

New drought-tolerant rainfed upland rice (*Oryza sp.*) genotypes adapted to the west, centre-west, and centre regions of Côte d'Ivoire

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Abstract. To select new rainfed upland rice genotypes, adapted to the West, Centre-West, and Centre regions of Côte d'Ivoire, a study was conducted in research stations. Six genotypes (ART15-11-8-5-2-B-1, WAB891-SG12, WAB1092-B-40AB.1, ARCC3Fa3L10P1-1-B-1, and ART15-16-12 -3-1-B-1-B-3-1) including the control IDSA 10, widely cultivated across the country, were evaluated on three research stations of the National Center of Agricultural Research (CNRA), during the wet seasons of the year 2016 and 2017. These stations are located at the West, Center, and West-Center of Côte d'Ivoire. The trial was set up in a randomised complete block design with four replications. The agromorphological traits such as tillering ability, sowing-50% heading cycle, plant height, percentage of productive tillers, sowing-maturity cycle, and paddy yield were collected for each genotype. In all the environments evaluated, the genotypes ART15-11-8-5-2-B-1, WAB891-SG12, ARCC3Fa3L10P1-1-B-1, and ART15-16-12-3-1-B-1-B-3-1 were characterised by high percentages of productive tillers (87 to 91%), intermediate plant heights (114 to 121 cm), and high average paddy yields (2,601 to 2,810 kg/ha). Yield gains of these genotypes compared to the control ranged from 16 to 25%. The Genotype × Environment interaction (G × E) was highly significant for paddy yield ($p < 0.001$). The study of the interaction based on the first two principal components analysis of the GGE biplot, explained a 97% of the main effect of the Genotype and the G × E interaction. The polygon tool of the biplot suggested the existence of a single complex mega-environment. Visualizing the mean and stability of genotypes' paddy yield in the biplot indicated that genotypes ART15-11-8-5-2-B-1, WAB891-SG12, ARCC3Fa3L10P1-1-B-1, and ART15-16-12-3-1-B-1-B-3-1 were more adapted to upland rice-growing regions of the West, Center-West, and Center of Côte d'Ivoire. These genotypes can be released for large scale rice production in these regions.

Keywords: Rainfed upland rice, G × E interaction, GGE biplot analysis.

INTRODUCTION

In Côte d'Ivoire, rice (*Oryza sp.*) is the staple food of the population. It is the first cereal consumed by the population with 70 kg of milled rice per person, per year (MINADER, 2019). Unfortunately, milled rice production of 1,304,468 tons fails to meet the consumption quantity estimated at 1,830,385 tons. To fill the gap between

supply and demand, the government imports €450 million of rice annually (Ciyow, 2019). Improving the productivity and competitiveness of rice in all rice-growing ecologies must be one of the priorities for achieving self-sufficiency in rice.

Four (4) major rice-growing ecologies exist in the

Table 1. Geographical and pedoclimatic characteristics of study areas.

Research station	Longitude (W)	Latitude (N)	Altitude (masl)	Soil texture	Wet season	Annual rainfall (mm)*	
						2016	2017
Man	7°36'14"	7°20'59"	337	Sandy-silty-clay	Avril-November	1788.8	1636.5
Gagnoa	5°53'60"	6°08'11"	210	Silty-sandy-clay	March-June and September-October	1439.1	1305.6
Bouaké	5°7'00"	7°45'00"	300	Sandy-clay	March-June and August-October	1001.2	1059.1

Sources: Bahan *et al.* (2016) and Bahan *et al.* (2019). *Rainfall data was provided by weather stations of CNRA.

country. These include: irrigated, rainfed lowland, rainfed upland, and flood plains (ADERIZ, 2019). The rainfed upland rice cultivation is predominant with about 50% of the area covered (ADERIZ, 2019). It is characterised by small fields (0.5 to 1 ha) and is intensive in family labour (Depieu *et al.*, 2010). It uses very few agricultural inputs, is not mechanised and, is practiced in association with other crops (maize, cassava, etc.) (Bahan *et al.*, 2012). The yield of this type of rice farming is about 1 t/ha. The recent survey indicated that the rainfed upland rice contributed about 23% to national rice production (ADERIZ, 2019). Furthermore, the decline in soil fertility, drought, and the use of poorly performing varieties are the main factors responsible for the low production of the rainfed upland rice (Manneh *et al.*, 2007; Bouet and Tahouo, 2015).

Among the abiotic stresses, drought constitutes the most important constraint in the production of rainfed rice (Bernier *et al.*, 2008). Consequently, drought stress can reduce tillering, plant height, delay flowering, and increase spikelet sterility (Manneh *et al.*, 2007). It can significantly reduce the paddy yield and lead to total crop failure. Previous reports indicated that between 1998 to 2002, several varieties of rainfed upland rice have been released to improve rice production in Côte d'Ivoire (CTIC, 2015). However, most of these varieties are not adaptable to the climatic conditions of Côte d'Ivoire, especially long periods of drought during the cropping cycle.

To reduce the impact of climate change on rice production, new drought-tolerant rainfed upland rice genotypes, have been developed by AfricaRice, in collaboration with the National Agronomic Research Systems (NARS) as part of the « Stress Tolerant Rice for poor farmers of Africa and Southeast-Asia (STRASA) » project (AfricaRice, 2009; AfricaRice, 2011). The adaptation tests of these lines have been carried out and varieties have been released for production in different countries (Maji AT *et al.*, 2015; Sié *et al.*, 2017). However, no adaptation study of these genotypes has been carried out in Côte d'Ivoire, particularly in the country's largest rainfed upland rice production areas.

This study aims to identify rainfed upland rice genotypes

adapted to the West, Centre, and Centre-West regions of Côte d'Ivoire based on a multi-local trial in research stations.

MATERIALS AND METHODS

Study areas

The study was carried out in a two-year (2016 and 2017) period, under rainfed upland conditions at the stations of the National Center of Agricultural Research (CNRA) of Man, Gagnoa, and Bouaké (Côte d'Ivoire). These three stations are located in the West, Centre-West, and Centre regions of Côte d'Ivoire. In total, six environments (STATION × YEAR) that are Bouaké × 2016 (BKE-1), Bouaké × 2017 (BKE-2), Man × 2016 (Man-1), Man × 2017 (Man-2), Gagnoa × 2016 (GAG-1), and Gagnoa × 2017 (GAG-2) were used for this study. These environments had different soil textures, rainy season regimes, and annual rainfall patterns (Table 1).

Plant materials

Five new rainfed upland rice genotypes namely: ART15-11-8-5-2-B-1 (L1), WAB891-SG12 (L2), WAB1092-B-40AB.1 (L3), ARCC3Fa3L10P1-1-B-1 (L4), and ART15-16-12 -3-1-B-1-B-3-1 (L5) were used as experimental materials. These genotypes were created by AfricaRice within the framework of the STRASA project. The rice genotypes were obtained from a cross between genotypes belonging to the *Oryza sativa* L. and *Oryza glaberrima* Steud species. The IDSA 10 variety was used as a control. It is one of the improved varieties of rainfed upland rice that has been widely cultivated in Côte d'Ivoire.

Experimental design and trial management

In each environment, after clearing and collecting biomass from the plot, soil ploughing was carried out

twice to make the land suitable for plant growth, uniform seed establishment and to lessen weed population. The basic fertilizer NPK 15-15-15 was applied at the rate of 200 kg/ha during the second ploughing. The genotypes were sown in the wet season on 408 m², in a randomised complete block design with four replications. Each elementary plot with an area of 12 m² was represented by 21 lines of 3 m. Sowing was carried out manually in aligned hills at a spacing of 20 cm × 20 cm with the seeds rate recommended by the research (40 kg/ha). A pre-emergence herbicide, CALLISTAR (oxadiazon 250 g/l) was applied to the plots at a rate of 3 l/ha just after sowing. Urea (46% N) was applied twice at a rate of 100 kg/ha. The first half was applied at 21 days after seeding (DAS) and the second half at 42 DAS. Manual weeding was carried out before each application of urea. The paddy was harvested manually at technological maturity, i.e. when the grain's moisture ranged from 20 to 22%.

Data collection

The tillering ability (TILLER) was determined on 16 plants per replication by counting the number of tillers, at the booting stage of each genotype (IRRI, 2014). The sowing-50% heading cycle (Heading_50%) was determined by counting the number of days from the date of sowing to the date when 50% of the plants had half of the spikelets out from the leaf sheath. The height of the plants (cm) was determined on 16 plants by measuring the distance between the ground level and the top of the panicle of the longest tiller (IRRI, 2014). The sowing-maturity cycle (MATURITY) was determined by counting the number of days from the date of sowing until the date when 85% of grains on the panicles ripened (IRRI, 2014). The percentage of productive tillers (% PANH) was determined from the ratio between the number of panicles and the number of tillers produced on 16 plants. The paddy weight of each useful plot, adjusted to 14% humidity, was estimated according to the formula previously described by Yoshida *et al.* (1976) after removing two borderlines on each side of the experimental unit, harvesting, drying, ginning, winnowing, and weighing of the grains. The paddy yield (GRYNLD) in kg/ha was estimated from the ratio between the paddy weight of the useful plot and the harvested area.

Data analysis

Analysis of variance

The different traits measured were subjected to a two-way analysis of variance (ANOVA) to test the main effects of genotype (G), environment (E), and G × E interaction. The following mixed linear model was used for this analysis:

$$Y_{ijkl} = \mu + E_i + R(E_i)_j + G_k + (G \times E)_{ki} + e_{ijkl}$$

Y_{ijkl} = measurement of the variable in the i th environment, in replication j of the i th environment, on genotype k of elementary plot l ;

M = general average of elementary plots in all environments ;

E_i = effect of the environment j

$R(E_i)_j$ = effect of replication j with in environment i ;

G_k = effect of the genotype k ;

$(G \times E)_{ki}$ = interaction between genotype k and environment i ;

e_{ijkl} = residual of the plot

The homogeneity of variances and the normality of residuals were checked for each variable before performing the ANOVA. When the main effect of the genotype was significant, a comparison of means according to the Newman and Keuls test at the risk of 5% was carried out to compare the agronomic profiles of the different genotypes. The checking of homogeneity of variances, the normality of residuals, variance analyses and multiple comparisons of means were performed with GenStat version 10.1 (VSN International, 2007).

Analysis of G × E interaction and stability paddy yield

When G × E interaction for paddy yield was significant, the GGE biplot (Yan and Tinker, 2006) was used to study the adaptation of genotypes to different environments. Three biplots were made. The "which-won-where" biplot was used to search mega-environments; that is, the environments in which genotypes have been specifically adapted. The average-environment coordination (AEC) biplots were based on average yield and yield stability and both mean and stability were used to identify the best genotypes adapted to all environments. The graphs were made using the GGE Biplot software version 7.0 (Yan, 2012).

RESULTS

Agromorphological profiles of genotypes

The environment, genotype, and their interaction had highly significant effects on all measured traits (Table 2). Agromorphological differences were observed between the different genotypes and the control IDSA 10 (Table 3). The genotypes L2, L1, L4, and L5 were characterized by plant heights and paddy yields significantly greater than those of the control (Table 3). The paddy yield gains of these four lines relative to the control ranged from 16 to 25%. No significant difference was observed between these lines and the control for the percentage of productive tillers (% PANH) ; however, the number of

Table 2. Effects of the environment, genotype, and their interaction on the traits.

Factor	Fisher's values calculated for each collected trait					
	TILLER	PLTHGT	Heading_50%	%PANH	MATURITY	GRNYLD
Environment (E)	56.63***	127.93***	109.49***	5.67**	100.30***	201.47***
Genotype (G)	60.26***	22.95***	379.50***	11.90***	286.80***	16.03***
G x E	3.23***	4.98***	16.87***	2.00**	23.98***	7.33***

TILLER = tillering ability ; PLTHGT: plant height; Heading_50% = sowing-50% heading; %PANH = percentage of productive tillers; MATURITY = sowing-maturity cycle; GRNYLD = paddy yield; ** = highly significant effect (P < 0.01) ; *** = very highly significant effect (P < 0.001).

Table 3. Average agromorphological traits of genotypes in all environments.

Genotype	TILLER	PLTHGT (cm)	Heading_50% (days)	%PANH	MATURITY (days)	GRNYLD (kg/ha)
L2	7.07 ^b	115.30 ^b	74.29 ^d	87.45 ^a	101.80 ^c	2,810 ^a
L1	7.01 ^b	113.80 ^b	75.49 ^c	88.84 ^a	102.50 ^c	2,686 ^a
L4	6.40 ^c	120.90 ^a	70.46 ^e	90.79 ^a	100.70 ^d	2,648 ^a
L5	6.64 ^{bc}	120.60 ^a	77.25 ^b	89.81 ^a	103.70 ^b	2,601 ^a
IDSA10 (control)	7.14 ^b	110.40 ^c	73.58 ^d	87.38 ^a	100.70 ^d	2,245 ^b
L3	9.90 ^a	112.40 ^{bc}	90.63 ^a	73.61 ^b	117.50 ^a	1,690 ^c
h ²	0.95	0.78	0.86	0.83	0.92	0.54
Lsd (5%)	0.462	2.524	1.022	5.194	1.087	292.1

TILLER = tillering ability ; PLTHGT: plant height ; Heading_50% = sowing-50% heading ; %PANH = percentage of productive tillers ; MATURITY = sowing-maturity cycle ; GRNYLD = paddy yield ; h² = repetability ; Lsd (5%) = least significant differences at the risk of 5 % ; L1 = ART15-11-8-5-2-B-1; L2 = WAB891-SG12 ; L3 = ARCC3Fa3L10P1-1-B-1 ; L4 = ART15-16-12-3-1-B-1-B-3-1 and L5 = WAB1092-B-40AB.1

The numbers following by the same letter are not statistically different according to Newman and Keuls test

additional panicles of these genotypes compared to the control ranged from 1 to 4%. Moreover, they were less early than the control. Their sowing-maturity cycles ranged from 102 to 104 days, while that IDSA 10 cycle was 101 days. Line L3 was characterised by agronomic performances different from other genotypes. It had a significantly higher tillering ability (TILLER) (10 tillers per plant) than those of the other lines (Table 3). On the other hand, the percentage productivity of tillers and its grain yield were the lowest. Its sowing-maturity cycle was longer (118 days) compared to those of the other lines.

Adaptation of genotypes to different environments

Identification of mega-environments

The first two principal components, PC1 (84.8%) and PC2 (12.4%) represented 97% of the genotype and Genotype x Environment effects (Fig 1). A polygon was first drawn on genotypes that are furthest from the biplot origin so that all other genotypes are contained within the polygon. Then, perpendicular lines (equality line between adjacent genotypes) on each side of the polygon were drawn starting from the origin of the biplot. A genotype had high paddy yields in environments when these were located on its side of the equality line. Line L1 and the control IDSA 10 had higher paddy yields than genotype

L5 in all environments except in the environment GAG-2. The paddy yield of L2 was superior to that of the genotype L4 in environments MAN-1, MAN-2, and BKE-2. The line L4 was superior to the genotype L2 in the environments GAG-1 and BKE-1.

Each equality line divided the biplot into sectors with one or more environments. The best genotype for each sector was the one located on the respective vertex. The six environments fall into two sectors (mega-environments). Lines L1 and L2 perform best in environments MAN-1, MAN-2, BKE-1, BKE-2, and GAG-1. The genotype L3 showed enhanced performance in the environment GAG-2.

Identification of high-performance and stable genotypes for paddy yield

The red single-arrow line describes the average-environment coordination abscissa (AEA) (Figure 1). It points to higher average grain yield across environments and passes through the average environment (represented by a small red circle) and the biplot origin. Thus, L1, L2, L5 and L4 had the highest paddy yield. However, the line L2 was characterised by the highest grain yield. As for the line L3, it was characterised by the lowest yield (Figure 2).

The blue double-arrow line represent the average-

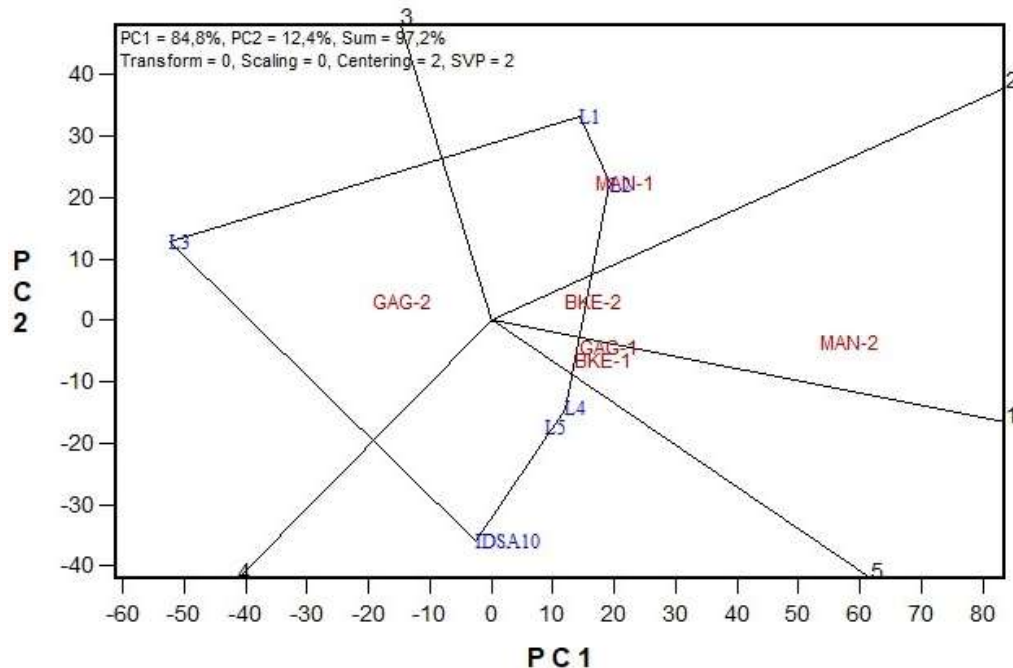


Figure 1. The which-won-where view of the GGE biplot showing two mega-environments. L1 = ART15-11-8-5-2-B-1 ; L2 = WAB891-SG12 ; L3 = ARCC3Fa3L10P1-1-B-1 ; L4 = ART15-16-12-3-1-B-1-B-3-1 and L5 = WAB1092-B-40AB.1 ; BKE-1= Bouaké × 2016 ; BKE-2 = Bouaké × 2017 ; Man-1 = Man × 2016 ; Man-2 = Man × 2017 ; GAG-1 = Gagnoa × 2016 ; GAG-2 = Gagnoa × 2017

environment coordination ordinate. It points to the greater variability (poorer stability) in either direction (Figure 2). Thus, lines L2, L1, L5, and L4 have been more stable than those of control IDSA 10 and L3. However, the genotype L2 was the most stable while the genotype L3 showed unstable performance.

Figure 3 defines an ideal genotype (center of the concentric circles) to be a point on the AEA (absolutely stable) in the positive direction and has a vector length equal to the longest vectors of the genotypes on the positive side of the AEA (highest mean performance). Therefore, genotypes located closer to the ideal genotype are more desirable than others. Thus, L1 and L2 were the most desirable.

DISCUSSION

The study of the adaptation of new drought-tolerant rainfed upland rice genotypes to the West, Centre, and Centre-West regions of Côte d'Ivoire was carried out on paddy yield and several agromorphological traits. The evaluation of these traits highlighted the strengths and weaknesses of the different genotypes. Thus, L2, L1, L4, and L5 distinguished themselves from the control IDSA 10 by their higher magnitude of increased plant heights (between 114 and 121 cm). Their intermediate heights, according to IRRI (2014) are important because, they

facilitate manual harvesting, which is an endogenous practice to the different study areas. Also, these genotypes have sowing-maturity cycles that ranged from 101 to 104 days. They are therefore very early and can be exploited for a double-cropping in areas with bimodal rainfall patterns, especially in Gagnoa and Bouaké. Besides, this early maturity of these lines could allow them to escape the drought. Indeed, the early maturity of these lines is similar to those of NERICA varieties which are considered adapted to climate change, as their early maturity allows them to avoid intermittent periods of drought at critical stages of development (CGIAR, 2007). Their high paddy yields (higher than that of the control DSA 10) are also an asset as these genotypes can improve the rice farmers' production. Line L3 had more defects than assets. Despite its high tillering capacity, it was characterised by a low percentage of productive tillers, a relatively longer cycle (118 days), and a low paddy yield (1.7 t/ha). The low yield of this genotype may be primarily due to its relatively long cycle compared to other lines. Indeed, the different phases of development of this genotype, especially the reproductive phase, were more exposed to the drought pockets observed in 2016 at Gagnoa and Bouaké and in 2017 at Bouaké. Similar observations were made by Kouakou *et al.* (2016) in Senegal on NERICA 1 and NERICA 4 with relatively longer sowing-maturity cycles (95 to 100 days) compared to NERICA 8 and NERICA 11 with shorter cycles (75 to

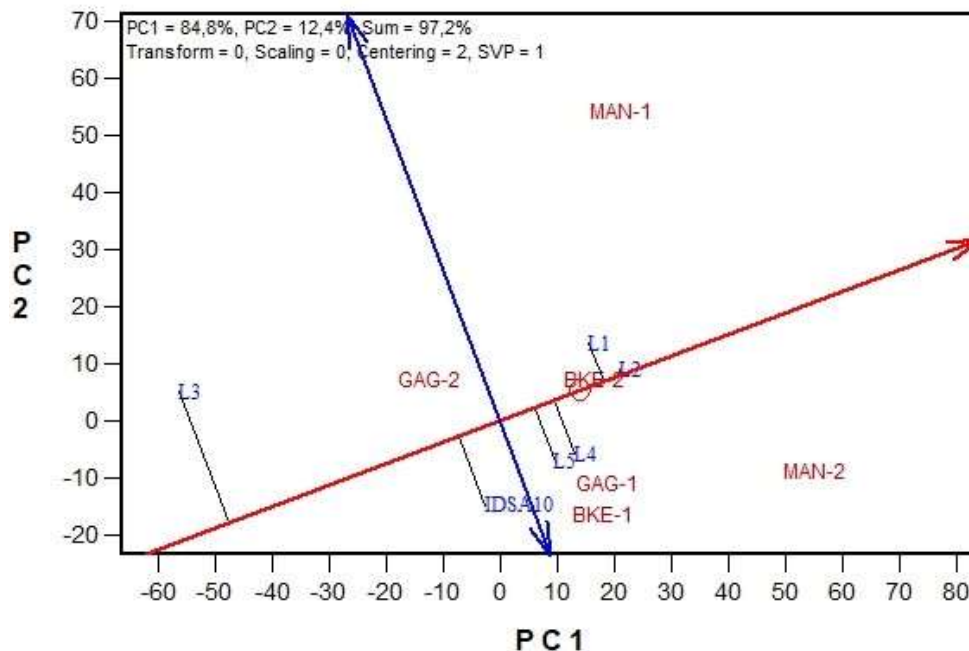


Figure 2. The average-environment coordination (AEC) view showing the mean performance and stability of the genotypes. L1 = ART15-11-8-5-2-B-1 ; L2 = WAB891-SG12 ; L3 = ARCC3Fa3L10P1-1-B-1 ; L4 = ART15-16-12-3-1-B-1-B-3-1 and L5 = WAB1092-B-40AB.1 ; BKE-1 = Bouaké x 2016 ; BKE-2 = Bouaké x 2017 ; Man-1 = Man x 2016 ; Man-2 = Man x 2017 ; GAG-1 = Gagnoa x 2016 ; GAG-2 = Gagnoa x 2017

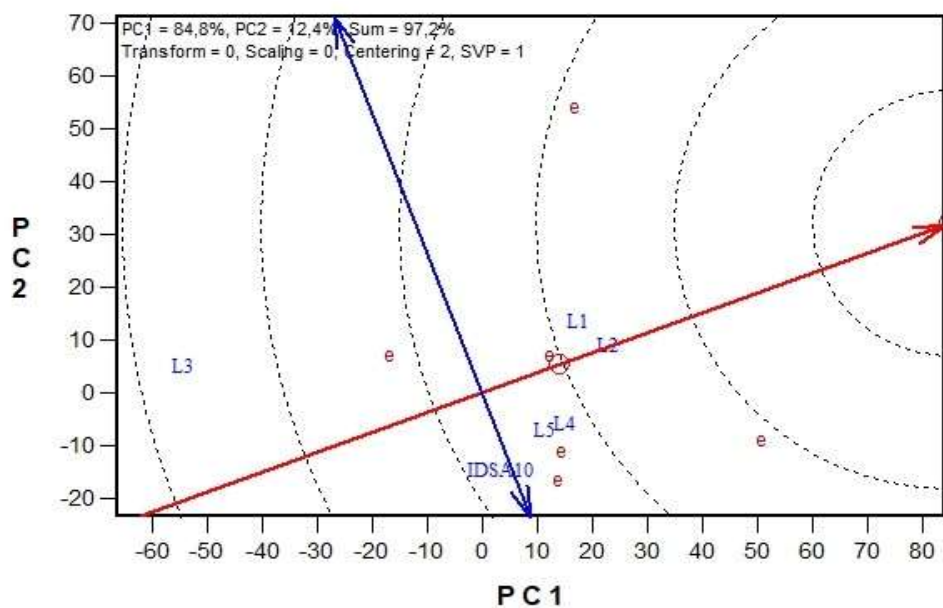


Figure 3. The average-environment coordination (AEC) view showing the genotypes rank relative to an ideal genotype (the center of the concentric circles). L1 = ART15-11-8-5-2-B-1 ; L2 = WAB891-SG12 ; L3 = ARCC3Fa3L10P1-1-B-1 ; L4 = ART15-16-12-3-1-B-1-B-3-1 and L5 = WAB1092-B-40AB.1

85 days).

The combined analyses of variance carried out highlighted the significant effect of the Genotype x Environment (G x E) interaction on all measured traits.

These results are similar to those obtained by Dessie *et al.* (2020). Furthermore, they confirm the need to conduct multi-environmental trials to have a good estimation of the performance of genotypes. Indeed, according to

Gauch and Zobel (1996), genotypes tested in different environments have variable performance due to their response to edaphic, climatic, and biotic factors. The nature and extent of this interaction are very useful for the breeder as it allows recommendations to be made according to the different growing environments of varieties. In other words, it makes it possible to identify genotypes adapted to different environments. However, the effects of genotype and $G \times E$ interaction should be considered simultaneously in the genotype selection decision. For this reason, Yan and Tinker (2006) proposed a graphical method for analyzing the effects of genotype (G) and $G \times E$ interaction of multi-environment trials data called GGE Biplot. It is one of the multivariate statistical models and a new technique for the graphical presentation of the $G \times E$ interaction (Yan *et al.*, 2000; Ding *et al.*, 2008). It has many advantages. It is an effective tool for mega-environmental analysis and genotypes and environments evaluation. It has been used on cereals, including maize, wheat, and rice, to select genotypes adapted to different regions (Butron *et al.*, 2004; Kaya *et al.*, 2006; Khanzaden *et al.*, 2017; Sewagene, 2017).

The three biplots produced to analyze the adaptation of the new genotypes to different environments captured 97.2% of the $G + G \times E$ effects on the two main components. According to Gauch and Zobel (1996), the expected variability, estimated from the table of the analysis of variance, should be 88.61%. As this expected variability is lower than that determined, the two main components of the different graphs, therefore, explained the maximum variability of the $G + G \times E$ effects. The "which won where" biplot suggested the presence of two mega-environments with genotypes specifically adapted to each of these areas. However, this model has not been repeatable in the different evaluation years, notably in Gagnoa in 2016 and 2017. Indeed, on this site, the best lines in 2016 were L2 and L1 while in 2017, the most performant genotype was L3. According to Yan and Tinker (2006), all environments must therefore be a single complex mega-environment. Similar observations were made by Lakew *et al.* (2014) during the analysis of agronomic performance and stability of 16 rainfed upland rice genotypes at several sites in North-East Ethiopia. Based on the single complex mega-environment represented by the different environments, the best genotypes were selected according to their average paddy yield and stability. To identify high-yielding genotypes, the different lines were therefore compared with an ideal genotype. According to Karimizadehi *et al.* (2013) and Ezatollah *et al.* (2013), a high-yielding genotype should have both the highest yield and be stable. Thus, the lines L2, L1, L4, and L5 have been identified as the closest to the ideal genotype. Furthermore, they were more productive and stable than the control, IDSA 10 which has been widely cultivated in Côte d'Ivoire. The good performance of L2, L1 resulted in their ARICA (Advanced Rice for Africa) nominations by

AfricaRice. Line L1 was nominated ARICA 14 and L2, ARICA 15. In addition, the four genotypes were also nominated CRAM 1 (L1), CRAM 2 (L2), CRAM 3 (L5) and CRAM 4 (L4) by the National Center for Agricultural Research (CNRA).

CONCLUSION

The evaluation of five new drought-tolerant rainfed upland rice genotypes was carried out at research stations in the west, centre-west and centre regions of Côte d'Ivoire. This evaluation made it possible to highlight the strengths and weaknesses of the different genotypes. It also made it possible to identify the lines adapted to different environments. The genotypes ART15-11-8-5-2-B-1 (L1), WAB891-SG12 (L2), ARCC3Fa3L10P1-1-B-1 (L5) and ART15-16-12-3-1-B-1-B-3-1 (L4) had various advantages. They were characterised by high percentages of productive tillers, intermediate plant heights, and high paddy yields. In all environments, these four genotypes performed better and were more stable than the control. These genotypes can be evaluated through national performance trials that will take into account, in addition to the agronomic traits, the palatability tests of the genotypes.

REFERENCES

- CTIC (2015).** Catalogue officiel des variétés de riz vulgarisées en Côte d'Ivoire. pp. 1-61.
- Dessie A., Zedwu Z., Berie A. and Atnaf M. (2020). GGE biplot analysis of Genotype x Environment interaction of cold tolerant green super rice genotypes in Ethiopia. *Int. J. Res. Rev.* 7(1):300-305.
- ADERIZ (2019).** Statistiques rizicoles en Côte d'Ivoire. Document de la Direction des statistiques et suivi-évaluation. Agence de Développement de la filière Riz (ADERIZ), Abidjan, Côte d'Ivoire.
- AfricaRice (2009).** Le riz tolérant au stress en Afrique: les acteurs font le point. Communiqués de presse, Cotonou, Bénin, 26 février 2009.
- AfricaRice (2011).** Mise en place des Groupes d'action à l'échelle du continent africain en vue d'accélérer la livraison de technologies rizicoles. Communiqués de presse, Cotonou, Bénin, 12 décembre 2011.
- AfricaRice (2020).** Innovation/variétés ARICA. <https://www.africarice-fr.org/arica>.
- Bahan F, Bouet A, Messoum F, Keli J, Zakra N, Adiko A (2019).** Efficacy of a biostimulant-a mycorrhizal inoculant on rice yield. *Int. J. Agric. Environ. Res.* 5(4):456-468.
- Bahan F, Kassin K, Koné B, Johnson J, Gbakatchéché H, Bouet A, Yao-Kouamé A, Camara M (2016).** Impact de la riziculture traditionnelle sur la fertilité du sol: incidence de l'association riz (*Oryza sativa* L.) - maïs (*Zea mays* L.) sur quelques propriétés physiques d'un ferrasol dans le Centre-Ouest de la Côte d'Ivoire. *Asian J. Sci. Technol.* 7(3):2588-2595.
- Bahan F, Yao-Kouamé A, Gbakatchéché H, Mahyao A, Bouet A, Camara M (2012).** Caractérisation des associations culturales à base de riz (*Oryza* sp.): Cas du Centre-Ouest forestier de la Côte d'Ivoire. *J. Appli. Biosci.* 56:4118-4132.
- Bernier J, Atlin G, Kumar A, Serraj R, Spaner D. (2008).** Review: breeding upland rice for drought resistance. *J. Sci. Food Agric.* 88:927-939.
- Bouet A, Tahouo O (2015).** La pyriculariose du riz en Côte d'Ivoire: Bilan de 10 années de recherche. <https://www.researchgate.net/publication/283854227>.

- Butron A, Velasco P, Ordas A, Malvar R (2004).** Yield evaluation of maize cultivars across environments with different levels of pink stem borer infestation. *Crop Sci.* 44:741-747.
- CGIAR (2007).** Global climate change: Can agriculture cope? Adapting Agricultural Systems to Climate Change. <https://hdl.handle.net/10947/5509>.
- Ciyow Y (2019).** Le long chemin de la Côte d'Ivoire vers l'autosuffisance en riz. *Journal le monde Afrique.* https://www.lemonde.fr/afrique/article/2019/12/16/le-long-chemin-de-la-cote-d-ivoire-vers-l-autosuffisance-en-riz_6023093_3212.html.
- Depieu ME, Doumbia S, Keli ZJ, Zouzou M (2010).** Typologie des exploitations en riziculture pluviale de la région de Saïoua, en zone forestière de la Côte d'Ivoire. *J. Appl. Biosci.* 35:2260-2278.
- Ding M, Tier B, Yan W, Wu HX, Powell MB, McRae TA (2008).** Application of GGE biplot analysis to evaluate genotype (G), environment (E), and G × E interaction on *pinus radiata*: A case study. *New Zealand J. For. Sci.* 38(1):132-142.
- Ezatollah F, Mahnaz R, Mohammad MJ, Hassan Z (2013).** GGE biplot analysis of genotype x environment interaction in chickpea genotypes. *Eur. J. Exp. Biol.* 3(1):417-423.
- Gauch H, Zobel R (1996).** AMMI analysis of yield trials. In *Genotype-by-environment interaction Kang Ms and Gauch H.G. (Eds.)*, New York, USA: CRC Press. pp. 85-122.
- IRRI (International Rice Research Institute) (2014).** Standard Evaluation System for Rice (SES), 5th edition. Los Banos (Philippines): International Rice Research.
- Karimizadehi R, Mohtasham M, Sabaghn A, Mahmood B, Roustami B, Seyyedi F, Akbari F (2013).** GGE Biplot Analysis of Yield Stability in Multi-environment Trials of Lentil Genotypes under Rainfed Condition. *Notulae Sci. Biol.* 5(2):256-262.
- Khazaden H, Asadi A, Mohammadi M, Ghogh H, Armiyun TH (2017).** Evaluation of adaptability in bread wheat genotypes under dryland conditions in tropical and subtropical locations. *J. Res. Ecol.* 5(2):948-957.
- Kouakou PM, Muller B, Fofana A, Guisse A (2016).** Performances agronomiques de quatre variétés de riz pluvial NERICA de plateau semées à différentes dates en zones Soudano-sahélienne au Sénégal. *J. Appl. Biosci.* 99:9382-9394.
- Lakew T, Tariku S, Bitew TA (2014).** Agronomic performances and stability analysis of upland rice genotypes in North West Ethiopia. *Int. J. Sci. Res. Publ.* 4(4):1-9.
- Maji AT, Bashir M, Odoba A, Gbanguba AU, Audu SD (2015).** Genotype x Environment interaction and stability estimate for grain yield of upland rice genotypes in Nigeria. *J. Rice Res.* 3(2):1-5.
- Manneh B, Kiepe P, Sié M, Ndjiondjop M, Dramé NK, Traoré K, Rodenburg J, Somado EA, Narteh L, Youm O, Diagne A, Futakuchi K (2007).** Exploiting Partnerships in Research and development to help African rice farmers cope with climate variability. *J. SAT Agric. Res. SAT Ej.* 4(1):1-24.
- MINADER (2019).** L'ADERIZ met en exergue les opportunités d'investissement dans la filière riz en Côte d'Ivoire. Conférence de presse au Salon International de l'Agriculture, Paris (France). http://www.agriculture.gouv.ci/uploads/Au_SIA_2019_1%E2%80%99ADERIZ_met_en_exergue_les_opportunit%C3%A9s_d%E2%80%99investissement_dans_la_fili%C3%A8re_riz.
- ONDR (2017).** Office National de Développement de la Riziculture: Statistiques, production de riz. http://www.ondr.ci/statistique_production.php.
- Sié M, Manneh B, Zhao D, Venuprasad R, Bimpong K, Zenna N, Semon M, Fofana M, Silué D, Manful J, Van Oort P, Dieng I (2017).** The Africa-wide Rice Breeding Task Force: a network for rapid deployment of superior rice varieties in Africa. International Workshop on Rice Breeding and Agribusiness in Rice Value Chain, December 4-8, St. Louis, Senegal.
- Tariku S (2017).** Evaluation of Upland Rice Genotypes and Mega Environment Investigation Based on GGE-Biplot Analysis. *J. Rice Res.* 5(3):1-7.
- VSN International (2007).** Genstat for windows 10th Edition. VSN International, Hemel Hempstead, UK. Web page: [Genstat.co.uk](http://www.genstat.co.uk).
- Yan W (2012).** Data analysis and management system. GGE Biplot, Version 7.0.
- Yan W, Tinker N (2006).** Biplot analysis of multi-environment trial data: Principles and applications. *Can. J. Plant. Sci.* 86:623-645.
- Yan W, Hunt L, Sheng Q, Szlavnic Z (2000).** Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Sci.* 40:597-605.
- Yoshida S, Forno DA, Cook JH, Gomez KA (1976).** Laboratory manual for physiological studies of rice. 3rd Edition, International Rice Research Institute, Los Banos, Philippines. p. 74.