SNP markers are accelerating this process. Currently, rice germplasm available are being genotypes for presence of known genes of importance in rice breeding. Over 50 SNP markers covering major biotic and biotic, grains quality, yield and physiological traits are the current target are being used on the Uganda germplasm. With SNP markers being developed already aiding the process of selecting core populations for breeding and accelerating selection of promising lines, we believe that efforts to identify more SNPs in populations that show presence of genes through morphological but not positive under current SNP panel be given urgent attention. This will provide broad accumulations of preferred genes at genome level for *O sativa*. This is critical considering that core populations may

Variety details	Exceptional characteristics
Name: Chiga-1 Designation: DU 363-2 Cross: NA Source: China Year of release: 2019 Potential yield: 9.600 Kgs/ha Maturity period: 129 days Type: Hybrid	Bold and big grains like SUPA; Leaf blade has distinctive purple edge that warrants purity management; Strong stem, moderately resistant to RYMV
Name: ARIZE-1 Designation: ARIZE GOLD 6444 Cross: NA Source: Bayer Crop Science Year of release: 20149 Potential yield: 7,900 Kgs/ha Maturity period: 108 days Type: Hybrid	Has distinctive erect flag leaf; moderately tolerant to RYMV, tolerant to rice blast and BLS; Flaffy when cooked
Name: Komboka Designation: IR 79253-55-1-4-6 Cross: IR 74052-297-2-1/IR 71700-247-1-1-2 Source: IRRI Year of release: 2014 Potential yield: 6,900 Kgs/ha Maturity period: 118 days Type: Inbred	Has distinctive erect flag leaf; moderately tolerant to RYMV, tolerant to rice blast and BLS; Flaffy when cooked, Aromatic
Name: Agoro Designation: IR 09 A 136 Cross: IR 75000-69-2-1-2 / IR 71684-36-3-3-2 Source: IRRI Year of release: 2014 Potential yield: 6,100 Kgs/ha Maturity period: 124 days Type: Inbred	Has light green and erect flag leaf; moderately tolerant to RYMV, Rice blast and BLS; Flaffy when cooked
Name: Okile Designation: GSR-I-0057 Cross: ZGY 1 Source: IRRI/CAAS Year of release: 2014 Potential yield: 6,800 Kgs/ha Maturity period: 140 days Type: Inbred	Has large erect flag leaf; moderately tolerant to RYMV, Rice blast and BLS; Flaffy when cooked
Name: WITA-9 Designation: TOX 3058-28-1-1-1 Cross: IR 2042-178-1/CT19 Source: AfricaRice/IITA Year of release: 2014 Potential yield: Maturity period: Type: Inbred	Has short erect flag leaf; tolerant to RYMV, resistant to Rice blast and BLS; Flaffy when cooked, purple stipes in the leaf sheath and leaf margin
Name: NERICA-6 Designation: WAB450-1-B-P-160-HB Cross: CG 14/WAB56-104 Source: AfricaRice Year of release: 2014 Potential yield: 6100 Maturity period: Type: Inbred	Has long flag leaf; smooth leaf, Tolerant to RYMV, resistant to Rice blast and BLS; Flaffy when cooked

Table 7.
Irrigated and rainfed rice varieties released in Uganda.

solve current challenges but not necessarily emerging constraints. This is important considering that several breeding programs Uganda rice breeding developing varieties with relatives of *O.sativa* especially *O. glaberrima* and *O. barthi* in their background that may open new causative genes one by one sources of traits of importance. The Uganda rice breeding program urgently needs the global rice community to urgently work towards identification of numerous causative genes and the phenotypic performances for the current populations being developed with *O. glaberrima* and *O. barthi* in their background and understand biochemical pathways associated with them.

3. Conclusion

This paper provides information on the trends in the development of irrigated and lowland rice in Uganda. It reveals that there are more unreleased rice genotypes under cultivation than the released varieties. This observation points to the fact that rice improvement and variety release is a recent development in the country. Also, that more effort has been in screening introductions and conducting adaptation trials. These efforts contributed to selection of widely adapted genotypes that became accepted in the rice breeding program in Uganda. The panel of adapted lines have diverse parental background that includes *Oryza barthii*, *Oryza glaberrima* and the parent *O. sativa*. These lines will form basic germplasm for use in integrating the classical breeding to molecular biology led breeding.

Acknowledgements

The authors would like to acknowledge persons who were involved in various research on rice in Uganda and coordinating rice breeding initiatives in the country. We appreciate International Rice Research Institute (IRRI)-through STRASA and GSR projects, AfricaRice-through the AfricaWide Rice Breeding Task Force, CIAT Colombia, Crops Research Institute (Kumasi, Ghana) for sharing germplasm. We thank Prof Tongoona Pangirayi and Prof Patrick Okori who guided development of rice breeding program in Uganda through training and mentorship with support Alliance for Green Revolution AGRA.

Conflict of interest

The authors declare no competing interests.

Statement

Rice breeding is Uganda is still new. There is need to strengthen collaborative research with International and National partners in research and capacity (human and physical) development.

Author details

Jimmy Lamo[1]*, David Ochan[2], Desta Abebe[3], Zelalem Zewdu Ayalew[3], Anna Mlaki[4] and Cyprien Ndikuryayo[5]

1 National Agricultural Research Organization (NARO), Uganda

2 Gulu University, Gulu, Uganda

3 Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

4 International Institute of Tropical Agriculture, Arusha, Tanzania

5 Institut des Sciences Agronomiques du Burundi (ISABU), Burundi

*Address all correspondence to: jlamoayo@gmail.com

References

[1] Ojara M, A., Olivier Ann, L Aribo, B. A Ogwang B.A, and P Wasswa, *Predicting Suitability of Upland Rice for Adoption as Food Security and Poverty Alleviation Crop in Uganda* Journal of Geography and Earth Sciences, 2017(5: 1): p. 26-40.

[2] Biggs, C.E.J., *Agriculture in Uganda*. Agriculture in Uganda, ed. T. JD. 1940, London: Oxford University Press. 158-161.

[3] Tiley, G.E.D., *Rice – Oryza sativa L.* , in *Agriculture in Uganda*, J. JD, Editor. 1970, Oxford University Press: London. .

[4] Reid, R., *Political power in pre-colonial Buganda: Economy, Society and warfare in the nineteenth century*. 2002, Kampala Fountain Publisher

[5] McMaster, D.N., *A subsistence crop geography of Uganda*. 1962, Cornwall, England: Geographical Publications.

[6] Imanywaha, J.B., *Rice*, in *Agriculture in Uganda*, Mukiibi, Editor. 2001, Fountain Publishers: Kampala, Uganda. p. 70.

[7] Lamo, J., *Genetic studies on drought tolerance and grain shattering* in *Farmers preferred rice varieties and their implications for breeding in Uganda* 2010, Researchspace: University of Kwazulu Natal. p. 39-55.

[8] Alibu S, O.M., Adur-Okello SE, Lamo J, Ekobu M and Asea G. , *Farmer's Knowledge and Perceptions on Rice Insect Pests and Their Management in Uganda Agriculture* Agriculture, 2016. **6**(3):38 DOI: 10.3390/agriculture6030038

[9] Adur-Okello EE, A.S., Lamo J, Ekobu M and Otim MH, *Farmers' Knowledge and Management of Rice Diseases in Uganda.* Journal of Agricultural Sciences. , 2020. **1**(12:12).

[10] Winnyfred Amongi, S.T.N., Paul Gibson, Richard Edema and Mikdred Ochwo-Ssemakula. , *Genetics of drought tolerance in common beans genotypes adapted to Ugandan conditions* J.o.P.B.a. C. Science, Editor. 2015. p. 18-27. DOI: 10.5897/JPBS 2014.0462.

[11] Parviz Fasahat, A.R., Javad Mohseni Rad, John Derera, *Principles and utilization of combining ability in plant breeding*, B.a.B.I. Journal, Editor. 2016. p. 1–22. DOI: 10.15406/bbij.2016.04.00085.

[12] Kilimo-Trust., *Development of Inclusive Markets in Agriculture and Trade (DIMAT): The Nature and Markets of Rice Value Chains in Uganda.* . 2012.

[13] Lamo, J. 2010. Genetic studies on drought tolerance and grain shattering PhD Thesis. University of KwaZulu-Natal, South Africa. School of Agricultural Sciences and Agribusiness. pp 205. Farmers preferred rice varieties and their implications for breeding in Uganda 39-55 https://researchspace.ukzn.ac.za/xmliu/bitstream/handle/10413/735/Lamo_J_2010.pdf?sequence=1&isAllowed=y

[14] NARO, *Submission to the variety release committee for the release of 5 irrigated lowland rice varieties (Oryza sativa l.) candidate cultivars in 2014* N.A.R. Organization, Editor. 2014: National Agricultural Research Organization (NARO) Entebbe, Uganda. p. 52 pp.

[15] Haneishi, Y., Maruyama, M., Godfrey, A., Okello, S.E., Tsuboi, T., Takagaki, M., Kikuchi, M. 2013. Exploration of rainfed rice farming in Uganda based on a nationwide survey: Regionality, varieties and yield. Afric. J. of Ag. Res. In print.

[16] Kijima, Yoko, 2014. "Enhancing Rice Production in Uganda: Impact

Evaluation of a Training Program and Guidebook Distribution in Uganda," Working Papers 80, JICA Research Institute.

[17] Odogola WR (2006). Final Survey Report on the Status of Rice Production, Processing and Marketing in Uganda. Kampala, Uganda. 77

[18] Masette M, Candia A, Khahasa E, Okurut S, Tinyiro SE 2013. Preferences of Ugandan consumers for rice varieties and brands on the local market. Uganda Journal of Agricultural Sciences 14(2):1-11

[19] Lamo J. Enhancement of high yielding rice germplasm and breeding capacity of Uganda. pages 327-352 *in* Enhancement of high yielding rice germplasm and development of high-yielding grain quality rice variety. 2019 KAFACI evaluation meeting on the 1st phase of AfricaRice Development Partmeship. Dec. 2-9, 2019, Saint-Louis, Senegal.

[20] Mogga ML, L.J., Asea G, Gibson P, Edema R *Reaction of rice cultivars to a virulent rice yellow mottle virus strain in Uganda.* African Crop Science Society 2012. **20:1**.

[21] Munganyinka E, E., R, Lamo J and Gibson, P. , *The reaction of intraspecific and interspecific rice cultivars for resistance to rice yellow mottle virus disease.*, E.J.o.E. Biology, Editor. 2016. p. 13-18.

[22] Fauquet C, T.J., *Isolation of the Rice yellow mottle virus in Ivory Coas.* Plant Disease Reporter, 1977. **61:6**: p. 443–448. .

[23] Thottappilly, V.J.a.G., *A scoring system for rice yellow mottle virus* I.R.R. Newsletter, Editor. 1987 Los Banos

[24] IRRI, *Standard Evaluation System (SES) for Rice*, n.R.R.I. (IRRI), Editor. 2014: Los Banos. p. 52.

[25] Ndikuryayo C, M. Ochwo-Ssemakula , P. Gibson and J. Lamo 2019. Resistance to Rice yellow mottle virus and performance of selected improved rice genotypes in central Uganda December 2019 Crop Protection 129: 105041. https://doi.org/10.1016/j.cropro.2019.105041

[26] Lamo J, C.G., Ininda J, Ayirebi DPK, Ekebu J, Ekobu M, Alibu S, Okanya S, Oloka B, Otim M, Asea G, and Kang K., *Developing Lowland Rice Germplasm with Resistance to Multiple Biotic Stresses through Anther Culture in Uganda* K.J.o.I. Agriculture, Editor. 2015. p. 415-420.

[27] Lussewa, R., R Edema and J Lamo *Magnitude of genotype x environment interactions for bacterial leaf blight resistance in rice growing areas of Uganda*, A.J.o.C. Science, Editor. 2016.

[28] Zewdu Z, E.R.a.L.J., *Genetic Study of Resistance to Rice Blast in Crosses between Korean and Locally Adapted Rice Genotypes*, A.C.S.a. Technology, Editor. 2017, DOI: 10.4172/2329-8863.1000346

[29] Marco MM, O.-S.M.J.L., Paul G and Edema R,, *Reaction of upland rice genotypes to the brown spot disease pathogen Bipolaris oryzae* A.J.o.R. Development, Editor. 2017.

[30] Marco MM, O.-S.M., Paul G, Edema R, Jimmy, and Lamo J, *Inheritance of resistance to brown spot disease in upland rice in Uganda* J.o.P.B.a.C. Science., Editor. 2016. p. 16.09.16-0613.

[31] Kanaabi M, T.G., Tukamuhabwa P, Andaku J, Ocan D, and Lamo J., *Evaluation of Rice Germplasm Reveals Sources of Bacterial Leaf Streak Disease Resistance in Uganda*. 2018: Journal of Food Security. . p. 163-169.

[32] Belete, D.A., *Inheritance of resistance to African rice gall midge (Orseolia oryzivora) in lowland rice in Uganda*, M. T.M. University, Editor. 2020: Makerere University. p. 120.

[33] Ogah, E.O., Odebiyi, J.A., Omoloye, A.A., Nwilene, F.E., 2012. , *Evaluation of some rice genotypes for incidence of African rice gall midge and its parasitoid (P. diplosisae).* African Crop Science Society, 2012. **20**: p. 137-147.

[34] Charles Ganteh Weelar , J.L., Michael Hilary Otim, Bruno Awio, Mildred Ochwo-Ssemakula *Mode of inheritance of resistance to the stalk-eyed fly (Diopsis longicornis) in rice* International Journal of Agronomic and Agricultural Research, 2017. **10**: p. 9-20.

[35] Mlaki AB, G.P., Edema R, Habineza JC, Mwanje G, Lamo J and Nuwamanya E., *Identification of rice genotypes tolerant to submergence at seedling stage in Uganda*, J.o.P.B.a.C. Science, Editor. 2019. p. 173-184

[36] Marco MM, Ochwo-Ssemakula M J Lamo, Paul G and Edema R, 2017. Reaction of upland rice genotypes to the brown spot disease pathogen Bipolaris oryzae. African Journal of Rural Development, Vol. 2 (1): 2017: pp.127-133

[37] Kanaabi Michael, Tusiime, Geoffrey1., Tukamuhabwa, Phinehas., Zziwa, Simon JL Andaku , Lamo, Jimmy. Characterizing agronomic response of rice genotypes to bacterial leaf streak disease in Uganda. International Journal of Agronomy and Agricultural Research (IJAAR) ISSN: 2223-7054 (Print) 2225-3610 (Online) h ttp://www.innspub.net Vol. 14, No. 1, p. 1-10, 2019.

[38] Kitara IO, L.J., Edema R, Gipson P and Rubaihayo P., *Inheritance of Amylose content and relationship between grain appearance, quality traits and amylose content in rice genotypes in Uganda*, J.o.A. a.V. Science, Editor. 2018. p. 2319-2372.

[39] NARO, *Submission to the variety release committee for the release of rice varieties (Oryza sativa l.) candidate cultivars: DU 363-2 and ARIZE Gold 6444 in 2019*. 2019: National Agricultural Research Organization (NARO) Entebbe Uganda. p. 28 pp.