IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 18, Issue 7 Ser. 1 (July. 2025), Pp 07-12
www.iosrjournals.org

Potential of Rice Varieties for Cultivation in the Central-Southern Coast of Angola

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Abstract:
Background*: Rice (Oryza sativa L.) is crucial for global food security, especially in Angola, where its production growth has experienced very little growth despite rising consumer demand. Enhancing rice productivity in the country requires development and adoption of rice varieties well-adapted to local environmental conditions. Therefore, this study evaluated three rice varietiesto the central-southern coast of Angola.*
Materials and Methods*: A randomised block design with three replicates was used to test three rice varieties — Chilahila, Limpopo, and Sertaneja — over 2017-2018 growing season. Crops were cultivated in plots measuring 11m x 6m with 20cm plant spacing. All plots received continuous irrigation and the same fertilisation treatment (200 kg ha^{-1} urea).*
Results*: the crop cycle was approximately 150 days with an overall grain yield of 2.81 t ha^{-1} on average, but without significant differences among the varieties, highlighting uniformity in phenotypic traits under the tested conditions. Positive correlations were observed between the number of panicles per plant and grain weight, suggesting that selection for these traits could enhance yield.*
Conclusion: *Despite no significant varietal differences in grain yield, there is the potential for improvement through optimization of practices, emphasising the need for further investigation into environmental influences on production.*
Key Word*: Agronomy; Rice; Yield; Sustainability.*

Date of Submission: 24-06-2025 Date of Acceptance: 04-07-2025

I. Introduction

Rice (*Oryza sativa* L.) is one of the most widely cultivated cereals globally, second only to maize [6], and serves as a staple food for more than half of the global population [1]. Rice is primarily cultivated in the tropical wet regions of Angola, especially in the central provinces of Bié and Huambo, which together contribute to half of the country's total rice production. Between 2013 and 2023, Angola's rice production experienced modest growth of 5.8%, with an annual yield increase of just 1.4% [4]. The data suggest a non-linear relationship between production and yield, marked by significant variability. In some cases, there appears to be a potential negative correlation where high production growth rates coincide with declining yield improvements.

Meanwhile, consumer demand is rising exponentially owing to shifts in dietary preferences driven by various sociocultural factors. As a result, Angola imports over 320,000 tons of rice annually to satisfy its domestic consumption needs [4]. This continuous increase in local rice consumption places additional pressure on the agricultural sector to develop strategies to enhance domestic rice production, highlighting the difficulties in achieving self-sufficiency in the country. In response to these challenges, rice has been designated a priority crop under the National Plan for the Promotion of Grain Production (PLANAGRÃO), an initiative launched by the Angolan government aimed at boosting the commercial production of grains and addressing irregularities in the international grain supply market [11]. Consequently, rice research in Angola has primarily focused on interventions aimed at improving production and yield. This entailed collecting data on the adaptability of rice in various agroecological zones.

Several studies have investigated the agronomy of rice cultivation in diverse climatic contexts [2,9], revealing significant differences in the adaptability of rice cultivars to their environment. For example, temperate *japonica* rice cultivars generally demonstrate greater cold tolerance [18], whereas indica cultivars are more suited to hot conditions [10]. These differences led to variations in seedling vigour, growth duration, and yield [22]. This highlights the importance of selecting cultivars appropriate for local conditions, especially given that climate change is expected to significantly affect rice yields in certain regions [20, 10]. With rising temperatures and climate variability, it is imperative that farmers have access to varieties that can withstand these challenges [10], thereby ensuring food security and economic stability. However, specific information regarding rice adaptation to Angola climatic conditions is lacking. Therefore, this study aimed to evaluate the adaptability of three rice varieties to the edaphoclimatic conditions in Sumbe and Angola.

II. Material And Methods

The experiment was conducted at the experimental station of the Higher Polytechnic Institute of Cuanza Sul, Sumbe, Angola. The soil in the area is classified as a clayey-textured Acrisol, derived from sedimentary formations of marl-clay and clay formations with gypsum, dating from the Oligo-Miocene. The chemical characteristics of the soil, including pH, organic matter content, macro- and micronutrients, are detailed in Table 1. Climatic data were collected from a meteorological station located approximately 3 km from the experiment site. The information regarding environmental conditions (average temperature, rainfall, relative humidity, solar radiation, among others) during the experiment period is available in Table 2.

Table 1. Soil chemical properties for the 2017-2018 growing season

Organic matter (%)	2.2
pH_{KCl}	6.89
Total N (%)	0.11
Extractable P_2O_5 (mg/kg)	976
Extratable K_2O (mg/g)	580
Exchangeable Mn (mg/kg)	551.8

Table 2. Mean daily air temperature and cumulative monthly rainfall from sowing to harvest during the 2017-2018 growing season.

	Temperature (ºC)	Rainfall (mm)
November	27.5	21.7
December	27.1	0.0
January	28.0	14.6
February	29.3	21.6
March	28.8	72.5
April	30.3	26.3
May	26.8	0.0
June	24.4	0.0

The experimental design adopted was randomised blocks with three replicates. Three rice varieties were tested, namely Cahilahila, Limpopo, and Sertaneja. Each plot consisted of a nursery bed measuring 11m x 6m, with plant spacing of 20 cm x 20 cm. All plots received the same fertilisation treatment, applied as follows: 200 kg ha^{-1} of urea, divided into three applications (one-third at the tillering stage, and two-thirds during flowering). Irrigation was maintained continuously to ensure adequate moisture throughout the entire cropping cycle. The following variables were evaluated: plant height (cm), number of tillers per plant, and panicle length (cm), days to emergence (from planting to emergence) and growth cycle (from planting to maturity), number of panicles per plant, number of grains per panicle, and grain weight (grams).

Morphological and phenological measurements were performed on randomly selected plants within each plot throughout the crop cycle. The data obtained were subjected to analysis of variance (ANOVA) to detect significant differences among varieties, using SAS software, version 9.6 (SAS INSTITUTE, 2014). When significant differences were detected, the Tukey test was applied at a 5% significance level for multiple comparisons. Additionally, a correlation matrix among variables was generated, allowing analysis of relationships between different growth and production factors.

III. Result and Discussion

The amount and distribution of rainfall varied during the growing season, with little difference in the average monthly temperature. March and April were particularly wet (72.5 and 26.3 mm, respectively) and hot (28.8 and 30.3 ºC, respectively) but preceded by very dry and hot December. The lowest daily minimum temperature recorded was 15.3 ºC in June and the highest daily maximum temperature 32.2 ºC in February (**Table 2**). The overall grain yield was 2.81 t ha^{-1} across all varieties, ranging from 2.63 t ha^{-1} for the Sertaneja variety to 2.99 t ha^{-1} for the Limpopo variety; however, no statistically significant difference was observed between varieties (**Table 3**). Significant differences were detected in the number of panicles per plant and panicle length (**Table 4**).

Table 3. Yield and yield components of three rice varieties cultivated in the central-southern coastal region of Angola in 2018-2019.

	GW (mm)	GL (mm)	%FG	W100G (g)	Yield (t ha^{-1})
Cahilahila	9,98a	8,37a	85,79a	3,30a	2,92a
Limpopo	10,25a	8,59a	94,03a	3,30a	2,99a
Sertaneja	8,74b	6,68a	94,02a	3,50a	2,63a
Grand mean	9.65	7.87	85.87	3.36	2.81
Standard deviation	0.33	0.39	10.34	0.48	0.39
CV%	3.45	4.98	12.06	14.17	13.88

Means followed by the same letter within the column are not statistically different at $p < 0.05$. GW- grain width; GL- grain length; %FG- percentage of filled grains; W100G- weight of 100 grains.

Table 4. Yield components of three rice varieties cultivated in the central-southern coastal region of Angola in 2018-2019.

	NP/P	NG/P	PL (cm)	BP	W10P (g)
Cahilahila	25,87a	141,33a	22,59ab	11,40a	12,49a
Limpopo	25,00a	148,20a	20,37b	11,33a	12,49a
Sertaneja	19,78b	156,17a	24,59a	12,02a	10,37a
Grand mean	23.55	148.57	22.51	11.58	11.75
Standard deviation	2.71	6.08	1.73	0.31	1.15
CV%	6.85	4.18	4.15	6.54	6.78

Means followed by the same letter within the column are not statistically different at $p < 0.05$. NP/P- number of panicles per plant; NG/P- number of grains per panicle; PL- Panicle length; BP- Branching per panicle; W10P- Weight of 10 panicles

Both varieties were harvested at the same time with a crop cycle of 150 days, despite transplantation, which is suggested to be a contributing factor to prolonged crop cycles [13]. A crop cycle of 150 days is characteristic of medium-maturing varieties. This is likely due to the relatively warmer temperatures in summer (February – April) during the critical stage of flowering and grain filling, which enhances crop development, seed ripening, and harvest. Nevertheless, warmer temperatures can shorten rice biomass accumulation time, reduce carbohydrate accumulation, and lower crop yields [7].

Previous studies have shown that rice is a hydrophilic plant with high water requirements for growth and development [14]. Although supplementary irrigation was carried out to meet crop demands, it appeared that the crop yield was hampered by relatively dry conditions throughout the crop cycle. This is consistent with previous studies that have shown that crop yields are greatly influenced by insufficient moisture, particularly during critical stages, such as flowering and grain filling [5], leading to substantial yield losses. The overall grain yield of 2.81 t ha^{-1} across all varieties found in the present study was lower than the global average of 4.63 t ha^{-1} and 4-5 t ha^{-1} of irrigated rice in developing countries [5, 4]. This average yield was also much lower than that obtained for the same varieties tested in the province of Bié by the Agricultural Research Institute of Angola (IIAA), which reported yields ranging between 5.30-7.80 t ha^{-1}.

The lower yield obtained in the present study was likely due to suboptimal environmental conditions because too little precipitation and insufficient irrigation supply lead to a lack of water necessary for growth, which reduces photosynthesis and growth [16], and eventually decreases yield [7, 8]. The impact of water control and seasonal factors, such as solar radiation, account for up to 35% and 20% of the difference between the actual and potential yields, respectively [12, 19]. In the current study, the total accumulated rainfall was 156.7 mm from sowing to harvest, which, together with the relatively high average temperature of 27.8 ºC appeared to be the major factor contributing to the observed yields. In the present study, the mean daily temperature ranged from 27.1-30.3 ºC which was higher than the optimum temperature of 24.2-26.6 °C during the grain-filling stage for *indica* hybrid rice [10].

Under the central-southern coastal condition of Angola where average temperature is relatively high and rainfall distribution is low, then sufficient supplementary irrigation is required. Nevertheless, crop yield was significantly higher in the present study that obtained by the Agricultural Research Institute of Angola (IIAA) elsewhere in the provinces of Huambo and Cuanza Sul using the same varieties Cahilahila, Limpopo, and Sertaneja, recording crop yields of 1.5 t ha^{-1}, 0.2 t ha^{-1}, and 0.4 t ha^{-1} in Huambo, and 1.5 t ha^{-1}, 1.4 t ha^{-1}, and 1.5 t ha^{-1} in Cuanza Sul, respectively. The higher crop yield in the present study was likely due to the supplementary irrigation. Thus, a combination of environmental and management factors plays a fundamental role in the adaptability and productivity of rice varieties across different agro-ecological zones [7, 8, 10, 18]. These findings highlight the importance of implementing effective management strategies and utilising irrigation systems to optimise rice production in various contexts, underscoring the need to investigate the factors contributing to yield differences among regions to enhance production in low-performing areas [17].

Grain widths of 9.98 mm and 8.74 mm in the present study were exceptionally higher than previously observed grain widths ranging from 1.2 mm to 3.8 mm among domesticated rice varieties [6]. Although it seems very rare not only for farmers but also for researchers to obtain these exceptionally high grain widths, there is scope for exploitation of varietal differences to increase rice yield and production through the development of new hybrid rice varieties. Indeed, there was a clear significant difference in grain width between varieties, ranging from 0.25 mm in the Limpopo variety to 9.98 mm in the Cahilahila variety. This could, in part, be explained by plant development factors such as early tillering and assimilates accumulation during the pre-anthesis phase, but is more likely due to genes regulating cell division or cell expansion in the early inflorescence development stages, which is strongly determined by the genotype [21, 6, 3]. However, this varietal difference in grain size did not result in significant differences in final grain yield, highlighting the importance of both abiotic and biotic factors in the phenotypic traits of plants [10, 17, 18].

No significant differences were observed in the number of panicles per plant, number of grains per panicle, panicle branching, and panicle weight, suggesting that these varieties might have similar phenotypic characteristics under the evaluated cultivation conditions. Similarly, no significant differences were observed with respect to plant height, tillering, flag leaf length, or the distance between the penultimate and last internodes. This indicates uniformity in the evaluated characteristics, which could be reliable predictors of crop yield and development [17].

Table 5. Morphological characteristics of three rice varieties cultivated in the central-southern coastal region of Angola in 2018-2019.

	AP (cm)	PF (n)	PU (n)	CFB (cm)	PIUF (cm)	DPE (cm)
Cahilahila	116,20a	27,53a	19,47a	32,84a	24,93b	38,44a
Limpopo	108,60a	25,40a	21,20a	28,26a	28,42a	40,31a
Sertaneja	118,40a	27,60a	24,30a	27,31a	26,70ab	38,55a
Grand mean	115,05	26,84	21,65	29,47	26,68	39,1
Standard deviation	2,42	0,50	0,36	0,46	0,18	0,69
CV (%)	10,60	9,24	8,38	7,76	3,35	8,84

Means followed by the same letter within the column are not statistically different at $p < 0.05$. AP- Plant height; PF- Tillering per plant; PU- Useful tillering; CFB- Flag leaf length; PIUF- Insertion point of the last and penultimate leaf; DPE- distance between the penultimate and last internode.

Significant positive correlations were observed between the number of panicles per plant and weight of panicles and grain weight (**Table 6**). These findings suggest that selecting varieties that maximize the number of panicles per plant may be an effective strategy for enhancing productivity. Additionally, strong but non-significant positive correlations were noted, accompanied by negative correlations, indicating complex interactions that warrant further investigation. Identifying variables that do not show significant correlations may guide future research to explore new agronomic parameters that could influence rice crop yield. Incorporating data from multiple years and considering environmental variables could provide a more comprehensive understanding of the interactions among agronomic characteristics, thereby contributing to the development of more effective cultivation strategies.

Table 6. Pearson correlation coefficients between morphological parameters of three rice varieties. cultivated in the central-southern coastal region of Angola in 2018-2019.

	AP	PF	PU	CFB	PIUF	DPE	NP/P	NG/P	PL	BP	W10P	GL	W100G	GW	%FG	Yield
AP	1															
PF	-0,13	1														
PU	-0,03	0,53	1													
CFB	-0,33	0,54	-0,29	1												
PIUF	-0,48	-0,08	0,44	-0,32	1											
DPE	-0,02	-0,44	-0,22	-0,31	-0,28	1										

NP/P	-0,56	-0,13	-0,67	0,45	-0,16	0,33	1									
NG/P	0,16	0,25	0,56	-0,52	0,25	0,07	-0,38	1								
PL	0,22	0,44	0,44	-0,05	-0,43	-0,05	0,42	0,33	1							
BP	0,07	0,16	0,35	-0,25	-0,18	0,55	-0,03	0,39	0,37	1						
W10P	-0,44	-0,29	-0,66	0,21	-0,16	0,44	0,94**	-0,29	-0,41	0,17	1					
GW	-0,33	-0,15	-0,52	0,22	-0,06	0,48	0,82*	-0,18	-0,63	0,02	0,78	1				
W100G	0,58	-0,43	-0,20	-0,33	-0,15	-0,08	-0,49	0,14	0,13	-0,39	-0,48	-0,48	1			
GL	-0,16	-0,09	-0,29	0,31	0,18	-0.15	0,38	-0,63	-0,76	-0,24	0,36	0,53	-0,50	1		
%FG	-0,29	0,11	-0,03	0,13	0,29	0,19	0,46	-0,04	-0,68	0,18	0,46	0,78	-0,69	0,72	1	
Yield	-0,03	0,19	0,11	-0,12	0,02	0,07	-0,49	0,14	0,13	-0.15	-0,12	0,31	0,54	-0,08	-0,44	1

AP- plant height; PF- tillering per plant; P - effective tillering; CFB- length of the flag leaf; PIUF- insertion point of the last and penultimate leaf; DPE- distance between the penultimate and last internode; NP/P- number of panicle per plant; NG/P- number of grains per panicle; PL- panicle length; BP- branching per panicle; W10P - weight of 10 panicles; W100G- weight of 100 grains; GW- grain width; GL- grain length; %FG- percentage of filled grains. ** significant at $p < 0.01$; * significant at $p < 0.05$.

IV. Conclusion

There is significant potential for rice cultivation in Sumbe, particularly with the implementation of an irrigation system to maintain optimal soil moisture during critical periods of phenological development. This potential is further supported by increasing demand from the national market. Although the varieties tested in this study showed little variability, the pursuit of more productive varieties and optimisation of agricultural practices are essential for enhancing rice production, especially in regions where yields remain below their maximum potential.

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