


## Research Article

# Growth and Productivity Assessment of Short-Duration Rice (*Oryza sativa* L. and Upland NERICA) Genotypes in Semiarid North-Central Namibia

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In semiarid regions, drought is the major threat to crop production, but climate change and variability often bring floods to the regions, forming seasonal wetlands causing damage to local, drought-adapted staple grains and, hence, low yields and food deficit. Introduction of the semiaquatic crop rice (*Oryza* spp.) to these semiarid wetlands could complement the dryland crop low yields and overcome the food shortage problem. A field experiment was carried out at the University of Namibia-Ogongo Campus during the 2016/2017 and 2017/2018 cropping seasons to assess the growth and yield of rice genotypes. Twelve short-duration rice genotypes, nine from the International Rice Research Institute (IRRI) and three locally grown upland NERICA genotypes, were used. Parametric analysis of variance was performed to test their effects on crop growth and yield characters. The results showed significant genotype by year interaction for days to heading, plant height, the number of tillers per m<sup>2</sup>, shoot biomass, the number of panicles per m<sup>2</sup>, 1000-grain weight, harvest index, and grain yield. The IRRI genotypes produced a higher number of tillers, shoot biomass, and grain yield than the NERICA ones, which were early maturing, were taller, and had higher 1000-grain weight across the years. Generally, most of the genotypes had lower grain yield and higher shoot biomass in the first year, due to the prevailing cool, rainy, and seemingly cloudy weather conditions associated with lower temperature and lower solar radiation. Grain yield was positively correlated with most characters but negatively correlated with the 1000-grain weight. These results demonstrate the yield superiority of IRRI genotypes over their early-maturing NERICA counterparts. However, further studies on morphological characters and drought tolerance of the IRRI genotypes are warranted to ascertain production sustainability under semiarid environments.

## 1. Introduction

Food deficit is a serious problem in the Sub-Saharan region, especially in the semiarid areas of the subcontinent. Namibia, a semiarid Sub-Saharan country in southwestern Africa, faces a daunting challenge of food production to feed its growing population. The country's hydrological conditions are characterized by low and erratic rainfall, high

temperatures, and high evaporation rates [1]. The average annual rainfall ranges between 200 and 450 mm, and most of this rainfall is received in the country's northern region, comprising the most densely populated subsistence farming communities [2]. More than 60% of the total population lives in the northern region [3]. However, the majority of the inhabitants are resource-poor farmers, depending mainly on subsistence agriculture that is characterized by low-input,

low-output livestock and crop production systems [4]. Due to the relatively higher rainfall occurring in this region, compared with the rest of the country, nearly all local farmers are involved in crop production, cultivating dryland traditional crops, mainly pearl millet (*Pennisetum glaucum* L.), sorghum (*Sorghum bicolor* M.), maize (*Zea mays* L.), and cowpea (*Vigna unguiculata* L.) [2, 5]. Rice (*Oryza* spp.), on the other hand, is mainly imported as a milled product, and the import volumes have been increasing annually. These import trends are likely to continue for years as more food would be required to feed the growing population [6].

Although Namibia is such a dry country, like other nations in semiarid regions, it also experiences seasonal floods due to the effects of changes in global climatic systems and aberrations in local weather patterns [7–9]. Both spatial and temporal variations are a common characteristic of the local rainfall [5, 10]. For the temporal dimension, local rainfall is highly erratic, fluctuating intraseasonally resulting in intermittent dry spells or in-field flooding, and also changing interannually causing droughts or seasonal floods [5], depending on water abundance. Both droughts and floods cause local dryland crop failures, leading to low grain yields and hence persistent food deficit in the country [5, 6, 9, 11]. However, the Cuvelai system seasonal wetlands, having an aggregate area of 800,000 ha in southern Angola and the north-central zone of Namibia [12], can store a large amount of water for up to five months during the country's summer rainy season spanning November–April period [5, 6]. The stored water is the result of the inflows of seasonal floodwaters from Angolan highlands where rainfall is usually higher [2] as well as from occasionally high local summer rainfalls. However, in semiarid regions, including north-central Namibia, rainfall variability is associated with delayed rainy season onset, early rainy season cessation, reduced length of the growing season, and frequent or prolonged intraseasonal dry spells [13, 14], making the cropping season shorter than expected.

Food production in Namibia can be increased by exploiting underutilized natural resources and diversifying the local crop base. Rice is a grain crop cultivated in both lowland and upland agroecosystems [15]. The advent of upland NERICA rice [16] has created an opportunity to extend rice production into semiarid, Sub-Saharan agroecosystems [6, 17–19]. Recent studies in northern Namibia have demonstrated that rice can be cultivated in the local seasonal wetlands [9, 10, 20], without modifying the water environment in the system [21–23]. Currently, rice farming in the country was done by few producers; thus, the wetlands are traditionally used for seasonal livestock grazing and fishing [12, 24], despite the high demand for homegrown rice [6]. Moreover, since the wetlands are seasonal, most of the water is eventually lost through evaporation and by deep percolation. Increasing rice cultivation in the local wetland ecosystems has the potential to offer new rice-based food-stuffs and a new cropping land area, complementary to the existing arable land used for the production of traditional dryland crops, while simultaneously conserving the local water environment [23].

Despite sustained efforts to expedite rice production in the country [6, 10, 20, 25], scientific publications concerning varietal growth and yield performance under Namibian field conditions are currently limited. This information is crucial for the improvement of domestic rice production and also for strategic food security policy planning of the country. Rice cultivation in the local seasonal wetlands could complement the low yields of the local, traditional dryland crops of pearl millet and sorghum, especially in flooding years, thus helping increasing household food self-sufficiency and improving the socioeconomic status of the smallholder farming communities [6]. Since rice is used as both food and cash crop, intensifying small-scale production in the local wetlands of north-central Namibia would help curtail grain import, create employment (especially among youth who direly need farming land), and reduce poverty, consequently, contributing to the food security and economic growth of the country.

The objective of the present study was, therefore, to assess short-duration rice genotypes for growth and grain production under north-central Namibia's seasonal wetland conditions.

## 2. Materials and Methods

**2.1. Study Locations and Weather Conditions.** We evaluated growth and yield of short-duration rice genotypes in a field experiment conducted under seasonal wetland conditions during the 2016/17 and 2017/18 cropping seasons (December–April) at the University of Namibia-Ogongo Campus (17°41'S, 15°17'E, 1094 m altitude), north-central Namibia (Figure 1). This region is characterized by a semiarid climate with a mean temperature of >22°C [26] and annual mean rainfall ranging from 450 to 500 mm [5]. The campus lies in the Cuvelai Drainage Basin, originating in southern Angola. This basin is characterized by a natural, massive network of interconnected shallow pans locally called *iishana* and extensively interpolated deep water ponds called *oondombe*, which traverse huge areas of north-central Namibia before they converge to form an inland delta in the Etosha National Park (Figure 1). During the summer rainy season, water from the upper catchments of the basin in Angola, where rainfall is usually higher, and local rainwater transform the *iishana* and *oondombe* into seasonal wetlands in both Angola and Namibia, often causing flooding to the area and inundation of dryland crop fields [26]. Soil analysis in the experimental area was performed before executing the experiment in the first year. The topsoil (0–20 cm) in the experimental field was classified as sand, with a texture of 91.2% sand, 2.0% clay, and 5.6% silt, with 3.0 g total C kg<sup>-1</sup>, 0.36 g total N kg<sup>-1</sup>, 3.0 mg available P kg<sup>-1</sup>, 44.0 mg K kg<sup>-1</sup>, and a pH (H<sub>2</sub>O) of 7.6.

**2.2. Plant Materials.** The rice (*Oryza sativa* L.) germplasm consisting of nine short-duration genotypes was received in 2016 from the International Rice Research Institute (IRRI), the Philippines, for field evaluation in Namibia. The genotypes were IR 58, IR 60, PAGSANJAN (PSBRC10),

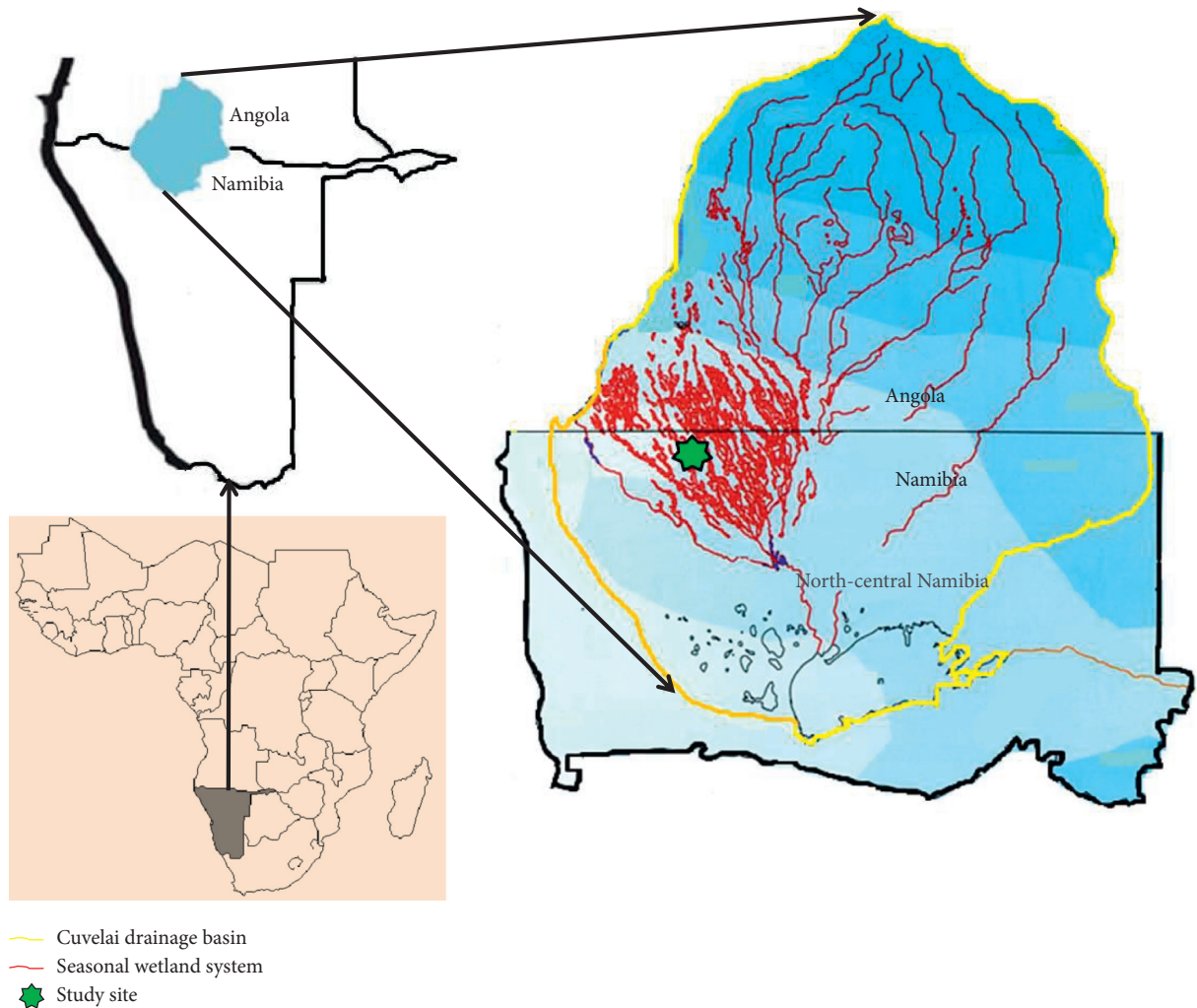


FIGURE 1: The Cuvelai Drainage Basin with seasonal wetlands formed in southern Angola and north-central Namibia where Ogongo Campus is situated. Adapted from [27, 28].

PSBRC 82, IRRI 148, NSIC RC 216, NSIS RC 298, NSIC2013 RC 346, and IRRI 175. We tested the IRRI genotypes alongside three upland NERICA genotypes—NERICA 1 (N1), NERICA 4 (N4), and NERICA 7 (N7)—acquired in 2011 from AfriRice, Benin, East Africa, which are promoted for cultivation under the local seasonal wetland conditions, north-central Namibia [9]. All the genotypes were selected for their short growth duration, a critical character for rainfed crop production under the short rainy season (December–April) in northern Namibia [5]. The rice seed stock is regenerated every three-to-four years to produce seeds for experimentation, and also for the farmers’ cultivation, in the case of NERICA genotypes.

**2.3. Treatments and Field Management.** The experimental design was a randomized complete block consisting of 12 rice genotypes replicated four times, totaling 48 plots. In each year of evaluation, the experimental area was dis-harrowed to 20–30 cm soil depth to loosen the soil and incorporate weed-plant materials into the soil, thus

producing a fine tilth for seedling establishment. A compacted Earth band (0.5 m high  $\times$  1.0 m wide) was constructed to serve as the perimeter of the experimental area and also to facilitate water retention in the plots during the experimental period. A day before transplanting, a preplanting basal fertilizer at the rate of 30–45–30 kg·ha<sup>-1</sup> of N, P, and K, respectively, was broadcast over the experimental area and mixed thoroughly with the topsoil by raking, and the area was then flooded and paddled to facilitate subsequent transplanting operation.

Four-week-old rice seedlings raised under nursery conditions were transplanted into the field plots on 16 January of 2017 and 2018. One seedling was transplanted per hill at the soil depth of 5.0 cm while maintaining a constant spacing of 0.3 m  $\times$  0.3 m. Individual plots of 3.6 m<sup>-2</sup> (3 m  $\times$  1.2 m) consisted of 4 rows, each having 10 plants, totaling a population of 40 plants. The total experimental area was 216 m<sup>2</sup> (15 m  $\times$  14.4 m). A 1 m wide alley separated the experimental blocks, thus facilitating movements during transplanting and subsequent experimental management and data collection operations. During plant growth, the

plots received supplementary surface irrigation as necessary to maintain a water depth of 5–10 cm, so water deficit never occurred in the plots during the crop growth cycle. Weeding was done manually, and the plots were kept free from weeds for the duration of the experiment. The same amount of NPK fertilizer as that applied at transplanting was given as topdressing just before heading began, to promote grain filling. Bird scaring activities commenced immediately upon the detection of the first heading to prevent any grain losses due to birds.

**2.4. Crop Measurements.** To assess the performance of different rice genotypes, we collected data on growth characters (days to 50% heading, plant height, total tillers, and shoot biomass) and yield characters (total panicles, 1000-grain weight, harvest index, and grain yield). Days to 50% heading were determined using 16 plants in the net plot area of 1.44 m<sup>2</sup> (2.4 m × 0.6 m), excluding the outermost border plants, as the total number of days from field transplanting to the day when 50% of the plants had their panicles emerged from the boots. At crop maturity, eight plants were randomly selected from each net plot for the collection of data on plant height, the total number of tillers per plant, and the number of panicles per plant. Plant height was measured from the base to the tip of the panicle of the tallest tiller. The number of tillers per plant was counted and used to estimate the total number of tillers per square meter. In each net plot, at crop maturity, all the panicles were harvested and counted, and the total number of panicles per m<sup>2</sup> was determined as the number of panicles harvested divided by the net plot area. The panicles were air-dried for 3–4 weeks and weighed; then, the panicle weight per m<sup>2</sup> was determined as the weight of panicles per net plot divided by the net plot area. Corresponding stover materials (stems + leaves) were also harvested by cutting the stover at the stem base. The stover materials were chopped into pieces of 5–10 cm, using a harvesting knife, to facilitate drying. The materials were then packaged in paper bags, oven-dried at 80°C for 7 days, and finally weighed. The shoot dry weight per m<sup>2</sup> was determined as the sum of panicle weight and stover dry weight per net plot divided by the net plot area. The dry panicles were manually threshed and winnowed to obtain clean grains. The grains were weighed, and their moisture contents were measured by Grain Moisture Tester (PM-830-2, Kett, Japan) to adjust the grain weights to 14% moisture content. Grain weight per m<sup>2</sup> was then calculated as the weight of the moisture-adjusted grains per net plot divided by the net plot area. The paddy yields per hectare of the rice genotypes were subsequently determined at this grain moisture level.

**2.5. Statistical Analysis.** The two-year experimental data, each generated from a randomized complete block design (see Section 2.3), was analyzed as a split-plot design. Year (whole plot factor) was treated as a random variable, and so the error term was the genotype × environment (year)

interaction mean square. The statistical model adopted in the analysis is given by

$$y_{ijk} = \mu + \alpha_i + \rho_j + (\alpha\rho)_{ij} + \beta_k + (\alpha\beta)_{ik} + \varepsilon_{ijk}, \quad (1)$$

where  $\mu$  represents the overall mean or fixed constant,  $\alpha_i$  are constants subject to the constraint  $\sum \alpha_i = 0$ ,  $\rho_j$  are the random whole plot effects nested within the levels of the fixed factor “genotype,”  $(\alpha\rho)_{ij}$  are random independent  $N(0, \sigma_{\alpha\rho}^2)$  interaction effects, and  $\beta_k$  are fixed constants subject to the constraint  $\sum \beta_k = 0$ .  $(\alpha\beta)_{ik}$  are constants subject to  $\sum_i (\alpha\beta)_{ik} = 0$ , and  $\sum_k (\alpha\beta)_{ik} = 0$ .  $\varepsilon_{ijk}$  are independent  $N(0, \sigma^2)$ .

Based on the linear statistical model displayed in equation (1), the parametric analysis of variance (Table 1) was produced to test the effects of fixed factor (rice genotypes) and random factor (experimental year, 2017 and 2018) on plant growth, yield, and yield components. Fisher’s protected least significance method was used to perform pairwise comparisons (Table 2).

### 3. Results

**3.1. Weather Conditions.** The weather statistics during the 2017 and 2018 experimental years are presented in Table 3. The overall mean temperature for the first year of the study was 23.8 ± 0.7°C, slightly lower than that for the second year (24.1 ± 0.9°C). The temperature was noticeably lower throughout the crop life cycle (January–April) in the first year of the study than in the second year. Mean solar radiation was 5% lower in the first year than in the second year of the experiment. Like temperature, solar radiation was consistently lower during the 2017 experimental period. Also, in each year, both temperature and solar radiation decreased progressively over time. Mean relative humidity was 55% across the experimental years. However, in the first year, relative humidity was highest in March (68.1 ± 1.8%), followed by February (60.0 ± 3.6%); whereas in the second year, the highest relative humidity prevailed during April (66.6 ± 2.3%), followed by March (66.3 ± 2.8%). Total rainfall, on the other hand, was 33% more in the first year than in the second year of the study. However, in both years, the rainfall was unevenly distributed during the crop cycle. In 2017, most rainfall, constituting 45%, occurred in March; whereas, in 2018, 57% of the rainfall was received in April. However, May did not receive any rainfall at all in both years. Like the rainfall, there were more rainy days in the first year than in the second year of the study, and both years had rainier days in March, although the rainy days were 18% more in March of 2017 than in March of 2018. Generally, the two experimental years showed notable differences in weather conditions, with lower temperatures occurring throughout the crop life cycle from January and April in the first year of the study compared with the second year, which, on the other hand, had more rainfall and rainfall days. However, rainfall was unevenly distributed in both years.

TABLE 1: Summary of analysis of variance for growth, yield components, and yield of rice as influenced by experimental year, genotype, and their interaction.

Treatment structure	DF	Days to heading (no.)	Plant height (cm)	Total tillers (no. m <sup>-2</sup> )	Shoot biomass (t·ha <sup>-1</sup> )	Total panicles (no. m <sup>-2</sup> )	1000-grain weight (g)	Grain yield (t·ha <sup>-1</sup> )	Harvest index
Replication	3	0.538	11.88	0.394	724.3	1224.6	2.172	0.004875	0.534
Year (Y)	1	15.844	1492**	58.1104**	17339.5	88354.5*	11.652#	0.231732**	10.112#
Error (Ey)	3	4.399	15.44	1.0977	3727.9	3653.7	1.322	0.004665	1.0173
Genotype (G)	11	372.2***	913.7***	4.1797***	46479.8***	32097.5***	102.215***	0.00574**	4.2795***
Y × G	11	4.753*	46.72#	1.8285***	3924.7***	6525.6***	7.124***	0.018762***	1.9099***
Error (EYG)	66	2.181	24.12	0.535	997.7	941.2	1.976	0.002115	0.3353

\*\*\*, \*\*, \*, and # refer significant difference at  $P < 0.001$ ,  $P < 0.01$ ,  $P < 0.05$ , and  $P < 0.1$ .

TABLE 2: Interactive effect of years and rice genotypes on growth characters.

Year × genotype	Days to 50% heading	Plant height (cm)	Total tillers (no. m <sup>-2</sup> )	Shoot biomass (t ha <sup>-1</sup> )
2017	IR58	61jk	61.3k	265.8cdef
	IR60	73c	66.4jk	296.4bc
	IRI176	63hij	86.6cde	203.1ghijk
	IRRI148	70defg	80.7efgh	159.3kl
	N1	59kl	79.1fghi	145.4lm
	N4	61jk	88.6bcd	101.8mn
	N7	61jk	93.3bc	88.7n
	NSIC 2013 RC346	68g	80.2efgh	209.8ghij
	NSIC RC216	78ab	77.9ghi	214.8ghi
	NSIS RC298	77b	73.2ij	220.3ghi
	PSBRC10	62ij	65.0k	188.7hijkl
PSBRC82	69fg	76.5ghi	177.0ijkl	
2018	IR58	58l	65.5k	362.7a
	IR60	72cd	75.8hi	339.7ab
	IRI176	65h	103.0a	221.4fghi
	IRRI148	71cde	93.1bc	159.8jkl
	N1	60kl	85.7def	91.0n
	N4	62ij	94.7b	84.9n
	N7	63hij	106.8a	82.7n
	NSIC 2013 RC346	70defg	79.5fghi	272.0cde
	NSIC RC216	80a	83.0defg	229.2efgh
	NSIS RC298	79ab	77.0ghi	239.2defg
	PSBRC10	64hi	76.2ghi	275.3cd
PSBRC82	70defg	82.7defg	235.9defgh	

Means followed by the same letters within the column are not significantly different by the LSD test at the 5% probability level.

TABLE 3: Weather conditions during the 2017 and 2018 experimental years.

Month	Tem. (°C)		SR (MJ·m <sup>-2</sup> )		RH (%)		Rainfall (mm)		Rain days	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Mean	<b>23.8 ± 0.7</b>	<b>24.1 ± 0.9</b>	<b>20.7 ± 0.6</b>	<b>21.7 ± 1.3</b>	<b>55.1 ± 4.6</b>	<b>55.3 ± 4.6</b>				
Jan.	25.7 ± 0.5	26.2 ± 0.3	23.1 ± 1.4	24.3 ± 0.7	46.6 ± 4.6	50.5 ± 2.5	44.6 ± 5.2	0.8 ± 0.1	8	3
Feb.	24.5 ± 0.5	26.0 ± 0.2	19.8 ± 1.3	25.2 ± 0.8	60.0 ± 3.6	48.4 ± 3.0	76.6 ± 1.5	16.4 ± 0.2	7	12
Mar.	23.9 ± 0.2	23.9 ± 0.3	20.2 ± 0.9	20.5 ± 1.0	68.1 ± 1.8	66.3 ± 2.8	118.2 ± 1.9	63.6 ± 1.0	22	14
Apr.	22.7 ± 0.3	22.9 ± 0.2	20.7 ± 0.7	18.3 ± 0.7	58.3 ± 1.7	66.6 ± 2.3	23.0 ± 0.3	106.9 ± 1.7	10	11
May	22.0 ± 0.4	21.3 ± 0.1	19.9 ± 0.5	20.2 ± 0.4	42.6 ± 1.6	44.8 ± 1.4	0.0 ± 0.0	0.0 ± 0.0	0	0
Total							<b>262.4 ± 20.7</b>	<b>187.7 ± 20.9</b>	<b>47.0 ± 3.6</b>	<b>40.0 ± 2.7</b>

Temp., air temperature; SR, solar radiation; RH, relative humidity.

3.2. Parametric Analysis of Variance. Results of the parametric analysis of variance for the growth characters, yield components, and yield of rice genotypes grown in the 2017 and 2018 years (environments) are shown in Table 1. The effect of environment or year was statistically significant on

plant height, total tillers, grain yield ( $P < 0.01$ ), total panicles ( $P < 0.05$ ), 1000-grain weight, and harvest index ( $P < 0.1$ ). However, the environment did not have a significant influence on the number of day to 50% heading and shoot biomass of the rice genotypes. The genotypic effect was

highly significant ( $P < 0.001$ ) on all the characters measured, but just significant ( $P < 0.01$ ) on grain yield. The effect of genotype  $\times$  year interaction was also highly significant ( $P < 0.001$ ) on all the characters, but the number of days to 50% heading and plant height were significant ( $P < 0.05$  and  $P < 0.1$ , respectively). The presence of significant genotype  $\times$  year interactions for all the characters studied suggested that the genotypes performed differently across the experimental years.

**3.3. Effect of Genotype by Year Interaction on Rice Growth Characters.** It was previously established that the effect of genotype  $\times$  year interaction was statistically significant on all the growth characters measured among the rice genotypes (see Table 1). The mean values of the growth characters—days to 50% heading, plant height, total tillers, and shoot biomass—as influenced by the interaction, are statistically compared in Table 2. For the days to 50% heading, the maximum days to heading in 2017 were recorded in NSIC RC216 (77 days) and NSIS RC298 (78), which were also the latest in 2018 though they took slightly more days. However, the least days to heading in 2017 were noted in N1 (59), N4, N7, IR58 (61), PSBRC10 (62), and IRI176 (63), which likewise had the least days in 2018, although those of IR58 decreased significantly to 58 days, and those of others just increased slightly. Other genotypes such as NSIC2013 RC346, IRR148, and PSBRC82 consistently maintained intermediate days to heading of 70 days across the study years. In the case of plant height, the tallest genotypes in 2017 were N4, N7, and IRI176, measuring 87–93 cm, but N7 and IRI176 were significantly the tallest in 2018, measuring 107 cm and 103 cm, respectively, while N4 plant height did not increase significantly though it was comparable to that of IRR148. On the other hand, the shortest genotypes in 2017 were IR58 (61.3 cm), IR60 (66.4 cm), and PSBRC10 (65.0 cm), although the latter two had significant height increase in 2018. NSIC2013 RC346 was the only genotype that showed a decline in plant height in 2018.

The total number of tillers per  $m^2$  in 2017 was the highest in IR60 (296 tillers) and IR58 (265), followed by NSIS RC298 (220) and NSIC RC216 (214). The same genotypes still produced the most tillers in 2018, but the tillers were significantly more in IR60 (363) and IR58 (340). On the other hand, the lowest number of tillers per  $m^2$  was observed in N1, N4, and N7 in both 2017 and 2018 experimental years. However, those of N4 declined significantly in 2018. With a total of 159 tillers per  $m^2$ , IRR148 was the only genotype in which the number of tillers remained numerically unchanged across the years. Regarding shoot biomass, the maximum production in 2017 was noted in PSBRC82, NSIC 2013 RC346, IR58, and IR60, producing 5.1–5.7  $t \cdot ha^{-1}$ . Although shoot biomass generally decreased significantly among the genotypes in 2018, these genotypes still produced higher shoot biomass, after NSIC RC216 that had the maximum biomass of 4.1  $t \cdot ha^{-1}$ . The NERICA genotypes produced the lowest shoot biomass across the years, and PSBRC10, PSBRC82, NSIC2013 RC346, and IRI148 likewise produced the lowest biomass in 2018. However, N4, N7, and

NSIC RC216 tended to have constant shoot biomass across the years. These results of the growth characters indicated that the rice genotypes reacted differently to the experimental years, with most of the IRRI genotypes producing more tillers and higher shoot biomass than the NERICA genotypes which were predominantly taller and had headed earlier.

**3.4. Effect of Genotype by Year Interaction on Rice Yield Characters.** The interactive effect of genotype  $\times$  year was found to be highly significant on all the yield characters studied among the rice genotypes (see Table 1). The mean values of the yield characters—total panicles, 1000-grain weight, harvest index, and grain yield—as affected by the interaction, are therefore statistically compared in Table 4. The highest number of panicles per  $m^2$  in 2017 was observed in IR60, producing 237 panicles, followed by IRI176 (187) and IR58 (166). In contrast, the number of panicles per  $m^2$  in NSIC RC216, NSIC 2013 RC346, PSBRC82, and PSBRC10 just ranged from 145 to 156. Panicles in 2018 were significantly more in most of the genotypes compared with those observed in 2017. However, IR58 and IR60 produced the maximum number of panicles per  $m^2$ , which were 344 and 304, respectively. Nevertheless, the majority of the genotypes had more than 200 panicles per  $m^2$ , except the NERICA genotypes and IRR148 that had the lowest number of panicles across the years. Panicle number decreased in N1, N4, and N7 in the second year of evaluation. Across the years, the 1000-grain weight was consistently the highest in IRI176, N7, and N1, weighing between 33.1 and 36.6 g, followed by N4, NSIC RC216, and PSBRC82, measuring 27.0–32.2 g. Moreover, IR60 had a minimum grain weight of 22.1 g across the years.

Like most of the characters, grain yield among the genotypes was generally higher in 2018 than in 2017. However, the yield in 2017 was the highest in IR60, yielding 4.7  $kg \cdot ha^{-1}$ , followed by PSBRC82 (3.9), NSIC RC216 (3.8), IR58, IRI176, and NSIS RC298 (3.5). The same genotypes produced more grain in 2018, but NSIC RC216 attained the maximum yield level of 5.5  $t \cdot ha^{-1}$ , which was statistically similar to that of IR58, IRR148, and PSBRC10 with 4.7  $kg \cdot ha^{-1}$ . They were followed by PSBRC82, NSIC 2013 RC346, IRI176, and IR60 with a yield range of 4.1–4.6  $kg \cdot ha^{-1}$ . On contrary, N1, N4, and N7, consistently producing the lowest yield across years, range between 2.2 and 3.2  $kg \cdot ha^{-1}$ , but N1 had a significant yield reduction in the second study year. Despite their low yields, N4 and N7 had consistent grain production across the years, alongside IR60, NSIS RC298, and PSBRC82. For the harvest index, rice genotypes had lower index values in 2017 than in 2018. These results of the yield characters demonstrated that the rice genotypes responded variably to the experimental years, but those from IRRI had more panicles and higher grain yield compared with their NERICA counterparts which predominantly had heavier grains.

**3.5. Correlations among Growth and Yield Characters.** Table 5 presents a partial correlation matrix for growth and yield characters of the 12 rice genotypes evaluated in this study. The results showed that grain yield was positively

TABLE 4: Interactive effect of years and rice genotype on yield components and yield.

Year × genotype	Total panicles (no. m <sup>-2</sup> )	1000-grain weight (g)	Grain yield (t·ha <sup>-1</sup> )	Harvest index		
2017	IR58	166.5def	26.6defgh	3.5def	0.38hi	
	IR60	237.5b	22.1j	4.7abc	0.44efgh	
	IRI176	186.5cde	33.6b	3.5def	0.40hi	
	IRRI148	93.2jk	26.0efgh	2.6ghi	0.38i	
	N1	107.1gijk	33.2b	3.2efg	0.48cdef	
	N4	87.8jk	28.2d	2.5ghi	0.50cdef	
	N7	79.3k	33.5b	2.6ghi	0.47defg	
	NSIC 2013 RC346	152.9efgh	25.5ghi	3.2efg	0.37i	
	NSIC RC216	156.5ef	27.9de	3.8cde	0.41ghi	
	NSIS RC298	128.8fghij	26.5defgh	3.5def	0.39hi	
	PSBRC10	144.9efghi	27.0defgh	3.1efgh	0.40hi	
	PSBRC82	151.5efgh	27.4defg	3.9cde	0.38hi	
	2018	IR58	344.9a	25.2hi	4.7abc	0.53abcd
		IR60	304.1a	23.9ij	4.1bcd	0.50cdef
IRI176		208.7bcd	32.2bc	4.4bc	0.55abc	
IRRI148		154.8efg	27.0defgh	4.7abc	0.59a	
N1		86.6jkj	32.1bc	2.3hi	0.50bcde	
N4		78.8k	32.2bc	2.7fghi	0.50cdef	
N7		76.6k	36.6a	2.2i	0.37i	
NSIC 2013 RC346		251.4b	25.7fghi	4.6bc	0.57ab	
NSIC RC216		212.0bcd	30.7c	5.5a	0.50cdef	
NSIS RC298		225.3bc	26.8defgh	3.5def	0.43fghi	
PSBRC10		251.4b	25.9fghi	4.7abc	0.59a	
PSBRC82		225.9bc	27.5def	4.6bc	0.57ab	

Means followed by the same letters within the column are not significantly different by the LSD test at the 5% probability level.

TABLE 5: Upper triangular Pearson's product-moment correlation matrix for growth characters, yield components, and yield.

Character	Days to 50% heading	Plant height	Total tillers	Shoot biomass	Total panicles	1000-grain weight	Harvest index	Grain yield
Days to heading	—	-0.127	0.309**	0.311**	0.242*	-0.368***	-0.095	0.370***
Plant height		—	-0.531***	-0.368***	-0.347***	0.633***	0.157	-0.161
Total tillers			—	0.304**	0.935***	-0.640***	0.111	0.663***
Shoot biomass				—	0.099	-0.298**	-0.726***	0.172
Total panicles					—	-0.514***	0.301**	0.719***
1000-grain weight						—	-0.026	-0.383***
Harvest index							—	0.465***
Grain yield								—

\*\*\* and \*\* refer significant difference at  $P < 0.001$  and  $P < 0.01$ .

correlated with days to 50% heading, total tillers per m<sup>2</sup>, total panicles m<sup>2</sup>, and harvest index but negatively correlated with the 1000-grain weight. However, grain yield had no significant correlation with plant height and shoot biomass. The 1000-grain weight was negatively correlated with all the characters studied, except plant height which showed a significant positive correlation. Nonetheless, plant height was negative correlated with most of the characters. Days to heading were also positively correlated with total tillers per m<sup>2</sup>, shoot biomass per hectare, and total panicles m<sup>2</sup>, in addition to its correlation with grain yield. These results showed that grain yield in this study was positively correlated with the days to heading, number of tillers, number of panicles, and harvest index, but negatively correlated with the 1000-grain weight.

## 4. Discussion

**4.1. Genotypic Performance.** The main objective of the present study was to assess the growth and yield performance of short-duration rice genotypes under north-central Namibia's seasonal wetland conditions. The results showed a significant effect of genotype by year interaction on the growth characters of the rice genotypes (Table 1). These results seem to reflect high genotypic diversity, which is expressed through variable genotypic responses to the prevailing weather environmental conditions. Most of the IRRI genotypes, such as PSBRC82, NSIC 2013 RC346, IR58, and IR60, produced a higher number of total tillers and shoot biomass than their NERICA counterparts, which were predominantly taller and attained 50% heading earlier across the years (Table 2). Upland NERICA



genotypes, including N1, N4, and N7, were developed for cultivation under upland conditions [16]. In this study, rice was grown under paddy field conditions; the plots received supplementary surface irrigation to maintain a water depth of 5–10 cm throughout the crop growth cycle. Such conditions might have favored the IRRI genotypes which are adapted to the lowland ecosystem.

Furthermore, the higher number of tillers in the IRRI genotypes than in the NERICA genotypes may be responsible for the higher shoot biomass production by the IRRI genotypes. Tillering is a genetically controlled trait, so the differences in biomass production between the two rice groups may be due to their differences in genetic potentials [17]. Based on the results of the study, there was a significant interaction between the genotypes and years for days to heading; however, the changes across the years were numerically small, signifying that this character was not influenced much by the weather conditions.

The results also indicated a significant effect of genotype by year interaction on yield characters (Table 1), indicating the presence of genotype by environment ( $G \times E$ ) interaction. Like the shoot biomass, rice grain yield was higher in the IRRI genotypes compared with the NERICA ones (Table 4). Most of the rice genotypes that produced the highest grain yields were virtually those that also had the highest shoot biomass. Such genotypes include IR60, PSBRC82, NSIC RC216, IR58, IRI176, and NSIS RC298. Grain yield is a function of genotype and environment [17]; thus both the genetic makeup of the individual rice genotypes and the prevailing growing environment had contributed to the realization of grain yield level. Additionally, the IRRI genotypes had more number of panicles per  $m^2$  than their NERICA counterparts, although the NERICA genotypes possessed a higher 1000-grain weight.

Furthermore, the results revealed that most genotypes had lower grain yield and higher shoot biomass in the first year than in the second year of the experiment (Tables 2 and 4). This may have been attributed to the differences in the rice-growing environments created by the different weather conditions. The first year of the experiment was characterized by higher rainfall and more rainfall days with concomitant lower temperature and weaker solar radiation during the crop growth cycle compared with the second year of evaluation which had lower rainfall, higher temperature, and higher solar radiation (Table 3). The prevailing poor weather conditions in the first year seem to have promoted shoot growth but inhibited the translocation of photosynthetic assimilates to reproductive organs, resulting in many unproductive tillers and unfilled grains, consequently, leading to higher shoot biomass production and low grain yields among the genotypes. It is also possible that the higher rainfall in the first year had weakened the effectiveness of the fertilizer applied through dilution, particularly during the panicle formation and grain setting stages, thus contributing to overall low grain yields. Also, correlation analysis indicated that grain yield was positively correlated with days to heading, tiller number per  $m^2$ , panicles per  $m^2$ , and harvest index, but negatively correlated with the 1000-grain weight (Table 5). These results suggest that selection for grain yield

among the rice genotypes evaluated in this study can be done indirectly using the characters that have positive correlations with grain yield.

Conventionally, grain production is the character of primary importance in crop improvement and agronomic studies. However, in semiarid regions, such as northern Namibia, other characters, for example, growth duration, plant height, and plant growth pattern, may also take equal precedence. The short growing season in these regions dictates for the production of early-maturing rice genotypes [13, 14], as their late-maturing counterparts would often fail to produce the grains under such a short cropping season. In this study, the NERICA genotypes were not only the earliest as far as the number of days to 50% heading is concerned but also the poorest yielding genotypes compared with their IRRI counterparts. Rice genotypic selection criteria should therefore not only focus on high grain yield but also be integrative to include physiological and morphological characters enhancing plant adaptation to the prevailing environment. Promising IRRI genotypes such as IR60, PSBRC82, NSIC RC216, IR58, IRI176, and NSIS RC298 would therefore need further investigations.

*4.2. Agronomical Implications.* In semiarid regions, crop production is generally limited by recurrent droughts, but the increasing frequencies of seasonal floods also cause crop failure and food shortage in these areas [7–9]. Rainfall variability is a common phenomenon in the semiarid regions [5]. The north-central Namibian region, like the entire country, is characterized by highly variable summer rainfall, associated with contrasting drought and flood episodes, occurring either in the same year or in alternate years. This temporal rainfall fluctuations cause the failure of the local dryland crops of pearl millet, sorghum, and maize [9, 11], consequently resulting in persistent grain deficit and food insecurity in the country [6]. As drought and flood seem to occur alternately, but unpredictably, the need for crop diversification in northern Namibia has become inevitable. However, such efforts require an integrated production approach involving the cultivation of the flooding-tolerant crop species rice with the local dryland crops to provide a buffer against complete crop failure due to flood or drought phenomenon, by utilizing rice to complement the low yields of the dryland crops in normal or flooding years [6, 9]. In addition to the provision of grain security, crop diversification through the introduction of rice cultivation in northern Namibia's seasonal wetlands would also offer a new land area for cropping. These wetlands are currently used for livestock grazing and fishing, but not for cropping, despite persistent grain shortage in the country [12, 27] and the high demand for locally grown rice [6]. However, since the wetlands are seasonal, water eventually evaporates or percolates into the soil without being used productively. These ecosystems can, therefore, be utilized effectively for rice cultivation to increase domestic grain production and improve food security.

The complementarity of rice to the local crop yields is twofold. Firstly, rice would be introduced to the wetland



ecosystem alongside the upland ecosystem where the local dryland crops are cultivated, so there is no competition for cultivation land. Secondly, rice being a flood-tolerant crop, it would thrive well in years with normal rainfall, just like the local dryland crops, but in years of flooding, the crop would also tolerate the flooding and produce grains, unlike the dryland crops which are always damaged by flooding thus producing low yields [9]. This integrated differential cultivation system of rice and dryland crops offers opportunities for increasing the cropping area, which, in turn, can improve overall grain production in Namibia. Additionally, growing these species in tandem may also increase access to the scarce production land by new young farmers, thereby contributing to employment creation, income generation, and poverty reduction, especially among the small-scale farming communities, thereby contributing to agricultural sector growth and national food security.

In the semiarid regions of southern Africa, between the borders of Angola, Namibia, Botswana, and Zambia, extensive seasonal wetlands are formed during the summer rainy season by floodwater originating from the Angolan highlands and occasionally high local rainfall [26]. Rice introduction efforts have been ongoing in the seasonal wetlands formed in semiarid, north-central Namibia [20, 21], because most of the pearl millet fields are interspersed by small wetlands where rainfed, lowland rice can be grown [6, 9]. Flash floods that have become common in this region often hamper the production of the staple crop pearl millet. In the future, climate change would probably cause more frequent and considerably severe floods in the semiarid regions. Under such conditions, the risk of complete crop failure of flood-susceptible cereals may significantly increase. Continued rice genotypic selection efforts, going beyond mere grain production and growth duration, are needed to select ecotypes suitable for cultivation in seasonal wetlands in the semiarid areas to stabilize grain production and complement the low yields of traditional drought-tolerant staple grains cultivated by local subsistence farmers.

## 5. Conclusion

The IRRI rice genotypes have proven to be more productive than the NERICA genotypes, which are so far recommended for cultivation under the local semiarid conditions of northern Namibia. IR60, PSBRC82, NSIC RC216, IR58, IRI176, and NSIS RC298 rice genotypes maintained higher biomass and grain yield production across the two experimental years, despite variation in production levels, compared with N1, N4, and N7, which by contrast were taller, were early maturing, and had bold grains. Furthermore, grain yield was positively correlated with days to heading, tiller number per m<sup>2</sup>, panicles per m<sup>2</sup>, and harvest index, which are associated with the IRRI genotypes but negatively correlated with the 1000-grain weight, which is related to the NERICA genotypes. The promising IRRI genotypes should be investigated further for physiological and morphological characters enhancing plant adaptation to the local seasonal wetlands and other wetlands in semiarid regions.

## Data Availability

The data used in the study are included in the manuscript.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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## Supplementary Materials

The supplementary data supporting the findings of this study are provided by means of an attachment file (supplementary data Table 1S). (*Supplementary Materials*)

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