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Genotype x Environment Interaction and stability analysis of agronomic performance in aromatic rice accessions in Benin

Rosanoff Y. S. Kouke[1*], Cocou A. Djihinto[1], Fiacre Zavinon[2], Patrick G. Djehoungo[1], Daniel Chougourou[3]

[1] Institut National des Recherches Agricoles du Bénin, 01 BP 884 Recette principale, Cotonou Bénin.
[2] Department of Genetic and Biotechnologies, Faculty of Sciences and Techniques, University of Abomey-Calavi 01 BP 526 Cotonou, Benin
[3] Ecole Polytechnique d'Abomey-Calavi (EPAC), University of Abomey-Calavi 01 BP 526, Cotonou, Republic of Benin
*Corresponding author: krosanoff@gmail.com , Email: sp.inrab@yahoo.com Tél: (+229) 64 28 37 02

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ABSTRACT

Objectives: Aromatic rice accessions are playing a vital role in global rice trading. The present study aimed to assess agronomic performance and evaluate the genotype by environment interaction in aromatic rice accessions from Benin in order to select agronomically stable genotypes.

Methodology and Results: the plant material was composed of a collection of 28 aromatic rice accessions evaluated in two different locations based on 11 quantitative traits. Through descriptive statistics, the results revealed that the 28 individuals presented good agronomic performance across the two environments. Genotypic effect assessed based on ANOVA showed high significant difference between the varieties for almost all traits indicating the existence of wide phenotypic variability in the collection. The effect of Genotype x Environment interaction evaluated by using data from the two locations in an ANOVA showed significant effect on five traits out of the 11 studied. By considering the three factors (genotype, environment and Genotype x environment) it was identify that the characters PH, NFeT and CSM were the traits mostly influenced. Therefore, based on the variability observed in these traits, specific adaptability was performed through AMMI and enabled to identify the genotypes, which present some adaptability to the different locations. Based on genotypic superiority calculated for the three most variable traits as stability index, the genotypes ARA01, ARA16, ARA17 and ARA18 are the most stable aromatic rice accessions.

Conclusion and application of results: The results of this study indicated that the environment did not influence the grain yield performance while the GxEI contributed the least phenotypic variation in PH, NFeT and CSM. The different stable genotypes identified in present study could serve as parent in a breeding program of aromatic rice.

Keywords: Aromatic rice; Genotype x Environment interaction; agronomic performance; Stability index; Benin

INTRODUCTION

Rice (Oryza spp.) is one of the most important food crops cultivated in 117 countries. It is the staple food for more than half of the world's population, cultivated annually on 159 million ha with a production of over 428.7 million tons and the productivity of 4.1 tons/ha (FAOSTAT, 2019). It represents an important place in human nutrition, providing 20% of the calories and 15% of proteins consumed by world's population (Sajid *et al.,* 2015). In Benin, rice contributes to food security and poverty reduction. It ranks the third place among cereal crop in terms of production, after maize and sorghum, with a production of 459,313 tons in 2018 (Fatondji *et al.,* 2020). Like in many African countries, rice production in Benin has increased up to 179,000 tons in the year 2018/2019 while its consumption during the same period was reported to 799,000 tons. This gap observed between rice production and the needs of the population is huge and it is even bigger for aromatic rice. Indeed, aromatic rice varieties are playing a vital role in global rice trading (Golam *et al.,* 2011). They constitute a small but an important sub-group of landraces. These are rated as the best in quality and fetch much higher price than high quality non-aromatic rice in the international market. Major feature of these aromatic rice varieties is aroma, which is being appreciated by many people and represents a high value-added trait (Dela Cruz and Khush, 2000). Thus, aromatic rice has become an important commercial commodity. In Benin, the demand of aromatic rice increasing day by day due to the change in nutrition habit of the population (Fatondji *et al.,* 2020). However, the aromatic rice often has undesirable agronomic characters, such as low yield, susceptibility to pests and diseases (Golam *et al.,* 2011). According to Prasad *et al.,* (2020), Aromatic genotypes predominantly have long growth duration, photoperiod sensitivity, low yields and susceptibility to lodging. In addition to these undesirable characteristics, the majority of aromatic rice varieties in use in Beninese agriculture are exotic varieties. Hence, the productivity level of the aromatic rice varieties in Benin, development of stable varieties with wider adaptability and high yielding potential is essential. Therefore, it is necessary and indispensable that the agronomic performance of introduced aromatic rice be evaluated under the new growing conditions. Genotype × Environment interactions (GEI) plays a pivotal role in the positioning of genotypes from their native to non-native environment, which further hampers the plant breeding advancement (Pham and Kang, 1988). In the present study, a collection of 28 aromatic rice accessions from the rice gene bank of National institute of agricultural research of Benin was assessed to study the G x E interaction and stability in order to identify rice genotypes for their agronomic performance stability across two different locations.

MATERIEL AND METHOD

Description of experimental sites: Two trials were conducted in two Benin's department during the rainy season of 2021. The first site is experimental site of the Laboratory of Genetics, Biotechnology and Seed Science of the University of Abomey-Calavi (6°25'00.8" N; 2°20'24.5" E) Atlantic department. For the second trial, Dome experimental site of INRAB in Zogbodomey (2°17' N latitude and 2°6' E longitude at an altitude of 70 m) in the Zou Department was selected. Both sites are located in the same region of Benin considered as a tropical humid zone marked by high heat and high relative humidity varying between 69% and 97% (Agbossou 1994). In this area, the rainfall is bimodal with an annual average of 1200 mm. (Yabi and Afouda 2012). The average temperature varies between 25 and 29°C. The climate is subequatorial characterized by four (4) seasons including two (2) rainy seasons from March to June and from September to November. They are separated by two (2) dry seasons: from November to March and from July to August. Though the experimental sites are located in, the same regions there are some differences between them. It is a swampy valley of the Zou River and the soil was a clay-silty texture, while it is ferralitic on the site of Abomey-Calavi.

Plant material and experimental design: The plant material was composed of aromatic rice genotypes. A total of 28 genotypes among which the popular and reference aromatic varieties **IR841 and Orylux 6** were used as check varieties in the sample. The rest of the samples are accessions identified in the rice gene bank of the National Institute of Agricultural Research of Benin. The table 1 gives details of origin and level of aroma of each genotype. At both experimental sites, the plant material is planted in a randomized complete block design (RCBD) with three replications following the method described in Jain *et al.,* (2019). Each experimental plot consisted of five rows of 1 m long with 0.20 m row spacing. Recommended package of practices were adopted to raise a healthy crop and regular plant protection measures were undertaken.

Table 1: List of aromatic rice genotypes with their origin and aroma level

N°	Genotype	Origin	Aroma level	N°	Genotype	Origin	Aroma level
1	ARA01	Local accessions	Medium	15	ARA15	Local accessions	High
2	ARA02	Local accessions	Medium	16	ARA16	Local accessions	High
3	ARA03	Local accessions	High	17	ARA17	Local accessions	medium
4	ARA04	Local accessions	Medium	18	ARA18	Local accessions	medium
5	ARA05	Local accessions	Medium	19	ARA19	Local accessions	High
6	ARA06	Local accessions	Medium	20	ARA20	Local accessions	medium
7	ARA07	Local accessions	Medium	21	ARA21	Local accessions	medium
8	ARA08	Local accessions	Medium	22	ARA22	Local accessions	medium
9	ARA09	Local accessions	High	23	ARA23	Local accessions	High
10	ARA10	Local accessions	Medium	24	ARA24	**Released variety**	medium
11	ARA11	Local accessions	Medium	25	ARA25	Local accessions	medium
12	ARA12	Local accessions	High	26	ARA26	Local accessions	High
13	ARA13	**Released variety**	Medium	27	ARA27	Local accessions	medium
14	ARA14	Local accessions	Medium	28	ARA28	Local accessions	medium

Data collection: In total 13 quantitative traits were measured during the trials. Grain yield and morphological traits such as days to 80 per cent heading, plant height (cm), number of tillers per plant, number of productive tillers per plant, panicle length (cm), number of filled grains per panicle. Number of empty grains per panicle, total number of grains per panicle, cycle of 80% maturity, 1000-grain weight (g), grain yield per plant (g), kernel length (mm) and kernel breadth (mm). Description of all traits and the different codes used as abbreviation are presented in table 2. The observations were recorded on five randomly selected plants in each entry and the mean of randomly chosen plants per plot is used for statistical analysis.

Table 2: Abbreviation and description of all measured characters

Traits	**Code**	**Description**
Plant height	PH	Unit (cm) (measured at maturity)
Number of tillers	NT	Count numerical value
Number of fertile tillers	NFeT	Count numerical value
Cycle of 80% heading	CSE	Number of days from sowing to 80% heading
Cycle of 80% maturity	CSM	Number of days from sowing to 80% maturity
Panicle length	PaL	Unit (cm)
Number of filled grain	NFiG	Count numerical value
Number of empty grains	NEG	Count numerical value
Total number of grains	TNG	Count numerical value
Kernel length	KL	Unit mm
kernel width	KW	Unit mm
1000 grains weight	1000GW	Weight (g)
grain yield	GY	Unit g/plant

Statistical data analysis: Data were analyzed using descriptive statistics such as mean, coefficient of variation, minimum and maximum to assess overall variability within each trait. An analysis of variance (ANOVA) was performed on the data from each experimental site to test the genotype effect by site. A second ANOVA was performed with the combined data. For this analysis, the means of each genotype at each site were used following the method described by Sharma (2006) to highlight the effect of Genotype x Environment Interaction. Genetic parameters such as genotypic variance, environmental variance and variance of Genotype x Environment interaction were used to estimate the broad heritability of the different traits. The Genotype x Environment Interaction has also been studied by the analysis of additive effects and multiplicative interaction (AMMI) which is a robust multi-variate method for multi-environment trials (Mohammadi *et al.,* 2016). The analysis of additive effects and multiplicative interaction (AMMI) method integrates analysis of variance (ANOVA) and principal component analysis (PCA) that enables to study cultivar adaptability (Malick *et al.,* 2018). To analyse the stability of the genotypes, the stability index, genotypic superiority (P) was calculated. This index (P) is an estimate of genotype adaptability over a range of environments. It is calculated using the high performing genotype in each environment as a reference point. The most interesting genotypes would be those with the lowest P values (Lin and Binns 1988). All the analyses as well as the various stability parameters calculated are carried out with the R software version 4.0.1

RESULTS

Data description across the two environments: Descriptive statistics and genotypic effect for all traits are summarized in table 1. For genotype effect at Abomey-Calavi site, it is highly significant for all traits excepted the panicle length (lpan) and 1000 seed weight (P1000g). For these two latter traits, the agronomic performances of the 28 genotypes were not different. However, a large variability exists in the collection for the other characters indicating high difference between the 28 genotypes. Contrary to the Abomey-Calavi environment, genotype effect was not significant for the majority of the studied traits at Zogbodomey site except the traits lanoy and lanoy. Though there is not difference between the aromatic rice genotypes for almost all traits at Zogbodomey, high values were observed for dispersion statistics (minimum and maximum) indicating a large variation exists within the genotypes for the different traits recorded. A preliminary comparison of mean performance between both environments revealed that the agronomic performance of the genotypes at Zogbodomey is greater than those recorded at Abomey-Calavi site. The mean value of grain yield at Calavi was 0.38 while at Zogbodomey site, grain yield averaged of 1.19 and varied from 0.72 to 2.12.

Table 3 Descriptive statistics and ANOVA test for each experimental site

	Abomey-Calavi				Zogbodomey			
Traits	**Min**	**Max**	**Mean**	**F_test**	**Min**	**Max**	**Mean**	**F_test**
PH	62	131	95	***	81.75	143.75	111.96	NS
NT	3.33	27.67	12.06	***	5.60	39.60	17.53	NS
NFeT	2.67	25	10.63	***	5.5	27.5	13.22	NS
CSE	46	96	79.24	***	56	110	79.98	NS
CSM	73	118	99.89	***	87	109	96.08	NS
PaL	21.4	121.27	27.77	NS	22	31.33	26.55	NS
NFiG	80.67	293	157	***	95.8	351.4	171.7	NS
NEV	5.33	124.67	38.93	***	6	99	39.71	NS
TNG	105.3	381.7	195.9	***	113	450.4	200.3	NS
KL	6.01	7.95	6.95	***	5.59	8	6.90	***
KW	1.74	2.88	2.33	***	1.78	2.83	2.35	***
1000GW	13.19	35.04	25.70	NS	17.17	32.50	23.96	NS
GY	0.04	0.75	0.38	***	0.72	2.12	1.19	NS

***Min: Minimum; Max: Maximum; F_test: Fisher exact test; NS: not significant**

Genotype x Environment Interaction and heritability estimation: Data from both environments were pooled together in an analysis of variance for detecting Genotype x Environment Interaction and heritability estimation. The results of this analysis are presented in Table 4. Based on the data from each environment, genotype effect is significant for all trait except grain yield, which is in contrary influenced by environment effects. Apart the character grain yield, environment effect was also significant for the traits PH, NT, NFeT,CSM and NFiG. Among the 13 quantitative traits measured, effect of the interaction Genotype x Environment was significant on five characters that are PH, NFeT, CSE, CSM and NFiG. Based on the significance level of GxEI effect on the characters, cycle of 80% maturity was very highly significant at $p < 0.001$followed by PH and NFeT which were very significant at $p < 0.01$. For CSE and NEG, the GEI effect was significant ($p < 0.05$). Traits PH, NFeT and CSM were simultaneously influenced by the components of the three factors (genotype, environment and Genotype x Environment Interaction).. These traits were the most variable between the 28 genotypes across both environments. The decomposition of the phenotypic variance in genotypic and environmental variance enables to estimate heritability. The results showed that among the 13 characters, some of them are highly heritable. The characters lanoy and lonoy presented a value that exceeds 90% for heritability; they were mostly heritable. In contrast, no genotypic variance was deduced in phenotypic variance for the characters grain yield. The value of heritability of this trait was zero. For the rest of characters, heritability value ranged from 0.09 to 0.67.

Table 4: Estimation of G x E interaction and heritability of agronomic traits

Traits	Env		Gen		Gen x Env		V_G	V_GxE	V_E	H
	Mean Sq	F_test	Mean Sq	F_test	Mean Sq	F_test				
PH	11724.5	***	391.4	**	352.3	**	6.5	59.71	173.18	0.09
NT	1228.94	***	139.38	***	62.25	NS	12.85	5.7	45.14	0.55
NFeT	268.81	***	74.15	***	30;73	**	7.23	5.42	14.45	0.58
CSE	16.72	NS	280.52	***	90.72	*	31.63	13.83	49.20	0.67
CSM	644.29	***	171.38	***	65.82	***	17.59	12.62	27.94	0.61
NFiG	8675.3	*	6213.5	***	2852.9	NS	560.09	314.18	1910.34	0.54
NEV	45.50	NS	1271.52	***	678.15	*	98.89	94.87	393.51	0.46
KL	0.11	NS	1.04	***	0.02	NS	0.16	0.00	0.03	0.96
KW	0.01	NS	0.32	***	0.00	NS	0.05	0.00	0.00	0.97
1000GW	123.65	NS	85.17	*	48.32	NS	5.85	0.00	50.06	0.41
GY	27.18	***	0.06	NS	0.07	NS	0	0	0.07	0

AMMI analysis for specific adaptability: The results from AMMI analysis were employed to study the genotype adaptability. For this analysis the most influenced traits such as PH, NFeT and CSM according to the three factors were considered.. For each trait, a biplot was constructed against the principal component that stores the total variation (Fig. 1). The projection of the 28 genotypes as well the two environments in the biplots showed some specific adaptabilities. Therefore, for the traits PH, the genotype ARA3, ARA8 and ARA22 were more adapted to Abomey-Calavi while ARA5, ARA23 and ARA28 were adapted to Zogbodomey. Based on NFeT, ARA6, ARA15 and ARA24 were adapted to the Zogbodomey environment while ARA3 and ARA5 were adapted to Abomey-Calavi. A wide adaptability was observed among the genotypes for the characters CSM. However, ARA6 presented a specific adaptation to the Zogbodomey environment.

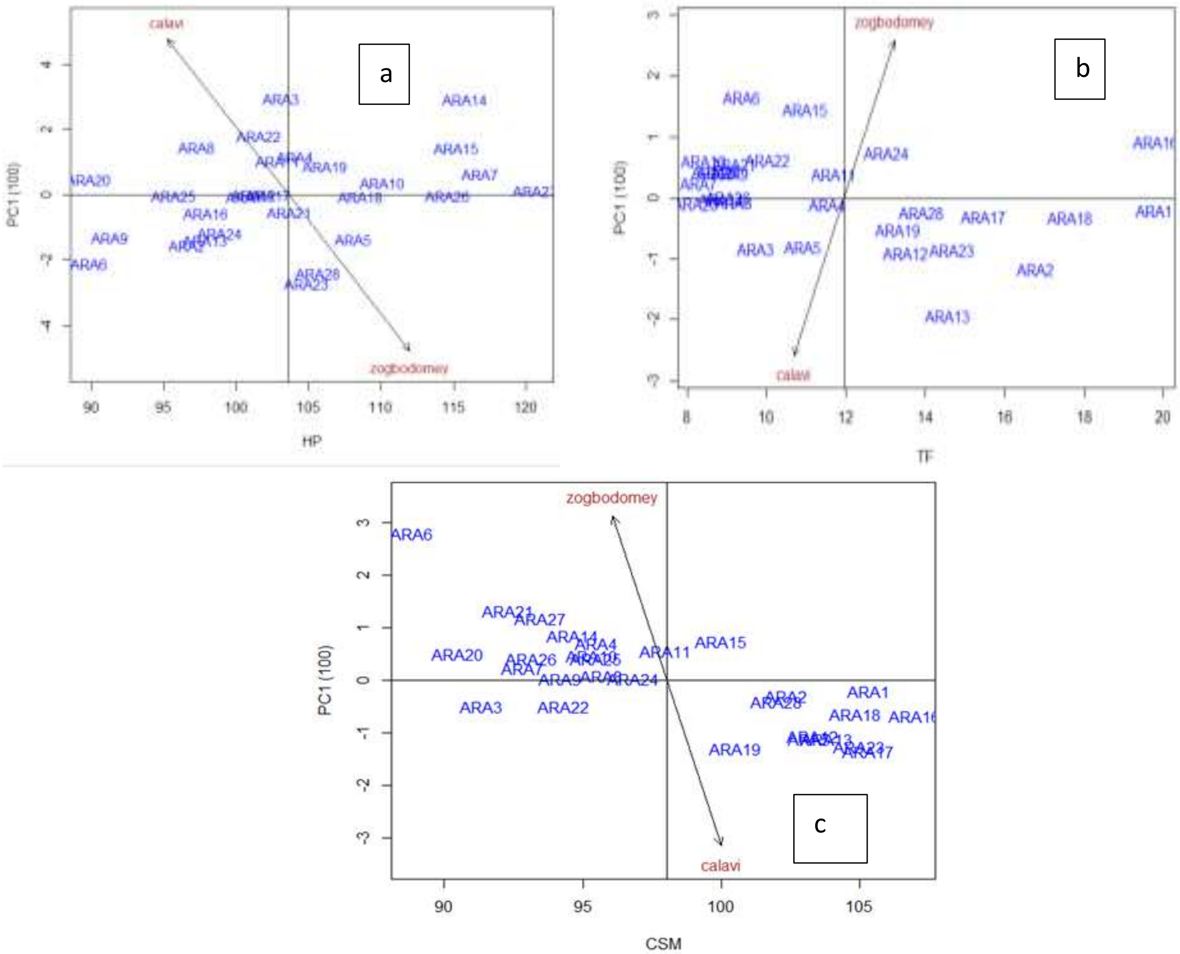

Fig.1: Biplot showing cultivars adaptability for (a) plant height (b) Number of fertile tillers and (c) days to 80% maturity

Mean performance and stability parameter analysis: Genotypic superiority was used as index in stability analyses. Three characters were considered in this analysis. Mean values and genotypic superiority of each aromatic rice for the three traits are presented in table 5. For the character plant height, the mean value varied from 89.81 to 120.62. The superiority index varied from 112.61 to 1054.65. Based on these values, the five most stable genotype for plant height are ARA07, ARA14, ARA15, ARA26 and ARA27. About number of fertile tillers, it varied from 8.23 to 19.82 and superiority index calculated for this trait ranged from 15.03 to 133.88. The five most stable genotypes for TF are ARA01, ARA02, ARA16, ARA17 and ARA18. For days of 80% maturity, the mean value varied from 88.83 to 107 and the value of the stability index recorded by each genotype ranged from 22.83 to 325.75. The top five genotype with low value of genotypic superiority for days of 80% maturity are ARA01, ARA16, ARA17, ARA18 and ARA23. From results, stability index analysis, it was observed that four genotypes were simultaneously stable for the characters number of fertile tillers and days of 80% maturity. These genotypes are ARA01, ARA16, ARA17 and ARA18.

Table 5: Mean performance and stability parameters for yield and quality traits.

Genotype	Plant Height		TF		CSM	
	mean	superiority	mean	superiority	mean	superiority
ARA01	100,57	543,85	19,76	12,37	105,33	22,83
ARA02	96,58	712,75	16,77	43,67	102,33	45,83
ARA03	103,09	632,23	9,73	102,82	91,33	198
ARA04	104,07	478,83	11,52	88,06	95,5	149,58
ARA05	108,05	345,13	10,91	93,31	103,16	48,75
ARA06	89,81	1054,65	9,37	122,11	88,83	325,75
ARA07	116,8	192,23	8,29	124,46	92,83	169,25
ARA08	97,25	681,5	9,18	107,17	95,66	146,83
ARA09	91,25	920,08	9,08	110,54	94,16	153,25
ARA10	110,12	319,67	8,43	133,88	95,33	148,16
ARA11	102,87	465,93	11,7	82,82	98	121,66
ARA12	101,23	548,56	13,52	64,62	103,33	51
ARA13	97,88	730,94	14,57	58,37	103,83	33,91
ARA14	115,79	289,45	8,87	110,28	94,66	158,5
ARA15	115,18	207,94	10,98	100,86	100	76,16
ARA16	97,9	610,36	19,82	15,03	107	19,5
ARA17	102,23	475,64	15,47	45,66	105,33	29,5
ARA18	108,62	305,95	17,66	23,12	104,83	23,58
ARA19	106,13	452,97	13,32	60,47	100,5	64,25
ARA20	89,83	940,14	8,23	120,32	90,5	221,75
ARA21	103,69	455,59	9,2	113,65	92,33	218,33
ARA22	101,557	606,56	10,04	98,57	94,33	146
ARA23	104,88	534,55	14,69	55,59	105	31,16
ARA24	98,87	616,48	13,04	66,86	96,83	111,08
ARA25	95,69	738,48	8,69	122,42	95,5	128,58
ARA26	114,59	230,16	9,05	111,6	93,16	167,25
ARA27	120,62	112,61	8,83	116,05	93,5	172,58
ARA28	105,65	487,47	13,91	56,76	102	46,66

DISCUSSION

In Benin, the majority of aromatic rice varieties produced was exotic varieties. This aspect represents one of the different factors, which limits the production of aromatic rice in Benin. Here, 28 aromatic rice gene banks of INRAB have been collected for assessing their agronomic performance and evaluate the Genotype x Environment Interaction. As there is not local aromatic rice landrace, the introduced varieties must be evaluated in different conditions to select high yielding and stable varieties. For that, the methodology widely use is the evaluation of Genotype x Environment Interaction (GEI). It has previously used in others crop such as maize (Nzuve *et al.,* 2013), sorghum (Oliveira *et al.,* 2020) or pigeon pea (Zavinon *et al.,* 2019) to select stable genotype. In rice, Vanisree *et al.,*

(2014) by employing GEI studied grain yield, its components and quality traits in 21 short duration varieties and hybrids under three representative locations. The same method was recently used to study stability of 21 elite basmati rice genotypes based important traits and production system in India (Jain *et al.,* 2019). In our investigation even though the number of environments tested is not sufficient, it enabled to understand the Genotype x Environment Interaction of the collection. Moreover, the significative difference observed among the 28 genotypes for almost all characters represents a great asset for this study. Indeed, the genotype effect tested by employing one-way anova test using data from each experimental site revealed highly significant difference between the 28 aromatic rice. This finding indicates that wide phenotypic diversity exists in collection and supports previous diversity study in aromatic rice (Jain *et al.,* 2019; Golam *et al.,* 2011). The high diversity observed in the study could be explained by the fact that the plant material was a collection of genotypes from different origin. In addition, it has been observed high differences in arithmetic means for all traits what could enable to select the promising varieties. Concerning GEI effect, the characters mostly affected are plant height and CSM. This result supports previous finding of GEI analysis in rice. Indeed, Jain *et al.,* (2019) reported significant G × E interaction effect on days of 75% maturity in their study of understanding G × E interaction of elite basmati rice genotypes under north Indian conditions using stability models. Similarly, Swapna *et al.,* (2014) reported that the mean sum of square due to G × E interaction was highly significant for plant height. Significance of G x E interaction component on these traits indicates differential behaviour of genotypes in changing environments (Panwar *et al.,* 2008; Sreedhar *et.al.* 2011). Among the characters in which no significance effect of G x E interaction was detected, there is grain yield. This result was surprising because grain yield is a complex trait. However, we can justify this result with the preliminary selection performed in choice of the plant material. This selection was carried out based the criteria of grain yield and its component. This selection was probably reduced genetic diversity among the collection for grain yield and null value of heritability observed for grain yield is in accordance with our hypothesis. Although, the studied traits were influenced by the environment factors, it was nevertheless observed some specific adaptability among the genotypes. Based on adaptability, stable genotypes were identified by using genotypic superiority as stability index. This index was widely used (Abderrahmane *et al.,* 2019) to identify stable genotypes in G x E interaction analysis. According to Georgieva *et al.,* (2018), the possible complications that may arise from G x E interactions can be limited by identifying genotypes with stable performance under diverse growing conditions. In our study based on the three most variable traits that are plant height, productive tillers and days of 80% maturity, stable genotypes among aromatic rice accessions were identified.

CONCLUSION AND APPLICATION OF RESULTS

The results of this study indicated that the environment did not influence the grain yield performance while the GxEI contributed the least phenotypic variation in plant height, number of fertile tillers and days of 80% maturity. Further testing of this aromatic rice in more environment could enhance breeding efficiency with reference to cultivar stability and adaptation. Genotype ARA05 was the ideal genotype followed by ARA20. Further tests of this aromatic rice could be done to enable their release given the need for increased aromatic rice production and productivity in Benin.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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