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Research Article

Morphological and Agronomic Performance of Some Maize (*Zea mays* L.) Hybrids in the Agro-ecological Conditions of North-East Benin

[1]Tchegnikpede Felix Amata Houessin, [1]Florent Jean-Baptiste Quenum, [2]Arnaud Agbidinoukoun and [3]Abdoul-Madjibou Yakoubou

[1]Department of Crop Production, Faculty of Agricultural Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin
[2]Central Laboratory of Plant Biotechnology and Plant Breeding, Department of Genetics and Biotechnology,
Faculty of Sciences and Technology, University of Abomey-Calavi, 01 BP 526 Cotonou, Benin
[3]National Institute for Agricultural Research of Benin, Northeast Agricultural Research Center, Ina, Benin

Abstract

Background and Objective: Maize (*Zea mays* L.) plays an important role in food security in Benin. However, its production is constrained by several factors, which constitute a threat to the food security and annual income of smallholder farmers. The objective of this study was to evaluate the agro-morphological performance of maize varieties in Northeastern Benin. **Materials and Methods:** Sixteen maize varieties, including fifteen hybrids and one composite variety, were evaluated in three experimental sites, Komkoma, Ina and Angaradébou. Thirteen agro-morphological traits and seven quantitative and six qualitative variables were studied. **Results:** Significant differences were observed among the hybrids for the different agro-morphological traits. The ascending hierarchical classification (HAC) revealed that this variability is structured in three genotypical clusters. Clusters 1 and 3 included respectively hybrids with intermediate and late vegetative cycles, more productive with medium size plants. **Conclusion:** Two promising hybrids belonging to genotypic clusters 2 and 3 were identified. These are all late-cycle hybrids (M1026-4 and M1026-7). These results can be directly used for a programme of dissemination and diffusion of resilient maize varieties in Northeast Benin, particularly in agricultural development clusters 2 and 4.

Key words: Cereal crops, adaptation, food security, promising hybrids, disease severity, genotype×environment interaction

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Corresponding Author: Tchegnikpede Felix Amata Houessin, Department of Crop Production, Faculty of Agricultural Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Maize (*Zea mays* L.) is the most cultivated plant in the world and the first cereal produced in africa[1]. In Sub-Saharan Africa (SSA), it remains the most cultivated cereal, with more than 70% of its grains going directly into human food[2]. In Benin, maize is the staple food for most of the population. The price of maize, which is the most consumed cereal in the country, recorded an increase of 220%, raising from 300-950 U.S[3]. More than 85% of the Beninese population's diet in various forms depending on the region and eating habits of the socio-cultural groups[4,5]. In Benin, the average level of maize consumption is estimated at more than 85 kg/inhabitant/year placing the country in first place among maize-consuming countries in West Africa[6]. In addition to being the staple food for the vast majority of the population, maize is traded both within the country and to sub-regional markets[7]. Moreover, it is the only cereal for which Benin has exportable surpluses to neighbouring countries, notably Niger and Nigeria[8]. Maize is therefore an essential sector for guaranteeing food and nutritional security and reducing poverty in a country like Benin.

In general, maize production in Benin has remained relatively static, despite the exponential increase in acreage in recent years. This phenomenon persists because maize cultivation is facing a serious problem of declining agricultural productivity due to several biotic and abiotic factors. Indeed, several factors limit the production and productivity of maize. Among the abiotic factors, we have drought and high temperatures which are increased by climate variation[9]. Crop pests (*Striga hermonthica,* armyworm, etc.) and declining soil fertility are the main constraints that most frequently limit maize production and productivity in most SSA countries including Benin[10,11].

However, in Benin, several research efforts are being carried out in the framework of production systems, pest control and the use of improved maize varieties to improve the potential and diversity of the crop[12]. Research in recent years has resulted in the development of improved varieties[13,14]. However, these improved varieties are very poorly adopted by producers because of their specific input requirements and their technological and organoleptic qualities that still do not meet users' needs[15,16]. Furthermore, the potential yields of these varieties are low and generally below 1,347 kg ha^{-1} and well below potential yields that can reach 5 t ha^{-1} [1,17]. Even in areas favourable to maize production such as North Benin, average maize yields in the good season hardly exceed 2.5-3 t ha^{-1}. However, apart from monitoring technology transfers that cover the technical dimensions of production, varietal improvement (seed) and combination of production factors (water, soil fertility, production system, etc.), there are also crop adaptations to climate change and especially to drought[18], social acceptability of the crops concerned and other non-technological constraints. Little research in Benin, as in most African countries, is being carried out in this respect. Studies conducted on the perceptual characterisation of Chinese hybrid varieties tested at the Sèmè-Podji station by the Centre Pilote Agricole showed yields of up to 10 t ha^{-1} [19]. Moreover, most of these hybrids are susceptible to stripe, mildew and pests.

In this perspective, the use of hybrid maize varieties tolerant to multiple stresses (biotic and abiotic) would be a major asset to increasing maize productivity in Benin[20]. IITA Nigeria, in collaboration with the National Agricultural Research Systems (NARS), has developed new hybrid varieties tolerant to multiple environmental stresses (leaf diseases, drought, Striga and low soil nitrogen) with very satisfactory preliminary results from the study on their agronomic performance in the sub-region. Thus, the potential to increase maize productivity exists elsewhere and it is up to us to take advantage of it in our country.

The present study aims to test hybrid maize varieties under different agroecological conditions in North-Eastern Benin to boost maize productivity in Benin.

MATERIALS AND METHODS

Materials: The study plant material consisted of 16 intermediate (105-110 days) and late (110-120 days) cycle maize varieties. A control variety (late 120 days), open-pollinated, was popularised in Benin and 15 hybrid maize varieties were newly identified by the Institut National de Recherches Agricoles du Benin (INRAB) in collaboration with the International Institute of Tropical Agriculture (IITA) through the Stress Tolerant Maize for Africa (STMA) project (Table 1).

Experimental sites: The trials were conducted on three different sites. We have the site of the University of Parakou Farm located at Komkoma in the Commune of Parakou (PDA 2), the site of the North-East Agricultural Research Centre (CRA North-East) of Ina located in the Commune of Bembèrèké and the site of Angaradébou located in the Commune of Kandi (PDA 4).

The Commune of Parakou is located at 9°21' North latitude, 2°36' East longitude, 350 m altitude, in the department of Borgou. It is characterised by a soil that rests on the granite-gneissic base where tropical ferruginous soils

Table 1: List of genotypes evaluated in this study

Genotypes	Codes	Genotypes	Codes	Genotypes	Codes	Genotypes	Codes
SAMMAZ 51	H_1	M1026-4	H_5	M1426-1	H_9	M1526-1	H_{13}
M1426-5	H_2	M1526-4	H_6	M1026-7	H_{10}	Sammaz 24	H_{14}
M1426-3	H_3	M1526-2	H_7	M0926-11	H_{11}	IAR1WH-1	H_{15}
Oba Supper 11	H_4	M0926-6	H_8	M1126-2	H_{12}	TZPB SR W (Control)	H_{16}

essentially evolve. It has a rainy season from May to October and a dry season from November to April. The average rainfall varies between 700 and 1100 mm per year. The temperature varies between 21 and 35°C.

The Commune of Bembereke is located at latitude 09°57' North, longitude 02°43' East, at an altitude of 371 m and also in the department of Borgou. It is characterised by tropical ferruginous soil with concretions formed on calco-alkaline granite materials[21]. It is marked by two seasons, a dry season from November to April and a rainy season from May to October. The high temperature in the growing season is between 30 and 31°C.

The Commune of Kandi is located at 11°20' North latitude, 2°43' East longitude, at an altitude of 256 m and in the Department of Alibori. It is characterised by tropical ferruginous soils with a Sudanese climate. The average rainfall varies between 800 and 1300 mm per year.

Methods

Experimental design: The trials were set up in a randomised Fisher block design with the three replications. Each treatment/hybrid was sown in two lines of 5 meters long representing a useful plot. The sowing distances were 0.75×0.50 m with three seeds per plot, dismated to two plants, two weeks after sowing. The replicates were separated by an alley of 1.5 m between them.

Three weeks after emergence, the plants received a mineral fertiliser of N14P18K18B1S6 formulation at a dose of 8.5 g per packet, i.e., 250 kg per hectare. Then, a supplement of urea (46%) at a dose of 5.62 g per packet, i.e., 150 kg per hectare, was applied at 45eme days after sowing, i.e. at the bolting stage, followed by sarclo-buttage. Regular weeding at three-week intervals was carried out during the vegetative phase of the crop. To control the *Spodoptera frugiperda* attack, the insecticide EMACOT 050WG (Emamectin benzoate 50 kg ha^{-1}) was used.

Data collected: The descriptors for the maize used by Ogunniyan *et al.*[22] were conserved for selection of variables, taking into account the CaBEV standards[14]. A total of thirteen variables were measured, of which seven were quantitative and six qualitative. The measurements were carried out on ten randomly selected plants per plot unit, i.e., a total of 30 plants per hybrid (Table 2).

Statistical analysis: R 3.6.1 software was used to perform the different analyses at the 5% significance level. Before the analysis, we carefully checked the normal distribution using the Shapiro-Wilk Test and assessed the homogeneity of variance using the Levene Test. The data were subjected to a combined Analysis of Variance (ANOVA) using the Generalized Linear Model (GLM). In this analysis, genotypes (hybrids) were treated as fixed effects, while replicates, sites (environments) and all interactions between fixed and random effects are treated as random effects. Means were separated by the Smallest Significant Difference (SSD). The statistical model of Singh by Japheth *et al.*[23] was used:

$$Y_{ijk} = \mu+g_i+e_j+g_{eij}+a_{jk}+a_{kl}+\varepsilon_{ijkl}$$

where, μ is the mean, g_i is the effect of the ith genotype, e_j is the effect of the jth environment, g_{eij} is the interaction of the ith genotype with the jth environment, a_{jk} is the effect of the kth replicate in the jth environment, a_{kl} is the effect of the lth block in the kth replicate and ε_{ijkl} is the random error

The broad heritability (H^2) for each trait[24].

$$H^2 = \frac{\sigma^2_g}{\sigma^2_g + \frac{\sigma^2_{g\times e}}{e} + \frac{\sigma^2_g}{er}}$$

where, σ^2_g: Genotypic variance, $\sigma^2_{g\times e}$: Genotype× environment interaction variance, σ^2_e: variance, e: Number of localities and r: Number of replicates

When, $H^2 = 1$, this means that all observed differences between genotype effects are entirely due to these differences. In this case, the traits are considered interesting. When H^2 is close to 0, the observed genetic differences are due to genotype x environment interactions or experimental errors and therefore the traits are not interesting. The Pearson's Correlation Test was used to assess the interaction between the different traits studied. Multivariate analysis methods (Principal Component Analysis) have also been used

Table 2: Quantitative and qualitative variables selected in the maize descriptors

No.	Quantitative variables
1	Number of days at 50% male flowering (FLOM): The number of days from sowing to the date when 50% of plants with the central axis of the panicle shedding pollen
2	Number of days to 50% female flowering (FLOF): The number of days from sowing to the date when 50% of the plants have emitted silk
3	Flowering interval (FTI): The interval between male and female flowering was calculated as the difference between the number of days of female and male flowering
4	Plant height (HPLT): The height of the plants at flowering from the crown to the last leaf (panicle leaf) was measured after the emergence of panicles and spikes
5	Height of ear insertion (HIE): the measurement of the height of the plants from the crown to the ear-bearing node of the 10 plants selected per variety was taken at the time of ear formation
6	The number of spikes per plant (NEP): This is determined by the simple ratio between the total number of spikes and the number of spikes per plant of harvested ears and the total number of plants at harvest on the useful plot
7	Grain yield (RDMT): It was calculated from the grain weight of all the ears harvested on the useful plot and the moisture content which is adjusted to 15%. The formula: $\text{RDMT} = \frac{\text{grw} \times (100 - \text{Th in field})}{(100 - \text{Th fixed})} \times \frac{10000}{\text{Splot surface}}$ from the IITA Ibadan Maize Improvement Programme was used for the yield calculation, With: Th fixed = 15%, grw: Grain weight of the useful plot and Th: Moisture content adjusted
8	Root Lodging (RL): Root lodging was assessed two weeks before harvest. These are the plants that fell without breakage under the ear according to a precise coding (1 = 0-20% of plants, 2 = 20- 40, 3 = 40-60, 4 = 60-80 and 5 = 80-100%)
9	Stem Lodging (SL): Stem lodging was assessed two weeks before harvest. These are the plants that showed breakage under the ear at more than a 45° angle according to a precise coding, (1 = 0-20% of plants, 2 = 20-40, 3 = 40-60, 4 = 60-80 and 5 = 80-100%)
10	Ear coverage (ER): This variable was measured at harvest by assessing the coverage of the ear by the spathe. The coverage of the spike is assessed according to precise coding (1 = Very good, 2 = Good, 3 = Average, 4 = Bad and 5 = Very bad)
11	Plant appearance (PASP): It was assessed according to the vigour of the plants and the following foliage on a scale of 1-5, where 1 = Excellent, 2 = Good, 3 = Fair, 4 = Poor and 5 = Bad
12	Ear appearance (EASP): This was assessed by uniformity, ear clarity and seed alignment on the ears on a scale of 1-5, where 1 = Clean, uniform, large and full ears and 5 = Ears with undesirable characteristics
13	Assessment of leaf diseases (Stripe, Rust, Curvilariosis and Helminthosporiosis). They were made by direct observations at mid-grain fill following a disease rating scale (1-5) where 1 = no symptoms or no evidence of a disease, 2 = Some symptoms or traces of one disease, 3 = Symptoms or traces of 2 diseases, 4 = Symptoms or traces of more than 2 diseases and 5 = All plants in the hybrid show symptoms of one disease

in a purely descriptive framework. The value of the adjusted mean grain yield from the ANOVA was subjected to Biplot GGE analysis to determine grain yield[25,26] to investigate the stability of the hybrids in each locality. The Biplot GGE model used is the following:

$$Y_{ij} - Y_j = \lambda_1 \varepsilon_{j1} n_{j1} + \lambda_2 \varepsilon_{j2} n_{j2} + \varepsilon_{ij}$$

where, Y_{ij} is the grain yield of a genotype i in an environment (locality) j, Y_j is the average grain yield of all genotypes in an environment j, 1 and 2 are the values of the axes (PC_1 and PC_2), i1 and j2 the respective scores of PC_1 and PC_2 for a genotype j, n_{j1} and n_{j2} the respective scores of PC_1 and PC_2 in environment j and e_{ij} the residual value of grain yield of a genotype i in environment j.

The analyses were performed using a CIMMYT GEA-R software as described by Amegbor *et al.*[27].

RESULTS

Analysis of the agro-morphological variability of hybrids

Variability in quantitative characteristics: The results of the combined analysis of variance revealed a significant difference ($p<0.05$) between genotypes (hybrid and control) across sites for all measured variables, except for the grain yield (RDMT), the interval between male and female flowering (IFM) and the number of spikes borne per plant (NEP). Significant induced variability within environments was noted for the measured traits, except for grain yield and female flowering date.

The genotype x environment (G×E) interaction analysis was highly significant ($p<0.0001$) for grain yield and flowering interval. Thus the environment (site) significantly influenced these quantitative variables measured in this study.

Significant differences were observed between the minima and maxima for all the traits studied. All quantitative traits showed a low variation (CV<10%) except for the interval between the two flowerings. A high heritability ($H^2>0.50$) was observed for all the traits studied, except for the interval between the two flowerings and the number of spikes borne per plant ($H^2<0.50$) (Table 3).

Analysis of qualitative characteristic

Analysis of plant and ear parameters: Assessments of plant and spike aspects, spike cover and plant worms of the

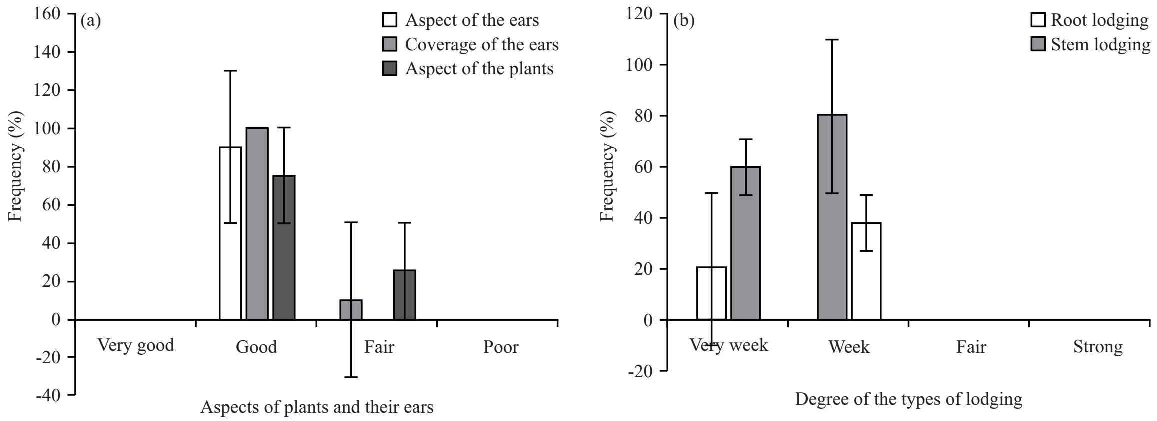


Fig. 1(a-b): Assessment of plant and ear parameters

Table 3: Variance, heritability and coefficient of variation of hybrid grain yield and its main components

Source of variations	DDL	FLOM	FLOF	HPLT	HIE	RDMT	IFM	CIP
Website	2	0.640*	0.491^{ns}	485.005**	148.938*	177236.274^{ns}	1.834***	0.001*
Genotype	15	1.225***	1.368***	63.541***	33.041*	97074.192^{ns}	0.053^{ns}	0ns
Genotype×site	30	0.048^{ns}	0ns	0ns	5.919^{ns}	201097.205***	0.067***	0.001^{ns}
Residual value	96	1.909	2.298	134.46	65.016	289114.4	0.474	0.003
Minimum value		51	54	110	40	2392	0	0.7
Average		56	58	191.07	105.36	5231.30	1.94	1.0
Maximum value		62	65	240	140	6190	4	1.19
SDPP (5%)		0.959	1.022	7.97	6.95	463.50	0.410	0
CV (%)		2.44	2.59	6.07	7.65	9.93	35.37	5.98
Heritability		0.84	0.84	0.81	0.71	0.69	0.32	0.25

*, **, ***at the 0.05, 0.01 and 0.0001 level respectively, ns: Not significance, DDL: Degree of freedom, RDMT: Grain yield, FLOM: Male flowering, FLOF: Female flowering, IFM: Interval between male and female flowering, HPLT: Plant height, HIE: Height of spike insertion and NEP: Number of spikes borne per plant

varieties (hybrids and control) evaluated were presented in Fig. 1. No significant differences were observed ($p<0.05$) within the hybrids for all plant and spike parameters.

From the analysis of this figure, it was found that all hybrids and the control showed a good plant appearance. Similarly, it was found that about 94 and 6% of the hybrids had good and fair ear appearances respectively. For spike cover, 75% of the hybrids had good cover while 25% had fair cover and the control had poor cover (Fig. 1a). Regarding plant worming, the hybrids generally had low root and stem worming and the control had high root and stem worming (Fig. 1b). Thus, we can conclude that the hybrids were more resistant to the worming than the control.

Analyses of the main leaf diseases: The assessment of the severity of the leaf diseases evaluated was shown in Fig. 2. The analysis of the results revealed a non-significant difference (p 0.05) within the hybrids. From the analysis of Fig. 3, it can be seen that all hybrids showed low severity for each of the main leaf diseases. In general, the hybrids were slightly tolerant of these diseases.

Correlation between the characteristics studies: The Pearson Correlation Matrix shows significant correlations between some pairs of variables (Table 4). The analysis reveals that there are positive and negative correlations between the different parameters. Indeed, grain yield is negatively correlated with phenological parameters (FLOM, $r = -0.63$, FLOF, $r = -0.70$, IFM, $r = -0.67$) and leaf diseases (Rust, $r = -0.25$ and Helminthosporiosis, $r = -0.07$) and positively correlated with the number of spikes borne per plant ($r = 0.54$). Plant height was also correlated with ear insertion height ($r = 0.73$). The phenological parameters (50% male flowering and 50% female flowering) are very strongly and significantly correlated with each other ($r = 0.89$).

Analyses of genetic diversity of hybrids

Principal component analyses: To characterise the agro-morphological variability of the hybrid maize varieties, a PCA (Principal Component Analysis) was carried out. The results (Table 5) showed that with axes, 73.55% of the information contained in the initial variables can be explained, which is sufficient to guarantee an accurate interpretation of the data. With the three axes retained for characterising the agro-

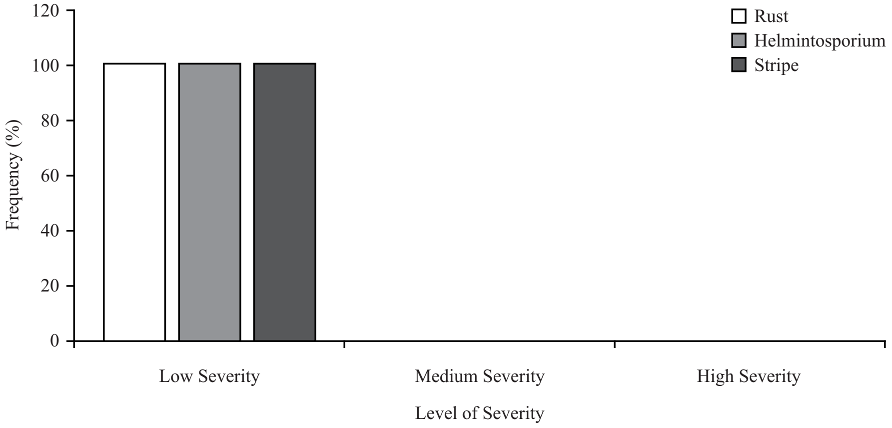


Fig. 2: Assessment of leaf disease severity of hybrids

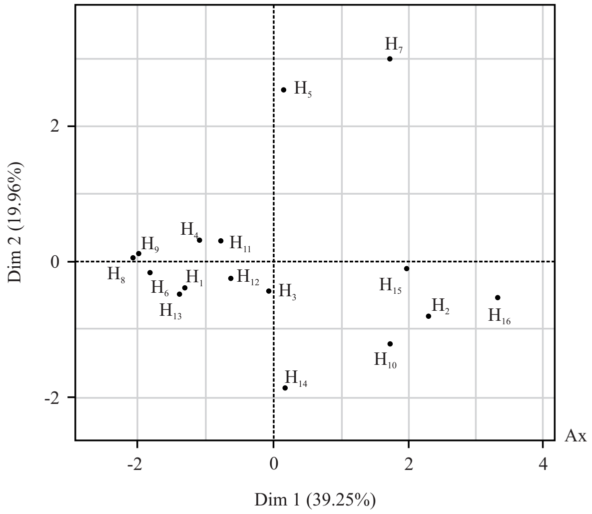


Fig. 3: Scatter plot of Comp1 and Comp2 values of the varieties assessed

morphological variability of hybrid maize varieties and describing the results between parameters, let us examine the correlations of these components with the 8 initial variables (50% male flowering, 50% female flowering, cob coverage, plant appearance, cob insertion height, grain yield, number of cobs borne per plant and the interval between the two flowerings).

The analysis of Table 5 showed that the variables 50% male flowering, 50% female flowering, spike coverage, plant appearance and spike insertion height are very well represented on the first axis with correlations of 0.88, 0.91, 0.72, 0.81 and -0.76 respectively. While the grain yield and number of spikes per plant variables are well represented on the second axis with correlations of 0.65 and 0.65. As for the third axis, it is well correlated with the variable interval between the two flowerings with a correlation of 0.64. Interpreting the results in Table 5, it can be noted that the variables 50% male flowering, 50% female flowering, spike coverage and plant appearance are positively correlated with axis 1 and the variable spike insertion height is negatively correlated. Comp 1 is defined as the axis of hybrid earliness because it is positively correlated with the variables number of days 50% of male and female flowering and negatively correlated with the variable height of spike insertion. Comp 2 is the productivity axis of these hybrids because it is positively correlated with the grain yield and number of spikes per plant variables. The variable interval between the two flowerings is positively correlated with axis 3, positively with axis 3, which makes this axis the axis of flowering synchronisation between the male and female organs of these hybrids.

The correlation coefficients between the first three principal components and the phenotypic variability of these hybrids indicate that: to the first component, several days at 50% male flowering is associated with several days at 50%

Table 4: Pearson correlation between the studied traits

Characters	FLOM	FLOF	HPLT	HIE	VR	VC	RE	PASP	EASP	Roui	Helm	RDMT	IFM
FLOF	0.89***												
HPLT	0.19	0.12											
HIE	0.40	0.31	0.73**										
VR	0.43	0.69	0.05	0.04									
VC	0.11	-0.10	0.09	0.28	-0.41								
RE	0.13	0.26	-0.03	-0.27	0.52*	-0.14							
PASP	-0.13	0.20	-0.44	-0.39	0.54*	-0.15	0.36						
EASP	-0.72	-0.51	0.06	-0.18	-0.19	-0.14	-0.15	0.22					
Roui	-0.19	-0.17	-0.23	0.01	-0.32	0.37	-0.44	0.16	0.34				
Helm	0.01	0.10	0.18	0.36	-0.01	-0.08	-0.51	-0.25	0.12	0.31			
RDMT	-0.63*	-0.70*	-0.01	0.12	-0.22	-0.04	-0.27	-0.56	-0.57	-0.25*	-0.07*		
IFM	0.12	0.55	-0.17	-0.09	0.71	-0.44	0.25	0.70	0.20	-0.02	0.20	-0.67*	-0.55*
NEP	-0.08	-0.12	0.19	0.00	0.09	-0.44	-0.23	-0.28	-0.03	-0.20	0.18	0.54**	-0.10

*, **, *** at the 0.05, 0.01 and 0.0001 level respectively, ns: Not significance, RDMT: Grain yield, FLOM: Male flowering, FLOF: Female flowering, IFM: Interval between male and female flowering, HPLT: Plant height, HIE: Height of spike insertion, NEP: Number of ears per plant, VR: Root worm, VC: Stem worm, RE: Recovery of ears, PASP: Appearance of plants, EASP: Appearance of ears, Roui: Rust severity and Helm: Helminthosporium severity

Table 5: Principal component analysis and contribution of each variable to the axes

Variables	Comp1	Comp2	Comp3
Grain yield	-0.44	0.65	0.47
Number of ears carried per plant	-0.25	0.65	-0.01
Height of the plants	0.48	0.42	-0.43
Height inserts spikes	-0.76	0.16	0.24
50% male flowering	0.88	0.31	0.21
50% female flowering	0.91	0.22	0.27
Interval between the two flowerings	0.24	-0.43	0.64
Covering the ears of corn	0.72	0.38	-0.08
Aspect spikes	-0.49	-0.18	0.22
Appearance of the plants	0.81	0.08	0.17
Rootworm	0.26	0.13	-0.27
Cauline verse	-0.39	0.45	0.03
Eigenvalue	2.747	1.397	1.005
%variance explained	39.24	19.95	14.35
Cumulative %variance	39.24	59.20	73.55

female flowering but with a low spike insertion height. Late male and female flowering are associated with taller spikes. To the second component, the higher the number of ears per maize plant, the higher the yield. From the analysis of these two components, it can be said that a good maize grain yield is also associated with late male and female flowering. To the third component, good grain yield of maize is associated with a short duration between male and female flowering. In sum, a genotype with late male and female flowering separated by a short duration bears enough ears and has a good grain yield.

The analysis of the scatter plot of Comp1 and Comp2 values of the varieties assessed (Fig. 3) showed that the varieties H_5, H_7, H_{15}, H_2, H_{16}, H_{10} and H_{14} were located on the positive side of axis 1. These varieties have plants with good vegetative appearance, early flowering and good ear coverage. The varieties H_8, H_9, H_4, H_{11}, H_6, H_1, H_{13}, H_{12} and H_3 are located on the negative side of axis 1. They, therefore, have plants with taller inserted ears than the other varieties. On axis 2, varieties H_8, H_9, H_4, H_5, H_7 and H_{11} are located on the positive side axis 2. They are characterized by the production of more ears per plant and therefore have the highest grain yields. The varieties H_3, H_6, H_1, H_{12}, H_{13}, H_{14}, H_{15}, H_{10}, H_2 and H_{16} are located on the negative side of axis 2. They are characterized by low values of earliness parameters but acceptable values of grain yield.

Structuring genotypic diversity: The bottom-up hierarchical classification of maize genotypes revealed three groups of genotypes at a class height of 1000. Groups G_1, G_2 and G_3 consisted of 10, 4 and 2 hybrids respectively (Fig. 4). Discriminant Factor Analysis (DFA) were carried out on the 13 variables studied and the three groups were defined by the hierarchical ascending classification and revealed that grain yield, plant height, spike insertion height, number of days to 50% male flowering, number of days to 50% female flowering and the interval between the two flowerings were the variables with a highly significant contribution of 5% (Table 6). Group G_1 consisted of intermediate cycle hybrids (105-110 days) with medium plant size and medium grain yield. Group G_2 consisted of the late-cycle genotypes

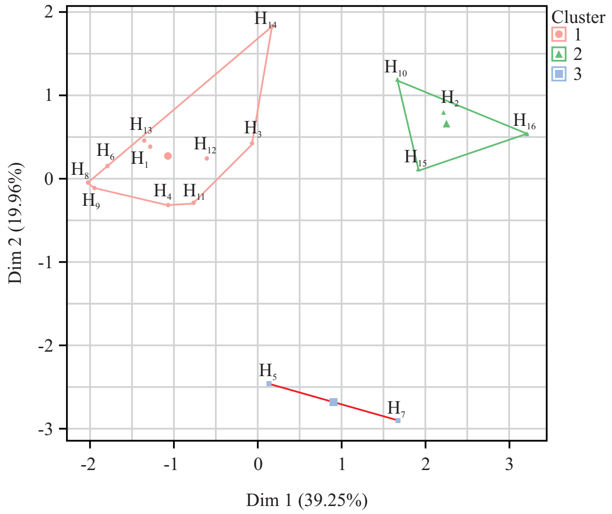


Fig. 4: Hierarchical bottom-up classification of hybrids based on numerical classification results

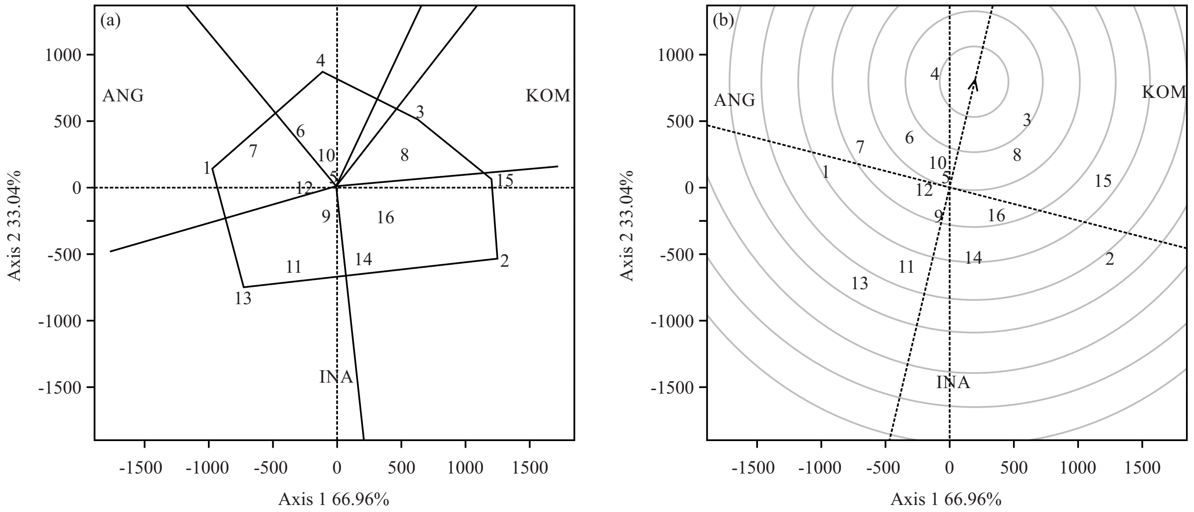
Table 6: Different hybrids groups' characteristics by numeric classification

Variables	G_1 (10)	G_2 (4)	G_3 (2)	x^2	Prob
Grain yield (t ha^{-1})	5.46 ± 0.35^{a}	4.27 ± 1.32^{b}	6.02 ± 0.07^{c}	8.355	0.0153
Number of spikes per plant	0.98 ± 0.02^{a}	0.95 ± 0.03^{a}	1.01 ± 0.02^{a}	4.797	0.09
50% male flowering (day)	55.7 ± 0.95^{a}	57.44 ± 0.36^{b}	58.05 ± 0.23^{b}	10.442	0.0054
50% female flowering (day)	57.7 ± 0.95^{a}	59.55 ± 0.55^{b}	59.77 ± 0.31^{b}	10.376	0.0055
Interval between the two flowerings (day)	2.00 ± 0.27^{a}	2.11 ± 0.27^{a}	1.72 ± 0.07^{a}	2.504	0.2859
Plant height (cm)	186.44 ± 7.34^{c}	197.38 ± 2.51^{c}	201.16 ± 8.82^{d}	7.455	0.024
Height of cob insertion (cm)	94.13 ± 3.41^{a}	103.58 ± 3.42^{b}	104.81 ± 9.74	9.282	0.0096
Plant appearance (1-5)	2.16 ± 0.16^{a}	2.18 ± 0.18^{a}	1.80 ± 0.03^{a}	6.963	0.0307
Appearance of ears (1-5)	2.5 ± 0.14^{b}	2.38 ± 0.11^{b}	1.86 ± 0.03^{b}	4.644	0.098
Rootworm (1-5)	1.54 ± 0.08^{b}	1.61 ± 0.11^{b}	1.55 ± 0.00^{b}	2.239	0.326
Cauliflower (1-5)	1.44 ± 0.10^{b}	1.61 ± 0.23^{b}	1.5 ± 0.07^{b}	2.457	0.292
Crop coverage (1-5)	2.36 ± 0.21^{b}	2.22 ± 0.09^{b}	2.05 ± 0.08^{b}	4.223	0.121
Rust (1-5)	2.18 ± 0.15^{b}	2.15 ± 0.02^{b}	2.05 ± 0.07^{b}	2.138	0.343
Helminthosporium (1-5)	2.01 ± 0.14^{b}	2.08 ± 0.22^{b}	1.83 ± 0.23^{b}	1.445	0.4854
Striure (1-5)	1.87 ± 0.12^{b}	1.83 ± 0.11^{b}	1.83 ± 0.23^{b}	2.138	0.343

Different letters in a column with mean values are significant at $p<0.05$

(110-120 days) with large plant sizes and acceptable grain yield. Group G_3 consisted of the late cycle hybrids (110-120 days) with large plants and high grain yield.

Genotype x environment interaction of hybrid performance and stability: Biplot GGE analysis was used to identify the best hybrids in each locality and to assess the stability of genotypes across all localities. The analysis in Fig. 5 revealed the effect of genotype plus genotype×environment interaction (GGE) based on grain yield. This effect was explained by the total variation (66.96% for Axis 1 and 33.04% for Axis 2) between sites. The results revealed a six-sector polygon, with the three sites located in three different sectors. The top hybrids in each sector were SAMMAZ 51, M1426-5, M1426-3, Oba Supper 11, IAR1WH-1 and M1526-1. Hybrids M1426-3, Oba Supper 11, M0926-6 and IARIWH-1 were the hybrids with the highest grain yields at the Komkoma site, while hybrids SAMMAZ 51, M1126-2 and M1526-2 had the highest yields at Angaradébou and hybrids M1426-1, M0926-11 and M1526-1 at Ina (Fig. 5a). The top genotype in each area represent the highest yielding hybrids in the locality in that particular area. Hybrid M1426-5 did not have a drop point in the areas where it was located, suggesting that this hybrid had a low yield in some (or all) of the sites. The performance stability Biplot was used to assess the stability of the 15 hybrids and the control at the three sites (Fig. 5b). In this figure, the x-axis, or mean environment axis, is the one-arrow line that passes through the origin of the biplot and is at the centre of the small circle. The y-axis is the second line that passes through the origin of the Biplot and which is perpendicular to the AO abscissa. The hybrids were ranked on the mean environment axis, with the arrow pointing to a higher value based on the mean performance at the site level. The three highest-ranked hybrids based on their projections on the mean environment axis were Oba Supper 11, M1426-3



Genotypes	Codes	Genotypes	Codes	Genotypes	Codes	Genotypes	Codes
SAMMAZ 51	H_1	M1026-4	H_5	M1426-1	H_9	M1526-1	H_{13}
M1426-5	H_2	M1526-4	H_6	M1026-7	H_{10}	Sammaz 24	H_{14}
M1426-3	H_3	M1526-2	H_7	M0926-11	H_{11}	IAR1WH-1	H_{15}
Oba Supper 11	H_4	M0926-6	H_8	M1126-2	H_{12}	TZPB SR W (Control)	H_{16}

Fig. 5a-b: GGE Biplot and stability of genotype performance, (a) Best genotypes through the three localities and (b) Genotype rankings in grain yield across the three locations

KOM :Site de Komkoma (Parakou), INA : Site d'Ina (Bembéréké) et and ANG : Site d'Angaradébou (Kandi)

and M0926-6. In this analysis, the stability of the genotypes is measured by their projection on the ordinate. The M1026-7 and M1026-4 hybrids are the most stable because of their short projection on the y-intercept. In contrast, the SAMMAZ 51 and M1426-5 hybrids were the most unstable due to their long projection on the y-axis.

DISCUSSION

This study was proposed to select the best-performing maize hybrids varieties for the target areas. Thus, 15 improved hybrid varieties and one local maize variety were tested in three sites in Northern Benin for a multi-environmental evaluation. The descriptive analyses showed significant differences between the minimum and maximum values for all the agro-morphological traits analysed. This indicates significant inter-hybrid variability. This diversity would result from the background or genetic heritage of these hybrids. A high heritability (H^2 0.50) was observed for all the traits studied except for the interval between the two flowerings and the number of spikes borne per plant. Positive and negative correlations between the different parameters were also observed. The grain yield of the hybrids was negatively correlated with earliness parameters and leaf diseases. As the interval between the two flowerings increased, grain yield decreased. The severity of the two main diseases was also reduced.

Furthermore, the stability of the desired genetic traits is important for the development of improved varieties for use under various agro-climatic conditions. Agronomic traits, such as grain yield, are quantitative and regularly show a genotype×environment interaction[28]. Thus, in this study, analysis of variance revealed that the effect of sites (environment) was significant for the trait's number of days between sowing and the appearance of 50% of male and female flowers and grain yield. As for the genotypes, the effect was also significant for the phenological traits (male and female flowering). Makumbi *et al*.[29] reported that significant genotype×environment interaction differences are recorded for grain yield of maize under artificial infestation of *Striga hermonthica*. Thus, our results are consistent with those found by Makumbi *et al*.[29]. Under environmental conditions, genotypes behave differently in different areas. Current results also the corroborated our finding[30,31]. Indeed, these authors studied the influence of genotype×environment interaction on maize hybrids and identified stable, better-performing hybrids with high grain yield. As mentioned by authors[32,33], multi-location evaluation is therefore useful in determining efficient methods for the use of time and resources in a breeding programme.

In general, the best-performing hybrids are less stable and those that are very stable are less successful except for a few hybrids that are both successful and stable for some traits. Tamene *et al.*[34] reported a similar finding that low-yielding genotypes for maize, soybean and coffee are respectively more stable. The differences observed between these results can be explained by the genetic nature of the varieties (local and improved) on the one hand and by the agroecological characteristics of the environments on the other. Studies were reported by Buton *et al.*[35] where they mentioned that the environment has an effect on the genotype for grain yield of maize in particular and this effect was mainly due to limiting factors such as minimum temperature, relative humidity, water stress and diseases.

The introduction of germplasm is a widely used strategy for enrichment, particularly in areas with high crop or cultivar variability. The introduction of varieties must therefore be accompanied by the evaluation of stability in performance and genotype × environment interaction[30]. The present study revealed through genotype × environment interactions, that two of the fifteen hybrids evaluated were the most stable (M1026-4 and M1026-7) and responded to the characteristics of the zones. However, previous work has shown that variability was observed among the tested populations for various morphological traits[36]. Thus, it is observed that compared to our results, the hybrids showed greater inter-hybrid variability. This is explained by the nature of the genetic material that differs between hybrids and lines.

CONCLUSION

The present study highlighted the variability of agromorphological traits with particular emphasis on grain yield of intermediate cycle maize hybrids from IITA Ibadan and compared to a local improved variety already adopted in Benin. This phenotypic variability was structured into three major groups of hybrids. However, the influence of genotype and environment (genotype × environment) interactions allowed us to identify the hybrids M1026-7 and M1026-4 as the most stable and productive varieties in all the localities studied. Several of these varieties yielded more than the local improved variety TZPB SR-W. Based on the preferences of the users of the research products, the best hybrids with stable grain yields across the three study sites M1026-4 (5795 kg ha^{-1}) and M1026-7 (5178 kg ha^{-1}) are to be promoted and would contribute to a 64% improvement in productivity in this region of the country. These performances should be accompanied by a technological and physico-chemical evaluation to select a little more according to the aptitudes for the preparation of derivatives and foods liked by the populations. Similarly, perception studies will make it possible to establish acceptance and preference criteria to facilitate the dissemination of these new maize varieties.

SIGNIFICANCE STATEMENT

In Benin, maize is the major staple food for most of the population. Despite the improvement of the local varieties by the research, the yield is still decreased and the occurrence of climate change limits this production. Hence, it is paramount important to introduce hybrids maize varieties for improving productivity in the production areas. Therefore, the experiment was conducted to recommend the best varieties which are well adapted to Benin the agroecology zones. Two promising hybrids (M1026-4 and M1026-7) were identified and recommended for the producers. These results can be directly used for a programme of dissemination and diffusion of resilient maize varieties in Northeast Benin, particularly in agricultural development clusters 2 and 4.

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REFERENCES

1. Kadango, T.L., Y. Assefa and S. Mnkeni, 2020. Effects of genetically modified (GM) maize adoption in small scale farms on cropping systems of the Eastern Cape Province, South Africa. Int. J. Biotechnol., 9: 67-80.
2. Vogel, E., M.G. Donat, L.V. Alexander, M. Meinshausen and D.K. Ray *et al.*, 2019. The effects of climate extremes on global agricultural yields. Environ. Res. Lett., Vol. 14. 10.1088/1748-9326/ab154b.
3. Yabi, A.J., S.D. Tovignan and R. Moustafa, 2013. Analysis of maize production and supply for food security improvement in the Borgou Region in Northeast of Benin. Afr. J. Agric. Res., 8: 943-951.
4. Hongbete, F., J.M. Kindossi, J.D. Hounhouigan and M.C. Nago, 2017. Production and nutritional quality of cob of boiled fresh maize consumed in Benin. Int. J. Bio. Chem. Sci., 11: 2378-2392.

5. Houngbo, E.N., 2016. Diversity and adoption criteria of maize (*Zea mays* L.) cultivars in Zounnou Village, Central Benin. J. Appl. Biosci., 96: 9094-9101.
6. Akinwale, R.O., B. Badu-Apraku and M.A.B. Fakorede, 2013. Evaluation of *striga*-resistant early maize hybrids and test locations under *striga*-infested and *striga*-free environments. Afr. Crop Sci. J., 21: 1-19.
7. Ba, M.N., 2017. Competiveness of maize value chains for smallholders in West Africa: Case of Benin, Ghana and Cote D'Ivoire. Agric. Sci., 8: 1372-1401.
8. Gbenou, E.S., Y.P. Adégbola, P.M. Hessavi, S.R.C. Zossou and G. Biaou, 2021. On-farm assessment of maize storage and conservation technologies in the Central and Northern Republic of Benin. Agriculture, Vol. 11. 10.3390/agriculture 11010032.
9. Teka, O., G.L. Houessou, M. Oumorou, J. Vogt and B. Sinsin, 2013. An assessment of climate variation risks on agricultural production. Int. J. Clim. Change Strategies Manage., 5: 166-180.
10. Badu-Apraku, B., M.A.B. Fakorede and R.O. Akinwale, 2017. Key Challenges in Maize Breeding in Sub-Saharan Africa. In: Achieving Sustainable Cultivation of Maize Volume 1: From Improved Varieties to Local Applications. Watson, D. (Ed.), Burleigh Dodds Science Publishing, Cambridge, England, ISBN: 9781786760081, pp: 51-58.
11. Das, B., G.N. Atlin, M. Olsen, J. Burgueño and A. Tarekegne *et al*., 2019. Identification of donors for low-nitrogen stress with maize lethal necrosis (MLN) tolerance for maize breeding in Sub-Saharan Africa. Euphytica, Vol. 215. 10.1007/s10681-019-2406-5.
12. Ezin, V., C.M.I. Kpanougo and A. Ahanchede, 2022. Genetic diversity and environmental influence on morphological and yield parameters of maize in Benin. Heliyon, Vol. 8. 10.1016/j.heliyon.2022.e09670.
13. Badu-Apraku, B., M. Ewool and C.G. Yallou, 2010. Registration of *striga*-resistant tropical extra-early maize population. J. Plant Regist., 4: 60-66.
14. Badu-Apraku, B., M.A.B. Fakorede, M. Oyekunle, G.C. Yallou and K. Obeng-Antwi *et al*., 2015. Gains in grain yield of early maize cultivars developed during three breeding eras under multiple environments. Crop Sci., 55: 527-539.
15. Hafiz, A.S., A. Djima, A. Adolphe, Y. Chabi, S. Haziz, P. Wilfrid and B.M. Lamine, 2015. Biodiversity of local varieties of corn cultivation among farmers in Benin. J. Agric. Crop Res., 3: 85-99.
16. Salami, H.A., A. Adjanohoun, W. Padonou, A.M. Yacoubou and D. Aly *et al*., 2015. Morphological diversity of corn's (*Zea mays* L.) local cultivar and improved varieties in central and North of Benin. Am. J. Plant Sci., 06: 2867-2877.
17. Amegnaglo, C.J., 2018. Determinants of maize farmers' performance in Benin, West Africa. Kasetsart J. Social Sci., 41: 296-302.
18. Kusa, K.A., S. Alemu and G. Teshome, 2022. Evaluation of drought tolerant maize varieties (*Zea mays* L.) for low land of Guji Zone, Southern Oromia, Ethiopia. J. Agron., 21: 8-13.
19. Dedehouanou, H., A. Affokpon, R. Sikirou, N. Akissoe and C.G. Yallou *et al*., 2019. Comprehensive perception approach of adoption: Experimenting hybrid chinese maize varieties in Benin. J. Agric. Sci., 11: 21-29.
20. Quenum, F.J.B., M.C. Djaboutou, S.S. Houédjissin, M.G. Sinha, C. Houénou, G.H. Cacaï and C. Ahanhanzo, 2017. Identification of elite cultivars in maize (*Zea mays* L.) germplasm based on agronomical characters. Int. J. innovations Agric., 1: 1-8.
21. Chabi, F.O., G.D. Dagbenonbakin, E.C. Agbangba, B.T. Oussou and B.K. Agban *et al*., 2021. Fertilizer recommendations for optimal soybean production in North and Center Benin. J. Soil Sci. Environ. Manage., 12: 29-43.
22. Ogunniyan, J.D., O.A. Oduwaye, S.A. Olakojo and D.K. Ojo, 2015. Genetic variability, repeatability, traits relationships and path coefficient analysis in low nitrogen donor white inbred lines of maize (*Zea mays* L.). Maydica, Vol. 60.
23. Jamoza, J.E., J. Owuoche and O. Kiplagat, 2019. Estimates of genetic parameters and genotype by environment interactions for sugar yield and its components in sugarcane genotypes in Western Kenya. J. Plant Breed. Crop Sci., 11: 206-212.
24. Pfeiffer, C., C. Fuerst, H. Schwarzenbacher and B. Fuerst-Waltl, 2016. Genotype by environment interaction in organic and conventional production systems and their consequences for breeding objectives in Austrian Fleckvieh cattle. Livest. Sci., 185: 50-55.
25. Yan, W., L.A. Hunt, Q. Sheng and Z. Szlavnics, 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Sci., 40: 597-605.
26. Yan, W., 2001. GGEbiplot-A windows application for graphical analysis of multi environment trial data and other types of two-way data. Agron. J., 93: 1111-1118.
27. Amegbor, I.K., A. Abe, J. Adjebeng-Danquah and G.B. Adu, 2022. Genetic analysis and yield assessment of maize hybrids under low and optimal nitrogen environments. Heliyon, Vol. 8. 10.1016/j.heliyon.2022.e09052.
28. Fan, X.M., M.S. Kang, H. Chen, Y. Zhang, J. Tan and C. Xu, 2007. Yield stability of maize hybrids evaluated in multi-environment trials in Yunnan, China. Agron. J., 99: 220-228.
29. Makumbi, D., A. Diallo, F. Kanampiu, S. Mugo and H. Karaya, 2015. Agronomic performance and genotype × environment interaction of herbicide-resistant maize varieties in Eastern Africa. Crop Sci., 55: 540-555.
30. Koroma, M.S., M. Swaray, R. Akromah and K. Obeng-Antwi, 2017. Genotype by environment interaction and stability of extra-early maize hybrids (*Zea mays* L.) for yield evaluated under irrigation. Int. J. Environ. Agric. Biotechnol., 2: 2573-2580.

31. Dosho, B.M., B.E. Ifie, I.K. Asante, E.Y. Danquah and H. Zeleke, 2022. Genotype-by-environment interaction and yield stability for grain yield of quality protein maize hybrids under low and optimum soil nitrogen environments. J. Crop Sci. Biotechnol., 25: 437-450.
32. Ceccarelli, S., 1989. Wide adaptation: How wide? Euphytica, 40: 197-205.
33. Merga, W., 2022. Plant breeding challenges posed by genotype-environment interaction and methods of measurement. Am. J. Biol. Environ. Stat., 8: 43-49.
34. Tamene, L., P. Mponela, G. Ndengu and J. Kihara, 2016. Assessment of maize yield gap and major determinant factors between smallholder farmers in the Dedza District of Malawi. Nutr. Cycling Agroecosyst., 105: 291-308.
35. Butron, A., N.W. Widstrom, M.E. Snook and B.R. Wiseman, 2002. Recurrent selection for corn earworm (Lepidoptera: Noctuidae) resistance in three closely related corn southern synthetics. J. Econ. Entomol., 95: 458-462.
36. Dhakal, B., K.P. Shrestha, B.P. Joshi and J. Shrestha, 2017. Evaluation of early maize genotypes for grain yield and agromorphological traits. J. Maize Res. Dev., 3: 67-76.