**Exploring the Feasibility of Growing upland Rice in flooded Paddy Ecosystems**

**ABSTRACT**

This study was conducted to evaluate the adaptability and performance of three upland rice varieties; NERICA 4, NamChe 5 and PR 107 under flooded paddy ecosystems in Doho, Tororo and Kween sites. The experiment was conducted in a Complete Randomized Block Design with three replications during March-June in 2022 and 2023. Data were collected on soil pH, organic matter, soil mineral nutrients and texture. Data were also collected on plant height, number of tillers plant-1/ hill-1, panicles plant-1, seeds panicle-1 and grain yield. Data were analysized (ANOVA) using 13th Edition of GenStat statistical package and significant differences between treatments means were separated using Fischer's least significant difference test at P<0.05. The pH range was neutral (5.8-6.6) at all the sites. The nitrogen levels were high under all treatments but Ngenge registered higher Phosphorus (70.4) than Doho (17.1) and Tororo (23.9) sites. The Potassium levels in the soils were similar at Doho and Tororo (0.5-0.6 Cmol/ kg) but higher in Ngenge (1.33 Cmol/ kg). The major soil textural class was sandy clay loam for Doho & Tororo but Ngenge had clay soil texture. NERICA and NamChe rice recorded taller plants than WITA 9 at all sites. Doho recorded higher seeds per panicle (190-192 seeds), tillers (9 plant-1 / 23 hill-1), panicles (321 m-2 / 22 hill-1) for WITA 9 than other treatments during 2022 and 2023. NERICA however, gave similar grain yield to WITA 9 during 2022 (4-5 Mtha-1) and 2023 (4.0 Mtha-1). The yield attributes for NERICA and NamChe were similar in 2022 but in 2023 NERICA at Doho recorded significantly, higher (P<0.05) tillers (19 tillers) and panicles hill-1 (19 panicles) than NamChe (17 tillers & 16 panicles).In Tororo WITA 9 recorded more seeds per panicle (192-193 seeds), tillers plant-1(9.0 tillers) besides panicles per square metre (314-315 panicles) than both NERICA and NamChe during 2022 and 2023. The yield parameters under the latter 2 treatments were at par and the grain yield for the three treatments was not significant in the 2 years. In Ngenge the growth attributes, yield parameters and yield for NERICA 4 and NamChe 5 were similar during the two seasons. NERICA 4 and NamChe 5 upland rice varieties could be adapted and adopted under flooded paddy conditions

**Key Words:** Adaptability, flooded paddy conditions, NERICA 4, NamChe 5. PR 107, WITA 9.

1. **INTRODUCTION**

As the population of the world increases, provision of food is crucial to all countries as it is desired to ensure global food security [1] Demont, M. (2013). In Uganda the importance of rice (*Oryza spp*.) forced the government to join the Coalition for Africa Rice Development (CARD) formed in 2008 [2] Nabikyu *et al.,* (2023). The goal of CARD was to double rice production for food security and incomes of smallholder farmers in Sub Saharan Africa (SSA) in a period of 10 years [2]. Rice is a commodity of strategic importance in the world considering area under cultivation and number of people who depend on it [3] (WARDA,.2009). In 2022 the total world rice production was 776.5 m Mt and China was the world highest producer (208.5 m Mt) followed by India (196.2 m Mt [4] (FAO Corporate Statistical Database, 2022). The African countries that each produced over 1.0 m Mt of paddy rice included Egypt, Nigeria, Tanzania, Ivory coast, Sierra Leone, Senegal, Ghana and Democratic republic of Congo [4]. Rice is the most rapidly growing food source across the African continent due to the great urbanization relative to other regions in the world [5] (Hegde and Hegde 2013) and it is widely grown in the Eastern and Northern regions of Uganda [6] (Kijima & Serunkuma, 2012). Paddy rice production in Uganda increased by 95% from 373,000 Mt in 2020 to 727,000 Mt during 2021 [7] (Uganda Statistical Abstracts 2023), The increase was attributed to among other factors; development of high yielding, pests, disease and drought tolerant cultivars, introduction and adoption of improved agronomic practices, besides other technologies [7] (Uganda Statistical Abstracts 2023). Most of the local paddy rice varieties grown in wetlands are sensitive to water stress [8] (Balasubramanian *et al.,* 2007). The varieties are late maturing (120-140 days) and susceptible to diseases, The impact of rice cultivation on wetlands depends on wetland type, intensity of drainage and agronomic practices including the use of fertilizers. There is need to adopt and adapt improved varieties to the prevailing farming conditions. The Uganda government has shifted the emphasis from paddy cultivation to upland rice growing. The main reason for this shift is the growing concern over ways to prevent the fragile wetland ecosystems from further damage caused by paddy cultivation [2]. Upland rice is easier to cultivate compared to traditional paddy varieties, and responds well to low rainfall as long as it is well distributed during growing phase [3].

Despite the commercialization of rice production with the establishment of rice schemes in Uganda, the output from Paddy ecosystems continues to lag behind demand in the country[2]. Soil fertility has also declined, and increased the production costs [9] Tsujimoto *et al*., 2019), leading to overuse of fertilizers that may negatively impact on wetland ecosystems. In order to increase agricultural productivity worldwide, the current strategy is to enhance the resilience of rice plants to biotic and abiotic stresses. [10] Ali *et al*., (2019) reported that continued disturbance of wetlands is not only disastrous to the ecosystems, but also increases greenhouse gas (GHG) emissions into the atmosphere resulting in global warming, The researchers remarked that since the cultivation of late maturing paddy rice varieties is known to increase GHG emissions including CH4, NO2 and CO2, strategies need to be sought to ensure optimal yields with reduction in GHG emissions. Adopting short term upland rice varieties with efficient water use under paddy conditions could be one strategic option. Farmers who grow upland rice varieties suited for paddy conditions have more flexibility, as they can adjust to different types of landscapes and climate conditions, reducing dependency on one farming method and diversifying risk. Upland rice varieties that adapt to flooded paddy conditions may benefit from pest suppressing effects, leading to healthier crops. Given the changing climate, regions that were previously too dry for traditional paddy rice cultivation might benefit from upland rice varieties adapted to wetter conditions, allowing farmers to grow rice in new areas and maintain food security. Upland rice cultivation in paddy flooded conditions may allow for year-round rice cultivation, leading to more consistent food production in regions where seasonal rainfall is unpredictable or where paddy rice production was previously not feasible. Since upland rice typically requires less inputs like fertilizers and pesticides compared to traditional paddy rice, varieties that can adapt to paddy conditions maintain cost saving traits, making farming more economically viable.

Organic matter (OM) is one of the key indicators of soil health as it plays a significant role in crop production and improves soil physical, chemical, and biological functions. Increasing the levels of organic matter aids soil structure, water-holding capacity, nutrient mineralization, biological activity, water and air infiltration rates. Soil OM improves the soil's capacity to store and supply essential nutrients and to retain toxic elements. OM allows the soil to cope with changes in soil acidity and fastens the decomposition of soil minerals. Nitrogen is the key macro-nutrient for plant growth and its limitation in the soil affects the crop’s vegetative growth. Deficiency symptoms are presented by the plant leaves yellowing starting from the old leaves and from the leaf tips. It is an important component of plant proteins. The N ranges are very low (<0.05%), low (0.05-0.15%), medium ( 0.15-0.25%), high (0.25-0.5%) and very high (>0.5 %). Phosphorus (P) is the key element where the rice crop derives energy and any deficiency affects many plant functions. In the wetland areas, P nutrients tend to accumulate and soil analysis may be high. P is considered very low when it ranges between 0-1ppm, low when 12.5-22ppm, medium in the range 23-35.parts per million (ppm), high at 36-68ppm and very high when over 69 ppm. Potassium (K) is taken in the form of K2O and is associated with the movement of water, nutrients and carbohydrates in plant tissues. K is involved in enzyme activation within the plant, which affects protein, starch and Adenosine Triphosphate production. Its deficiency in plants manifests as leaf cell dying at the edges. The optimum textural class that presents suitable conditions for nutrient uptake and plant growth is loam soil.

Rice yellow mottle disease, caused by rice yellow mottle virus (RYMV), is a major challenge to rice production in Africa [11] (Paul *et al.,* (2003) and has not been reported in other continents of the world [12].(Banwo *et al.,* 2004). In Uganda the disease was first reported in 2000 by [13]. Pinel-Galzi *et al.* (2006) as plants with yellow and mottling symptoms. The disease has since spread and varieties with good culinary properties including Super have been reported to be highly susceptible to the virus [14] (Ochola and Tusiime 2011). Development of RYMV resistance requires exploitation of natural resistance sources [15]. (Zouzou *et al.,*2008). The disease affects rice under all types of cultivation systems including lowland and upland, rainfed rice [16] (Hebrard *et al.,* 2009). The disease was initially described and named by [17]. Bakker (1974). RYMV primarily infects rice (*Oryza sativa*), but it can also infect several other grass species, including wild rice (*Oryza longistaminata* and *Oryza barthii*). Increased rice cultivation to meet the high demand for consumption across the continent due to the availability of water for sequential plantings throughout the year increases the spread of RYMV [18] (Reckhaus & Randrianangaly 1990). Sindano (IR22) and Basmati 217 rice varieties among others that were introduced into the African continent mostly proved to be highly susceptible to the virus [19]. (Thresh 1991). Barnyard Grass (*Echinochloa* spp.) is very common in rice fields and can harbor the virus. Cutgrass (*Leersia hexandra*), which is often found in rice-growing regions, and Bermuda Grass (*Cynodon dactylon*) are both known to be potential hosts [20]. (Abbo *et al.*1998). Wild rice species can also serve as reservoirs for the virus [21]. (Konate & Fargette 2001). The widespread distribution and ability to infect multiple hosts make RYMV a significant threat to rice production across SSA.

Uganda produces varieties of the New Rice for Africa (NERICA), namely NERICA 1, 4 and 10 developed by WARDA. NERICA rice is the product of interspecific hybridization between the cultivated rice species of Africa and Asia (*Oryza sativa* x *O. glaberrima*).

NERICA 4 is the most adopted upland rice variety, grown in more than 10 countries in Sub-Saharan Africa (SSA). It gives good yield (3-6 Mt ha-1), early maturing (85-100 days) and tolerant to biotic (pests,) and abiotic stresses like drought and soil conditions) which makes it suitable for SSA. NamChe 5 rice variety is not only high yielding (3-5 Mtha-1) under good management practices, but also of longer maturity (120-140 days), with mild aroma, good grain quality, high tillering ability and drought tolerant is being adopted in Uganda. The variety is also well suited for irrigated conditions. NARO rice 1 (PR 107) which is aromatic, high yielding (4-6 Mt ha-1), resistant to RYMV, rice blast and Bacterial Leaf Streak and is also being adapted and adopted in Uganda and matures in 90-110 days). WITA 9 rice is a high yielding variety (4-7Mtha-1) depending on the environment and management conditions. It is resistant to many diseases including rice blast and bacterial blight but may require management for insect pests. WITA 9 has excellent grain quality, high milling recovery and good adaptability to both upland and lowland conditions. It matures in about 120-130 days and often used in commercial farming. The upland varieties are currently competing with the commonly grown paddy rice varieties because they are highly resistant to diseases, mature earlier (90-110 days), high yielding (potentially 4-6 Mt ha-1 unmilled) and grows under moderate water availability (Lamo *et al.,* 2017). [22].reported that upland rice is a promising better alternative to paddy rice for sustainable production and household income generation. Upland rice was also reported as a good substitute for partially submerged paddy rice in dry land, hillside land or low-lying areas where rainfall is stable but lacking irrigation (Lamo *et al.,* 2017). [22]. Improved, high yielding upland rice varieties have been developed by the National Crop Resources Research Institute (NaCRRI) in Uganda in collaboration with other institutions (Lamo *et al.,* 2017).[22]. Although farmers grow some of these improved upland rice varieties (NERICA and NamChe), their performance under paddy flooded conditions is not well known. The objective of this study therefore, was to evaluate the adaptability and performance of three upland varieties under different ecological flooded paddy conditions as a viable alternative to cultivation of paddy varieties. It is considered that this work will be of significance in guiding a rational increase in rice production under both upland and paddy flooded ecosystems.

1. **MATERIALS AND METHODS**
	1. Study sites

**2.1.1 Location, rainfall and temperature**

The study was conducted in Uganda at Doho scheme on Butaleja district, Tororo swamp in Tororo district and in Ngenge scheme in Kween district during the first rain seasons (March-June) of 2022 and 2023. Doho is located at 000 26’23.2N 0330 28’40.9E, at 1209 meters above sea level. The rainfall at the site during the cropping season was 652 mm during 2022 and 850.6 mm during 2023. (Figure 1). During 2022 the mean cropping season’s minimum and maximum temperatures were 17.50C and 330C against the annual average temperatures of 18.20C and 350C. The mean minimum and maximum temperatures during 2023 cropping season were 18.40C and 32.60C respectively (Figure 2). The Tororo site is found at 0044’59.99N 34004’60.99E, at 1199 meters above sea level. Rainfall received at the site during the 2022 cropping season was 753 mm and 840 mm were recorded during 2023. (Figure 1). The mean cropping season’s minimum and maximum temperatures (2022) were 230C and 310C, relative to the annual average temperatures of 18.30C and 320C respectively. During 2023 cropping season the mean minimum and maximum temperatures were 22.80C and 31.60C respectively (Figure 2). Ngenge site is situated 1031’59’N 34030’0’E, at 1276 meters above sea level. At the site the rainfall received during the cropping season was 732 mm during 2022 and 740.6 mm during 2023. (Figure 1). In 2022 the mean minimum and maximum cropping season’s temperatures were 210C and 340C against the annual average temperatures of 200C and 330C. The mean minimum and maximum temperatures during 2023 cropping season were 20.40C and 320C respectively (Figure 2).

**Figure 1; Rainfall received at Doho, Tororo and Ngenge sites during March-June 2022 &2023**

**2.1.2 Plant Nutrients and soil texture**

The pH, organic matter (OM), soil nutrients; nitrogen (N), phosphorus (P) potassium (K), sodium (Na) and texture were determined prior to the study and data recorded. Nitrogen is the primary component of amino acids, proteins, enzymes, nucleic acids, chlorophyll and vital plant molecules fundamental for rice growth and development. N is absorbed through roots as amino acids, nitrite ions or ammonium ions. Phosphorus (P) is absorbed by plants as ortho-phosphate and as organic phosphorus It is essential for cell division and development of seedlings and young rice plants.

Figure 2: Minimum and maximum Temperatures at Doho, Tororo and Ngenge sites during 2022 & 2023

Potassium (K) is taken up by rice in the form of K2O and is associated with the movement of water, nutrients and carbohydrates in plant tissues. It is involved with enzyme activation within the plant, which affects protein, starch and Adenosine Tri Phosphate (ATP) production. Its deficiency in plants manifests as leaf cell dying at the edges. Soil texture influences drainage of soil water, air flow and holds the nutrients. The optimum textural class that presents suitable conditions for nutrient uptake and plant growth is loam soil.

**2.1.3 Experimental design and treatments**

The field experiment was conducted on each of 3 selected farms at Doho rice scheme in Butaleja district, Tororo farm in Tororo districts and on Ngenge rice scheme in Kween district during March - June of 2022 and 2023. Each of the treatments was applied in flooded lowland fields where rice had been previously planted for the past three years. The experimental plots measured 20m x 20m with inter plot spaces of 1m and arranged in a Completely Randomized Block Design, replicated three times. The rice varieties namely; NERICA 4 (Ner), NamChe 5 (Nam), PR 107 (Pr) and WITA 9 (Wit) collected from Uganda National Crops Resources Research Institute, Namulonge, were used. The treatments of rice adopted were the common varieties commonly grown in each of the districts at Doho (NERICA 4, NamChe 5, PR 107 & WITA 9); Tororo (NERICA 4, NamChe 5 & WITA 9) and Ngenge (NERICA 4 & NamChe 5). Pure 10 kg seeds of each of the four varieties were separately soaked and incubated for 24 hours at room temperature and then seeded on a well prepared nursery bed. Wet fields measuring 1,450 m-2 were divided into 3 replicates, ploughed, marked, leveled and puddled. Each of the replicates was divided into 4 equal plots, each measuring 100 m-2 with spacing of 1m between plots, considering the direction of water flow to be adjacent to the direction of replication. Rice was transplanted at 21 days after nursery establishment for all the varieties at a spacing of 30 x 12.5 cm. Fertilizers were applied to rice at 100 kg ha-1, 60 kg ha-1, 40 kg ha-1 of NPK in the form of Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP), respectively. The entire TSP and MOP were applied as basal at transplanting and Urea was top dressed in three equal splits at 15 days after transplanting (DAT), 25 DAT (tillering stage) and 30- 45 DAT (panicle initiation stage) to the rice crop.

**2.3 Data Collection**

**2.3.1 Soil pH, Organic matter, mineral nutrients and texture**

Soil litter was removed at the sampling spot and an auger driven to a depth of 15 cm to draw the soil sample from distinct randomly selected multiple locations in the experimental plots by zone sampling techniques at Doho, Tororo and Ngenge schemes. 10 samples were drawn from each sampling unit and placed in a bucket. The 10 samples from each experimental plot were thoroughly mixed and placed in a clean sample container. The sub samples were then taken to the soil laboratory for analysis. In the laboratories where the chemical elements were analyzed by loss on ignition method (organic matter), potentiometer (pH), Kjeldahl method (N), colorimeter (P) and an ion selective electrode for P. The soil texture was determined by soil sedimentation method.

**2.3.2 Field biometric data**

Strict data collection was carried out to compare the treatments. Two border rows in each plot and 5 border hills per row were not used for data collection and the remaining portion was considered as experimental plot. Plant height was measured from the base of the plant to the base of the flag leaf at panicle initiation, 30 days after transplanting (DAT) which coincided with the panicle initiation stage for NERICA, NamChe and PR 107 rice and at 45 DAT for Wita 9 rice. The mean numbers of leaves and tillers were counted per hill from panicle initiation till, full heading and at harvest on 10 tagged rice plants per treatment in the experimental plot. Data were collected on the incidences of Rice Yellow Mottle Virus (RYMV) disease in the experimental plots for all treatments at panicle initiation stage and before harvest. At maturity 10 hills were harvested in triplicates from 40m-2 of the experimental plot for determination of mean yield components namely; seeds panicle-1, tillers hill-1, tillers plant -1, panicles hill-1, panicles m-2, and grains panicle-1. The grain yield was determined from a 40m-2 net plot

**2.4 Data Analysis**

The collected data was subjected to analysis of variance (ANOVA) using Genstat statistical package (13th edition, 2013). The significant differences between treatments means were separated using Fischer's least significant difference (LSD) test at P<0.05.

 **3 RESULTS**

The data on soil analysis for the 3 sites (Doho, Tororo and Ngenge) are indicated in Table 1.

**3.1 PH Range, Soil Organic Matter content and Soil Texture**

The pH ranged between 5.8-6.6 in all the study sites. The pH of the soil at the 3 sites was not adjusted before the study. The soil OM was high (7.9%) in Tororo, low in Doho (6.1%) and a lower level was found in Ngenge (5.3%).

Table 1: Soil Analysis for Doho, Tororo and Ngenge sites

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Site/ Scheme | pH | O.M | N | P | K | Na+ | Sand | Clay | Silt | Texture |
| % | Mg/kg | Cmol/kg | % | % | % |  |
| Doho | 5.79b | 6.07b | 0.40a | 23.9b | 0.54b | 0.04b | 57.0a | 24.0b | 19.0b | Sandy clay loam |
| Tororo | 6.07a | 7.88a | 0.34a | 17.1c | 0.58b | 0.14a | 55.0a | 25.0b | 20.0b | Sandy clay loam |
| Ngenge  | 6.62a | 5.30c | 0.26b | 70.4a | 1.33a | 0.07b | 27.5b | 45.3a | 27.0a |  Clay |
| 1. Value

LSD (P<0.05)CV (%) | 0.040.572.7 | <.0010.093.4 | 0.040.099.2 | <.0015.184.4 | 0.0050.2911.3 | 0.0040.0312.0 | <0.0013.893.6 | <0.0012.913.9 | 0.013.675.2 |  |

*Note:* Values with different letters in a column are significantly different at P< .05

**3.2 Nitrogen, Phosphorus, Potassium and Sodium**

The levels of N were high at all sites and at par in Doho (0.4%) and Tororo (0.34%) though significantly (P>0.05) lower (0.26%) in Ngenge. Ngenge registered high levels of P (70.4 Mg/kg) and K (1.33 Cmol/kg) compared to Tororo and Doho sites. The Tororo site however recorded high levels of Na+ (0.14 Cmol/kg) than the other 2 sites. The major textural class was sandy clay loam found at Doho and Tororo and Ngenge site had clay soil texture.

**3.3 Rice plant height, seeds, tillers, panicles and yield for Doho during 2022****.**

The data on rice plant height, yield parameters and grain yield for rice planted in DOHO irrigation scheme during 2022 season are presented in Table 2. WITA 9 was a shorter (58 cm) treatment but exhibited significantly (P>0.05) more seeds per panicle (192 seeds), tillers per plant (9.0 tillers), panicles per square meter (321 panicles) and rice grain yield (5.0 Mtha-1) which was at par with NERICA 4 rice yield (3.94 Mtha-1). NERICA and NamChe produced rice of higher and similar height (80 & 82 cm) but together with PR 107 recorded significantly (P>0.05) lower seeds per panicle (145, 163 & 159 seeds), tillers per plant (6 tillers) and panicles per square meter (252, 213 & 220 panicles). The grain yield was high and similar (4.0 Mtha-1) under WiTA 9 and NERICA 4. NamChe 5 and PR 107 recorded significantly (P>0.05) lower (3.70 Mtha-1) grain yield.

Table 2 Growth parameters, Yield attributes and Yield of WITA 9, NERICA 4, NamChe 5 and PR IO7 under paddy conditions in Doho during 2022

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Treatments Plant height (cm) Seeds panicle-1 Tillers plant-1 Panicles m-2 Yield (Mtha-1}

WITA 9 57.83c 191.7a 8.75a 321.3a 4.99a

NERICA 4 80.25a 145.3b 6.40b 251.5b 3.98a

NamChe 5 82.03a 162.5b 5.73b 213.7b 3.74b

PR 107 66.13b 158.7b 6.20b 220.3b 3.69b

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

P-value <0.001 <0.001 0.003 <0.001 0.04

LSD (P≤ 0.05) 6.7 8.9 1.32 39.5 1.22

CV % 4.4 4.5 10.3 7.3 13.1

*Note:* Values with different letters in a column are significantly different at P< .05, NS: Not Significant

**3.4 Rice plant height, seeds, tillers, panicles and yield for Tororo during 2022**

The rice plant height, yield attributes and yield for WITA 9, NERICA 4 and NamChe 5 rice obtained from a study conducted in Tororo swamp during 2022 are indicated in Table 3. WITA rice was shorter in height than other treatments. The variety also recorded more tillers and seeds per panicle besides panicles per square metre than the other treatments. NERICA and NamChe produced similar seeds per panicle, tillers per plant and panicles per square metre. The grain yield for the three treatments was not significant .

Table 3 Growth parameters, Yield attributes and Yield of WITA 9, NERICA 4 and NamChe 5 in Tororo during 2022

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Treatments Plant height (cm) Seeds panicle-1 Tillers plant-1 Panicles m-2 Yield (Mt ha-1}

------------------------------------------------------------------------------------------------------------------------------------------- WITA 9 55.4b 193.0a 8.53a 314.3a 3.83

NERICA 4 76.5a 167.6b 6.72b 223.2b 3.26

NamChe 5 77.6a 171.5b 6.30b 208.5b 3.07

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

P-value <0.001 <0.001 0.007 <0.001 NS

LSD (P≤ 0.05) 4.7 11.17 1.18 31.4 0.77

CV % 5.5 5.7 6.9 5.3 9.7

*Note:* Values with different letters in a column are significantly different at P< .05, NS: Not Significant

The data on plant height, yield attributes and yield for NERICA 4 and NamChe 5 rice planted in Ngenge during 2022 are presented in Table 4. The two treatments were not significantly (P>0.05) different. NERICA rice however, recorded numerically higher (121 seeds ) seeds per panicle, tillers plant-1 (292 tillers), panicles per square metre and grain yield than NamChe 5.

Table 4 Growth parameters, Yield attributes and Yield of NERICA 4 and NamChe 5 in Ngenge during 2022

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Treatments Plant height (cm) Seeds panicle-1 Tillers plant-1 Panicles m-2 Yield (Mt/ha)

NERICA 4 73.7 121.0 5.71 272 3.17

NamChe 5 72.4 117.0 6.64 204 3.06

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

P-value NS NS NS NS NS

LSD (P≤ 0.05) 19.9 36.4 2.1 92.0 0.54

CV % 13.5 15.6 18.7 21.5 8.4

*Note:* Values with different letters in a column are significantly different at P< .05, NS: Not Significant

**3.5 Rice plant height, seeds, tillers, panicles and yield for Doho during 2023**

The results on rice plant height, yield parameters and grain yield for rice planted in Doho irrigation scheme during 2023 season are presented in Table 5. Plant height, seeds per panicle, tillers per hill, panicles per hill and grain yield significantly (P>0.05) differed amongst the treatments. NERICA 4 and NamChe 5 rice recorded taller plants than other treatments. The highest number of seeds per panicle were observed under WITA 9 and the latter treatment together with NERICA 4 rice produced similar and high tillers per hill of 3 seedlings, panicles per hill and rice grain yield. Lower numbers of tillers and panicles per hill besides grain yield was recorded under NamChe 5 rice. PR 107 rice produced lower seeds per panicle (107 seeds) amongst the treatments but had similar tillers, panicles and grain yield with NamChe 5 rice.

Table 5 Growth parameters, Yield attributes and Yield of WITA 9, NERICA 4, NamChe 5 and PR IO7 in Doho during 2023

--------------------------------------------------------------------------------------------------------------------------------------------

Treatments Plant height (cm) Seeds panicle-1 Tillers hill-1 Panicles hill-1 Yield (Mt ha-1}

WITA 9 57.7b 189.3a 23.1a 22.5a 3.55a

NERICA 4 76.9a 168.7b 18.8a 18.5a 3.60a

NamChe 5 79.0a 147.7b 17.5b 16.2b 2.83b

PR 107 64.5b 107.0c 18.4b 16.9b 2.63b

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

P-value <0.001 <0.001 0.004 0.05 0.05

LSD (P≤ 0.05) 7.07 8.34 4.56 4.13 0.70

CV % 5.0 4.3 11.9 15.1 11.0

 *Note:* Values with different letters in a column are significantly different at P< .05, NS: Not Significant

**3.6 Rice plant height, seeds, tillers, panicles and yield for Tororo during 2023**

The data on rice plant height, yield attributes and yield for WITA 9, NERICA 4 and NamChe 5 rice from a study conducted in Tororo swamp during 2023 are indicated in Table 6. WITA rice was shorter in height but recorded higher seeds per panicle and tillers besides panicles per square metre than other treatments. NamChe 5 rice variety recorded similar seeds per panicle tillers plant-1 and panicles m-2 to NERICA 4. The grain yield for the three treatments was not significant

Table 6 Growth parameters, Yield attributes and Yield of WITA 9, NERICA 4 and NamChe 5, in Tororo during 2023

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Treatments Plant height (cm) Seeds panicle-1 Tillers plant-1 Panicles m-2 Yield (Mt ha-1}

------------------------------------------------------------------------------------------------------------------------------------------ WITA 9 56.2b 192.0a 8.56a 315.6a 3.84

NERICA 4 76.0a 157.8b 6.05b 229.5b 3.23

NamChe 5 77.9a 172.5b 6.07b 211.1b 3.12

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

P-value 0.001 0.02 0.008 0.001 NS

LSD (P≤ 0.05) 8.0 18.44 1.34 33.0 0.82

CV % 4.9 5.0 8.0 6.4 10.2

*Note:* Values with different letters in a column are significantly different at P< .05, NS: Not Significant

**3.7 Rice plant height, seeds, tillers, panicles and yield for Ngenge during 2023**

The data on plant height, yield attributes and yield for NERICA 4 and NamChe 5 rice planted in Ngenge during 2023 are presented in Table 7. The two treatments were not significantly (P>0.05) different. NERICA rice however, recorded numerically higher seeds per panicle (125 seeds), tillers plant-1 (6.0 tillers), panicles per square metre (278 panicles) and grain yield (3.18 Mtha-1) than NamChe 5.

Table 7 Growth parameters, Yield attributes and Yield of NERICA 4, NamChe 5 in Ngenge during 2023

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Treatments Plant height (cm) Seeds panicle-1 Tillers plant-1 Panicles m-2 Yield (Mtha-1)

NERICA 4 76.2 125.0 6.01 278 3.18

NamChe 5 74.1 119.2 4.03 206 3.03

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

P-value NS NS NS NS NS

LSD (P≤ 0.05) 21.5 22.9 2.03 98.7 0.62

CV % 14.1 9.7 15.0 20.6 9.69

*Note:* NS: Not Significant

**3.8 Rice yellow mottle virus disease at Doho, Tororo and Ngenge during 2022 and 2023**

The Rice yellow mottle virus (RYMV) disease was not observed in the all the treatments of rice at the 3 sites during 2022 and 2023 cropping seasons’

**4. DISCUSSION**

**4.1 PH Range, Soil Organic Matter content and Soil Texture**

The pH range was found to be within the optimum range (5.2-7.0) for rice growing in all the study sites. The crop acidic levels therefore could have contributed to the proper environment for nutrient uptake and crop growth. At low pH, many soil elements become less available to plants, while others such as iron, aluminum and manganese become toxic to plants, The pH of the soil at the 3 sites was therefore not adjusted before the study. The soil OM was adequate at all the 3 sites but Tororo had higher (7.9%) OM content followed by Doho scheme (6.1%) and the least (5.3%) OM was in Ngenge site. The higher OM in both Tororo and Doho could have contributed to the improved sandy clay loam soil structure that was observed at the two sites relative to Ngenge site that was characterized with clay soil texture that has a poor structure. Organic matter improves soil aggregation, which enhances the ability of soil to retain water, allow better aeration, and facilitate root growth. Gao *et al.,* (2024) [23] reported higher rice yields under long term organic and inorganic treatments than under NPK fertilizer. Soil organic carbon, total nitrogen, available nitrogen and available potassium with long term organic and inorganic treatments were significantly (P≤ 0.05), higher than in inorganic fertilizer (NPK) treatments. Organic matter provides essential nutrients for plants and promotes activities of soil organisms, such as earthworms and microbes, which further improve soil structure. Over time organic matter helps to create a more loamy, well drained and fertile soil. Much as organic fertilizers increase crop yield and improve soil quality, they have disadvantages such as low efficiency, low nutrient content and high application rates. [24] Gai *et al.,* (2018); [25] Wang *et al.,* (2019) & [26] Liu *et al.,* (2021) reported that application of long term combined organic and inorganic fertilizers maintained and improved crop yield and soil fertility. Poor structured soils exhibit poor infiltration and low water holding capacity. The major textural class found at Doho and Tororo was sandy clay loam and Ngenge site had clay soil texture. Soils with good structures like in Tororo and Doho enhance root growth, resulting into better plant growth and movement of the soil nutrients such as nitrates to the roots.

**4.2 Nitrogen, Phosphorus, Potassium and Sodium**

The N levels were high (0.3-0.4%) under all treatments and the quantities were at par in Tororo (0.34%) and Doho (0.40%) sites though significantly, lower (0.26%) in Ngenge. Whereas, the recommended levels of Nitrogen were applied at all 3 sites, Tororo and Doho sites could have availed more N nutrients to the rice crop because of the higher OM and improved soil structure of sandy clay loam soils as reported by [24, 25 & 26] Gai *et al.,* (2018); Wang *et al.,* (2019) & Liu *et al.,* (2021). The significantly (P<0.05) higher levels of P recorded in Ngenge (70.4 Mgkg-1) relative to medium levels in Doho (24 0 Mgkg-1) and lower quantities found in Tororo (17.1Mgkg-1), possibly contributed to the low yield attributes and yield of rice recorded in Ngenge in the 2 seasons. Excessive Phosphorus reduces the plant’s ability to take up some nutrients like iron, zinc and Mn in the soil, The levels of K in the soils were low and at par in Doho and Tororo (0.5 cmol/kg) but a high level was observed in Ngenge (1.33 cmolkg-1). The K levels were lower than required for rice crop growth as the optimum level is 5-7 molkg-1. Potassium is associated with improved photosynthesis, cell wall strength, regulation of water and nutrients movement and enzyme activation within the plants which influence protein synthesis [27] (Deng *et al.,* 2020). It is implied that the applied K (40 kgha-1) at planting could have improved the growth of rice at the 3 sites. Potassium enhances root development, disease resistance, better photosynthesis, regulates water balance, increases grain quality, nutrient uptake and transport. [28] Jiang *et al* (2019; [29] Zhang, *et, al.,* (2021); [30] Chen *et al.* (2024 & [31] Deng (2024); observed that the rice grain yield and biomass of rice partly depended on plant K uptake. Due to the high cost of K fertilizers, farmers resort to applying more N fertilizer, resulting in significantly reduced rice yield and nitrogen use efficiency. Tororo recorded significantly (P<0.05) higher sodium levels than the other 2 sites.

**4.3 Rice plant height, seeds, tillers, panicles and yield for Doho during 2022 and 2023**

Plant height, seeds per panicle, tillers per hill, panicles per hill and grain yield significantly (P>0.05) differed amongst the treatments. NERICA and NamChe rice recorded taller plants (78-79 cm) than other treatments during the 2 seasons. The plant height could have been influenced by genetic potential coupled with the relatively high inherent NPK levels found in Doho sandy clay loam soils (Table 1). During the 2 seasons. The highest number of seeds per panicles was under WITA 9 and NERICA 4 rice which both produced similar and high tillers per plant, panicles per hill. The grain yield was high and similar (4.0 Mt/ha) under WITA 9 and NERICA 4 though NamChe 5 and PR 107 recorded significantly (P>0.05) lower (3.7 Mt/ha) grain yield during 2022 and 2023. This may be attributed to the high N levels found in the soil (Table 1). Similar observations were made by [32] Yan (2018) and [33] Jiang *et al*., (2020). Doho treatments had a longer growing period due to an extended rain period than at other sites. Both WITA 9 and NERICA 4 being late maturing rice varieties could have extensively benefited from high nutrient releases from the soil for tiller and panicle development. This condition coupled with possible deposits of photosynthates to the sinks possibly contributed to the high rice yield under the conducive sandy clay loam paddy soils. High grain yield was recorded in the current study under NamChe 5 (3.74 Mtha-1) in 2022 This was higher than the rice yield reported by [34] Kaiira *et al.,* (2023), under upland ecology for the same variety (2.0-2.3 Mtha-1) during 2022 in Uganda. The yield for the same variety during 2023 (2.83 Mtha-1) under the current study was however, lower than observed (3.8-4.4 Mtha-1) from different weed control treatments under in Uganda during 2023. The grain yield for NERICA 4 upland rice in this study during 2022 (3.89 Mtha-1) was similarly, higher than the yield reported (3.2-3.6Mtha-1) in 2022 by [35] Kaiira *et al* (2024). The NERICA 4 (3.6 Mtha-1) grain yield in 2023 under the current study was similarly lower than the yield (4.9-5.73 Mtha-1) reported by [24] in 2024 for the same variety under upland conditions in Uganda. The lower numbers of tillers, panicles per hill and grain yield recorded under NamChe 5 and PR 107 rice in DOHO, relative to WITA 9 and Nerica 4 rice varieties could be attributed to the high tolerance of NERICA 4 and WITA 9 to biotic and abiotic stresses relative to NamChe 5 and PR 107 rice varieties. As indicated in Figure 2 high maximum temperatures (330C) were recorded during both seasons with relatively low rainfall during 2022. Namche 5 and PR 107 varieties could have succumbed to water shortage and high temperature at critical growth stages that possibly hindered panicle formation and overall grain yield. There could also have been associated nutrient (NPK & micronutrients) deficiencies as a result of water stress to avail nutrients to the rice. Studies by [36] Saito *et al.,* (2019) indicated high resistance of WITA 9 to bacterial leaf blight, rice yellow mottling virus and rice blast. Several scientists have reported NERICA rice varieties as similarly tolerant to various biotic and abiotic stresses [37] (Saito *et al.,* 2012; [38] Sekiya *et al*, 2013 & [39] Saito *et al.,* 2018). Growth parameters, yield parameters and yield for different crop varieties are inherent genetic characteristics of crop varieties. It is implied that Namche 5 and PR 107could have also responded to their genetic yield potential.

**4.4 Rice plant height, seeds, tillers, panicles and yield for Tororo during 2022 and 2023**

During the 2 seasons, WITA 9 was shorter than other treatments but recorded higher seeds per panicle, tillers per plant and number of panicles m-2. The genetically shorter but late maturing WITA 9 crops, developed more tillers per plant over the extended growth period, that resulted into many panicles, seeds per panicle and high yield. NERICA and NamChe rice varieties recorded similar but lower seeds per panicle, tillers per plant and panicles per square metre than WITA 9, possibly due to the shorter maturity periods, leading to less period of exposure to solar radiation and nutrient uptake for deposition of synthates into the sinks of NERICA and NamChe rice varieties. The low yield attributes could also be attributed to the lower levels PK and high Na+ found at Tororo site. Low PK levels reduced photosynthesis, stress tolerance, cell structures and root development. [28] Jiang *et al* (2019; [27] Deng et al., (2020), [29] Zhang, et, al., (2021), [30] Chen *et al.* (2024 & [31] Deng (2024) confirmed that PK are required for proper rice crop growth and development especially for the grain yield and biomass. The grain yield was higher under WITA 9 (4.0 Mt/ha) and lower under NamChe 5 and NERICA 4 (3.0 Mtha-1) during the 2 seasons. This could be attributed to physiological processes of tiller development, panicle development, seed formation and filling of the sinks that could have been influenced by photo-period and nutrient availability for the long mature WITA 9 (120-140 days). The yield realized under the current study of 3.0 Mtha-1 is slightly lower than the grain yield (3.23 -4.0 Mtha-1) that was reported by [34] & [35] under upland conditions in Uganda.

**4.5 Rice plant height, seeds, tillers, panicles and yield for Ngenge during 2022 and 2023**

The growth and yield attributes of NERICA 5 and NamChe 4 were high and similar at Ngenge site and on average the yield for both varieties was 3.3 Mtha-1 for each of the varieties during the 2 seasons. The high PK level in Ngenge soils could have contributed to increased stress tolerance such as drought and extreme temperatures characterized in Ngenge, enhanced photosynthesis, regulated water balance and contribute to the observed increased number of seeds per panicle, tillers plant-1, panicles per square metre and grain yield (3.0 -3.6 Mtha-1) under NERICA 4 than NamChe 5. despite the high mean temperatures (320C-340C) during both seasons. The observed grain yield in the current study was relatively high and similar to the yield (3.23 - 4.0 Mt/ Ha) recorded by [34] Kaiira *et al.,* (2023) & [35] Kaiira *et al.,* (2024) for NamChe and NERICA rice under upland conditions in Uganda. The high yield may be attributed to the high number of panicles per square metre. [40] Zubair *et al.,* (2017) reported 5.0 -7.0 Mtha-1 as grain yield for NERICA 4 upland rice variety under paddy ecosystems. [41] Fujiie *et al.,* (2010) observed 2.0-3.3Mtha-1 as the potential for NERICA 4 under rainfed conditions and [42] Kinyumu (2009) reported an average yield of 3.27 Mtha-1 for NERICA 4 under upland ecosystem. Kaiira *et al.,* [34]) reported 3.0-4.0 Mtha-1 as the average grain rice yield for NamChe in Uganda.

**4.6 Rice yellow mottle virus disease at Doho, Tororo and Ngenge during 2022 and 2023**

The results indicated that NERICA 4, NamChe % and Wita 9 rice varieties were not susceptible to RYMV disease. The resistance to RYMV in the treatments may be attributed to genetic resistance. Resistance genes can produce proteins that inhibit growth of the disease causing organisms. Resistance may also arise from cellular and biochemical defenses of phytoalexins that inhibit pathogen penetration and growth or activate an immune or defense response in surrounding tissues and triggering programmed cell death to limit the spread of the pathogen. The results relate to reports by Africa Rice which noted that WITA 9 variety was not susceptible to RYMV. But another study found the presence of RYMV in leaf samples from WITA 9 suggesting susceptibility (http://scialert.net). The conflicting observations may arise from differences in environmental conditions, virus strain variations or research methodologies. [43] Ndikuryayo *et al.,* (2020) reported NAMCHE 2 rice variety as resistant to RYMV disease in Uganda while [44] Muganyinka *et al.,* (2015) similarly reported crosses with NERICA 1, 4 & 6 with best resistance to RYMV in Uganda.

**5. CONCLUSION**

NERICA 4 and NamChe 5 rice recorded taller plants than WITA 9 possibly due to their genetic inheritance. The upland varieties also produced high and similar number of seeds per panicles, tillers per plant, panicles per hill and grain yield. Low yield attributes and yield were however observed under PR 107 rice. NERICA 4 and NamChe 5 recorded on average similar to higher rice grain yield under flooded paddy conditions to the yields recorded from previous studies under upland ecosystems in Uganda. The two upland rice varieties (NamChe 5 and NERICA 4) indicate high potential for successful cultivation and adaptation under traditional flooded paddy conditions in Uganda and similar ecosystems. Based on the current study, NERICA 4 and NamChe 5 upland rice varieties matured earlier than WITA 9 and were similarly, not susceptible to RYMV disease or other biotic stresses. NERICA 4 and NamChe 5 could therefore be recommended for flooded paddy ecosystems since they were resilient and their yield performance was similar to that of WITA 9 paddy rice. Further studies are recommended to explore irrigation and nutrient management strategies that optimize performance of the upland rice varieties in flooded fields.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

**6. REFERENCES**

1.Demont, M. (2013) Reversing Urban Bias in African Rice Markets: A Review of 19 National Rice Development Strategies. Global Food Security, 2, 172-181.https://doi.org/10.1016/j.gfs.2013.07.001

2.Nabikyu, J., Twine, E. & Elliot D, Y (2023), Ban on Rice Cultivation in Uganda’s Wetlands; Implications for Household income, Food Security, Gender Equity and Social Safety Nets in the Rainfed Lowland Areas of Amuria, Soroti and Katakwi Districts. Africa Rice Center.

1. Africa Rice Centre (WARDA). 2009. The Growing NERICA Boom in Uganda. WARDA Publications: Cotonou, Benin.

4. FAO Corporate Statistical Database, 2022.

5. Hegde, S. and Hegde, V. (2013). Assessment of Global Rice Production and Export Opportunity for Economic Development in Ethiopia. ***International Journal of Science and Research* (**IJSR), 2(**6**): 2319-7064.

6. Kijima, Y. & Serunkuma, D. (2012). The adoption of NERICA rice varieties at the initial stage of the diffusion process in Uganda. ***African Journal of Agricultural and Resource Economics***, 8(**1**):44-56.

7. Uganda Statistical Abstracts, 2023).

8. Balasubramanian. V., S. M., Hijmans. R. J. & Otsuka, K., (2007). Increasing Rice Production in Sub-Saharan Africa. Challenges and Opportunities, ***Advances in Agronomy***. **94:**55-133. http://doi.org/10.1016/S0065-2113(06)94002-4.

9. Tsujimoto, Y., Rakotoson, T., Tanaka, A. and Saito, K. (2019) Challenges and Opportunities for Improving N Use Efficiency for Rice Production in Sub-Saharan Africa. ***Plant Production Science.*** https://doi.org/10.1080/1343943X.2019.1617638

10’ Ali, M. A., Inubushi, K., Kim, P. J. and Amin, S. (2019) Management of Paddy Soil towards Low Greenhouse Gas Emissions and Sustainable Rice Production in the Changing Climatic Conditions. In: ***Soil Contamination and Alternatives for Sustainable Development,*** Intech Open, London, **6**:90-107.

1. Paul. C. P., Ng N. Q. & Ladeinde T (2003). Mode of gene action of inheritance for resistance to rice yellow mottle Virus. ***Afr. Crop. Sci. J.*** **11**: 143-150.
2. Banwo, O. O., Alegbejo, M. D. & Abo. M. E, (2004). Rice yellow mottle virus genus sobemovirus: A continental problem in Africa. ***Plant protection Science*** **40**:26-36.

13. Pinel-Galzi. A., Fargette, D. & Hull, R (2006). First report of Rice yellow mottle virus in Uganda. (2007). Disease notes. https://doi.org/10.1094/PD.90-o683B.

14] Ochola, D and Tusiime, G. (2011). Survey on incidence and severity of Rice Yellow Mottle Virus in Eastern Uganda. International ***Journal of Plant Pathology****.* **2**(1):15-25.

1. Zouzou M., Kouakou. T. H., Kone. M. & Issaka. S. (2008). Screening rice (Oryza Sativa L.) varieties for resistance to rice yellow mottle virus. ***Scientific Research and Essay*** Vol. **3**(9):416-424.
2. Hebrard, E.; Fargette, D.; Konate, F.G.; Inera, O. & Faso, B. Rice yellow mottle virus. In ***Desk Encyclopedia of Plant and Fungal Virology***;
3. Bakker, W. *Characterization and Ecological Aspects of Rice Yellow Mottle Virus in Kenya*; ***Agricultural Research Reports*** 829; Wageningen
4. Reckhaus, P.M.; Randrianangaly, S. Rice yellow mottle virus (RYMV) on rice in Madagascar. *IRRI News.* 1990, **15**, 30.
5. Thresh, J.M. The ecology of tropical plant viruses. ***Plant Pathol.*****1991**, **40**, 324–339.
6. Abo, M.E.; Sy, A.A. & Alegbejo, M.D.(1998). Rice yellow mottle virus (RYMV) in Africa: Evolution, distribution, economic significance on sustainable rice production and management strategies. ***J. Sustain. Agric****.* **11,** 85-111.
7. Konate, G. & Fargette, D. (2001). Overview of Rice yellow mottle virus. In *Plant Virology in Sub-Saharan Africa, Proceedings of a Conference,*
8. Lamo, J., Tongoona, P., Sie, M., Semon, M., Onaga, G. and Okori, P. (2017) Upland Rice Breeding in Uganda: Initiatives and Progress. In: ***Advances in International Rice Research***, Intech Open, London, 11, 215-246. https://doi.org/10.5772/66826

23. Gao, P., Zhang, T., Lei, X., Cui, X., Lu, Y., Fan, P., Long, S., Huang, J., Gao, J., Zhang, Z. & Zhang, H, (2024). Improvement of soil fertility and rice yield after long-term application of cow manure combined with inorganic fertilizers. ***Journal of Integrative Agriculture***, **22**(7):2221-2232.

24. Gai, X, P., Liu, H. B., Liu, J., Zhai, L. M., Yang, B., Wu, S. X., Ren, T. Z., Lei, Q. L & Wang, H. Y.(2018). Long-term benefits of combining chemical fertilizer and manure applications on crop yields and soil carbon and nitrogen stocks in North China Plain. ***Agricultural Water Management,*** **208**, 384–392

25. Wang, H. X., Xu, J. L., Liu, X. J., Zhang, D., Li, L. W., Li, W, & Sheng, L. X. (2019). Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. ***Soil and Tillage Research,* 195**:104382

26. Liu, L. Y., Li, H. Y., Zhu, S. H., Gao, Y., Zheng, X. Q. & Xu, Y. (2021). The response of agronomic characters and rice yield to organic fertilization in subtropical China: A three-level meta analysis. ***Field Crops Research***, **263**, 108049.

27. Deng, J., Feng, X. Q., Wang, D. Y., Lu, J., Chong, H.T., Shang, C., Liu, K., Huang, L.Y.,Tian, X.H. & Zhang, Y. B. (2020). Root morphological traits and distribution in direct-seeded rice under dense planting with reduced nitrogen. 10.1371/journal.pane.0238362.

28. Jiang, W., Wang, X., Xing, Y., Liu, X., Cui, Z. & Yang. L. (2019). Enhancing rice production by Potassium management: Recommended reasonable fertilization strategies in different inherent soil productivity levels for a sustainable rice production system. ***Sustainability.*** 11(22):103390/su11226522.

29. Zhang, T., He, X., Chen, B, He, L. & Tang, X. (2021). Effects of different Potassium (K) fertilizer rates on yield formation and lodging of rice. ***Phyton-International Journal of Experimental Botany.*** DOI:10.32604 phyton,2021.014168.

30. Chen, G., Duan, Q., Wu, C., He, X., Hu, M., Li, C., Ouyang, Y., Peng, L., Yang, H., Zhang, Q., Jiang, Q., Lan, Y. & Li, T. (2024), Optimizing rice yield, quality and nutrient use efficienct through combined application of nitrogen and potassium. ***Front. Plant, Sci****.* **15**. http//doi.orrg/10.3389/fpls.2024.1335744.

31, Deng, J., Liu, K., Xiong, X., Hussain, T., Huang, L., Voil, P., Harrison, M. T., Tian, X. & Zhang, Y. (2024). Achieving sustainable rice production through nitrogen-potassium harmony for enhanced economic and environmental gains. ***Agricultural Water Management.*****302** (1): *https*//doi.org/10.1016/j.agwat.2024.108949.

32. Yan, K. (2018). Effects of nitrogen application and planting density on yield formation and quality of rice in coastal saline alkali land (Yangzihou,Jiangsu. Master’s thesis of Yangzihou University).

33. Jiang, H. F., Lan, Y. C., Wang, H. Y., Xu, L. Q., Li, M. & Zhao, Y. (2020). Effects of nitrogen fertilizer application on nutrient accumulation, translocation and distribution on rice in saline -alkali soil. ***Fert. Sci. China*** **289**, 45-55. Doi 10.11838/sfsc.1673-6257.19440.

34. Kaiira, M. G., Owere, L., Chemayek, B., Etiang, J., & Elesu, M., (2023). Effects of weeding regime and row direction on growth and yield of upland rice in Uganda. ***International Journal of Plant and Soil Science,*** **35**(9):455-457

35. Kaiira, M. G., Kisho Miyamoto, Kasozi, N., Elesu M, & Bayega E. (2024). Performance of direct seeded upland rice based intercropping systems under paired rows in East - West orientation. ***Journal of Agricultural Science***, **16**(4):35-45.

36. Saito, K., Toure, A., Arouma, A., Flamone, R., Slue, D. & Manful, J. (2019). Multidisciplinary assessment of agricultural innovation and its impact. A case study of lowland rice variety WITA 9 in Cote d’voire. *Plant Production Science,* 22(4):428-442. https//doi.org/10.1080/1343943X.2019.1667834.

37. Saito, K., Sokei, Y. & Wopereis, M. C. S. (2012). Enhancing rice productivity in West Africa through genetic improvement. *Crop Science,* 52:484-494

38. Sekiya, N., Khatib, K. J., Makame, S. M., Tomitaka, M.,Oizumi, N. & Araki, H (2013). Performance of a number of NERICA cultivars in Zanzibar, Tanzania. Yield, yield components and grain quality. ***Plant Production Science*. 16**;141-153.

39. Saito, K., Asai, H., Zhao, D.,Laborte, A. G. & Greiner, C. (2018). Progress in varietal improvement for increasing upland rice productivity in the tropics. ***Plant Production Science*, 21**; 145-158.

40. Zubair, N., Kifayatullah, K., Toshio, F. & Biaojun, J. (2017). Growth and yield characteristics of upland rice cultivar NERICA 4 grown under paddy field condition. ***International Journal of*** ***Agronomy and Agricultural Research***. **10**(5):49-68.

41. Fujiie, H., Agency, C., Fujiie, M., Kurauchi, N. & Takagati, M. (2010). Potential of NERICA production in Uganda. ***Trop. Agric. Dev***. **54**:44-50.

42. Kunyumu, D. M. (2009). Comparative study on the growth and yield of NERICA cultivated with organic and inorganic fertilizers: Participatory On-farm research at Marakwet District in Kenya. ***Journal of Developments in Sustainable Agriculture***, **4**:106-117.

43. Ndikulyayo, C., Ochwo-Semakula, Gibson, P and Lamo, J (2020) Resistance to Rice yellow mottle virus and performance of selected improved rice genotypes in central Uganda. ***Crop protection,*** 129:2020, 105041, ISSN 0261-2194, https://doi.grg/10.1016/j.cropro.2019.105041.

44. Munganyinka E., Edema R., Lammo J., Gibson, P. & Rukundo, R. (2015). Combining ability for resistance to rice yellow mottle virus disease in interspecific and intraspecific rice Genotypes. ***African Journal of Crop Science***, ISSN: 2375-1231. 3(1):102-107.