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Assessment of the stability and genotype-environment interaction of a spider plant (*Cleome gynandra* L.) collection in Burkina Faso: Application of the AMMI and GGE models

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Spider plant, *Cleome gynandra* L (Cleomaceae) is an important traditional leafy vegetable in Burkina Faso diets. Due to its high nutritional value and medicinal properties, it is a good dietary supplement for combating nutritional deficiencies and certain degenerative diseases. However, the lack of quality seeds and poor agronomic performance are limitations to crop improvement. The aim of the present study was to evaluate the agro-morphological performance of a collection of *C. gynandra* in relation to the three climatic zones of Burkina Faso. Thus, 36 accessions collected in the three climatic zones of Burkina Faso were evaluated using a Fisher block design. The trials were conducted in August 2019 during the rainy season in the country's three climatic zones. Measurements and observations were made on the traits of interest, including fresh biomass (BMF). The best agronomic performances were recorded at the Bobo Dioulasso Experimental Station, followed by Ouagadougou, while the poorest performances were noted at Dori. The stability test (AMMI and GGE biplot) enabled us to identify accessions adapted to each climate and six high-performing, stable accessions (OUA9, OUA10, KOU, KOM2, BOB3 and MAN) for all three climatic zones. These high-performing, stable accessions can then be popularized among local populations.

Key words: *Cleome gynandra,* agronomic performance, yield in fresh biomass, AMMI, Burkina Faso.

INTRODUCTION

The nutritional composition of *Cleome gynandra* L. (Cleomaceae) makes this crop an added value to be taken into account in achieving food and nutritional security for consumers (Meda et al., 2013; Chand et al.,

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2022). *C. gynandra* is also of economic importance to growers and traders, generating substantial income for market gardeners (Sakande et al., 2022).

Spider plant (*C. gynandra* L.) is of great pharmacological interest and could be used in the treatment of numerous diseases. Its leaves are said to facilitate childbirth and lactation (Mishra et al., 2011). Indeed, in many communities, to facilitate childbirth, a decoction or infusion of the boiled leaves and/or roots is administered to women during labor (Berhaut, 1976; Mishra et al., 2011). This same decoction taken after childbirth is said to promote milk secretion and compensate for blood lost during childbirth thanks to its rich iron content (Bosire, 2014). Iron and vitamin A richness are particularly important health issues in countries plagued by anemia, mainly caused by malaria (Kahane et al., 2005; Moyo and Aremu, 2022). Similarly, according to Mnzava and Chigumira (2004), an infusion of the leaves consumed as a drink treats anemia.

A better understanding of the diversity of *C. gynandra* is therefore essential for the design of initiatives to preserve and promote this crop (Marcia et al., 2014). Thus, agro-morphological characterizations of *C. gynandra* collections have been carried out but on a single site located in the Sudano-Sahelian zone (Kiébré, 2016). These agro-morphological characterizations made it possible to identify the plant's socio-cultural services for local populations. As a result, the effect of genotype-environment interaction on trait expression has not been assessed. Given that phenotype expression is the result of the combined action of genotype, environment and genotype-environment interaction, the behavior of an accession may vary, significantly, from one environment to another (Wasonga et al., 2015). It is, therefore, important that trials be carried out in Burkina Faso's three climatic zones in order to offer farmers *C. gynandra* varieties that are adapted to them. This work is part of the drive to identify accessions adapted to each climatic zone. It therefore aims to evaluate the agromorphological performance of *C. gynandra* collection in relation to the three climatic zones. Specifically, the aims are (i) to determine the effect of accession-experimental site interaction on the variability of *C. gynandra* traits of interest; (ii) to identify high-performance accessions for each of the three climatic zones; and (iii) to identify a batch of high-performance accessions for all three climatic zones.

MATERIALS AND METHODS

Plant

The plant material consists of 36 *C. gynandra* accessions collected in 2019 from gardeners in the three agro-climatic zones of Burkina Faso, namely the Sudanian, Soudano-Sahelian and Sahelian zones. As *C. gynandra* is still in protoculture, the number of accessions varies from one zone to another. Thus, six accessions were collected in the Sudanian zone, three accessions in the Sahelian zone and 27 accessions in the Sudano-Sahelian zone (Table 1).

Experimental sites

Trials were carried out at three sites in the three climatic zones of Burkina Faso.

Site 1

It is located in the Sudanian zone in the peri-urban area of Bobo Dioulasso at 11°12'0" North latitude and 4°18'0" West longitude. The average rainfall recorded during the 2019 trial in Bobo Dioulasso was around 1371 mm of water. Wooded savannah dominates the region, after gallery forest and grassland.

Site 2

It is located in the Soudano-Sahelian zone at Gampela, 18 km east of Ouagadougou on the Ouaga-Niamey axis at 12°15' North latitude and 1°12' West longitude. The average rainfall recorded during the 2019 trial, in Ouagadougou, was 852.7 mm of water. The vegetation is characterized by wooded and grassy savannah.

Site 3

It is located in the Sahelian zone at Djomga 8 km South of Dori on the Dori-Gorom-Gorom axis at 14°02′07″ latitude and 0°02′04″ longitude West North. The average rainfall recorded during the 2019 trial, in Dori, was 509.7 mm of water. The vegetation is characterized by tree and shrub steppe.

The soil types of Ouagadougou (Gampèla) and Bobo Dioulasso (Lafiabougou) are ferric lixisols (sandy-loam texture) according to the WRB (2006) classification. These soils have a strong weathering of the surface horizons and clay accumulation in a deep horizon called argillic horizon (WRB, 2006). The soils of Dori (Djomga) are aerosols with a high sand content.

Experimental design and cultivation practices

On all three sites, an incomplete Fisher block design was used. Each replicate was subdivided into two sub-blocks of 18 accessions. Repeats and successive sub-blocks were separated by 1 m. Within each block, each accession was represented by a 3 m line on which seven seed pots were sown at a rate of 10 seeds/ poquet. Accessions were randomly assigned to lines. The row spacing, and the spacing between bunches were 0.5 m, respectively.

Each plot was ploughed, harrowed, and levelled before planting. An organic amendment, at a rate of 6 tonnes per hectare, was applied to enable the plants to better express their potential (Kiébré et al., 2019). Manual sowing was carried out on August 09, 2019, for the Bobo site, and on August 12, 2019, for the Ouagadougou and Dori sites. A total of three weeding operations were carried out at each site. Demariage was carried out on the 10th day after sowing, with one plant/poquet.

Data collection

Quantitative variables were measured at 45 days after sowing. We determined the *C. gynandra* trait of interest, namely fresh biomass. Fresh biomass (BMF) was determined by weighing each plant in the field immediately after harvesting tender leaves and twigs.

Table 1. Accessions classification used, their morphotypes, and climatic origin.

No.	Genotype code	Morphotypes	Climate zones
1	OUA9	Green	Sudan-Sahel
2	OUA10	Green	Sudan-Sahel
3	OUA1	Green	Sudan-Sahel
4	OUA3	Green	Sudan-Sahel
5	OUA2	Green	Sudan-Sahel
6	BOB3	Green	Sudanese
7	KOU	Green	Sudan-Sahel
8	KOM1	Green	Sudan-Sahel
9	KOM2	Dark purple	Sudan-Sahel
10	OUA6	Green	Sudan-Sahel
11	GAN	Green	Sudan-Sahel
12	BOB2	Green	Sudanese
13	REO2	Light violet	Sudan-Sahel
14	MAN	Light violet	Sudan-Sahel
15	TEN	Light violet	Sudan-Sahel
16	DED2	Dark purple	Sudan-Sahel
17	ZOU	Light violet	Sudan-Sahel
18	DED3	Dark purple	Sudan-Sahel
19	OUA7	Green	Sudan-Sahel
20	GOU	Light violet	Sudan-Sahel
21	BOB4	Light violet	Sudanese
22	DED1	Dark purple	Sudan-Sahel
23	KAY2	Green	Sahelian
24	OUA5	Green	Sudan-Sahel
25	OHG	Dark purple	Sahelian
26	BOB1	Dark purple	Sudanese
27	DED4	Dark purple	Sudan-Sahel
28	FAD	Light violet	Sudan-Sahel
29	MOG	Green	Sudan-Sahel
30	BOND	Green	Sudanese
31	ZOR	Green	Sudan-Sahel
32	KOM3	Dark purple	Sudan-Sahel
33	KAY1	Light violet	Sahelian
34	REO 1	Light violet	Sudan-Sahel
35	DED5	Dark purple	Sudan-Sahel
36	BOB6	Light violet	Sudanese

Data analysis

Gen12ed software was used to perform metanalysis with the mean of fresh biomass yields to determine stability coefficients, propose AMMI and GGE biplot models.

Thus, the stability coefficient (Pi) is an estimate of the genotype's adaptability over a range of environments. According to Hannachi et al. (2019), it is calculated using the high-yielding genotype in each environment as the reference point. Genotypes with the greatest difference in yield from the reference genotype would have the highest Pi value (Lin and Binns, 1988). The most interesting genotypes would be those with the lowest Pi values, most of which would be attributed to genetic deviation (Lin and Binns, 1988).

Environments are ranked by measuring stability, which is given by the superiority of the genotype compared with the mean for each environment. This method is based on the estimation of IPCA2, which measures the probability that the performance of a given genotype is superior to the others (Vasconcelos et al., 2010). It also classifies environments according to IPCA2 as either favorable or unfavorable.

The AMMI model comprises an additive part (the mean, the effect of genotype, and the effect of environment), and a non-additive, multiplicative part (the G×E interaction). The AMMI method combines analysis of variance and principal component analysis (PCA). This model was developed by Zobel et al. (1988). First, the main effects of genotypes and environments (the additive part of the model) are estimated by an analysis of variance. Next, a PCA is performed on the non-additive part of the model, that is, the G×E interaction. As for the GGE biplot model, according to Yan et al. (2000), it essentially models the genotype effect associated with the

Table 2. Stability coefficient of 36 *Cleome gynandra* accessions evaluated.

Accessions	Pi	Accessions	Pi	Accessions	Pi
OUA10	3	OUA2	68	ZOR	89.8
OUA9	5.2	DED1	74.4	BOB6	90.6
MAN	17	OUA6	75.2	OUA5	92.8
KOU	17	BOB1	78.1	FAD	95.2
BOB3	18	REO2	79.1	KOM3	97.4
KOM2	19.1	OUA1	82.2	MOG	98.3
REO1	51.9	BOB2	84.1	KOM1	98.6
BOB4	55.9	OUA7	85.2	GAN	99.3
BOND	59.7	DED3	85.3	OHG	99.8
DED4	60.8	DED5	85.6	GOU	99.9
DED2	63.4	ZOU	85.6	KAY2	102.1
TEN	64.2	OUA3	88.2	KAY1	112.4

Pi: Stability coefficient.

G×E interaction. It was used to identify mega-environments, high-performing and stable genotypes. Statistical significance tests for the genotypic, environment and genotype × environment interaction components were calculated using Fisher's F-test.

RESULTS

Adaptability of accessions and classification of the three environments

The stability coefficients (Pi) of the 36 accessions are shown in Table 2. Accessions OUA9, OUA10, KOU, MAN, BOB3 and KOM2 had the lowest stability coefficients (Pi). On the other hand, accessions GAN, OHG, GOU, KAY2 and KAY1 with high stability coefficients are less stable.

The IPCA2 values (Table 3) show that the environments of Ouagadougou and Bobo-Dioulasso with positive IPCA2 values are favorable environments for growing *C. gynanda*. On the other hand, the Dori environment, with a negative IPCA2 value, is an unfavorable environment.

Effects of the combined analysis of variance of 36 accessions evaluated in three environments

The results of the combined analysis of variance of the 36 accessions evaluated in the three climatic zones according to the AMMI model show significant differences in yield linked to the effects of genotype, environment and genotype-environment interaction ($p < 0.001$). Of the total variation, 45.53% was explained by the environment, 30.45% by the genotype effect and 13.94% by the genotype × environment interaction. Most of the variation in the genotype × environment interaction is explained by the first two components IPCA1 (60.06%) and IPCA2 (39.74%) (Table 4). For the accession-environment interaction, the F-test is highly significant ($p < 0.001$) for the first axis IPCA1 and for the second axis IPCA2 ($p < 0.001$).

The AMMI biplot gave a model fit of 88.28% (Figure 1). Thus, the environments of the Bobo-Dioulasso and Ouagadougou sites contrast with the environment of the Dori site, and by the size of their positive scores. These environments are the most interactive. Accessions OUA2, DED2, DED4, BOB4, OUA9, OUA10, MAN, KOU BOB3 and KOM2 showed high yields and positive IPCA2 scores in the Bobo Dioulasso and Ouagadougou environments. In contrast, accessions KAY1, KAY2, GAN, GOU and OHG showed a negative IPCA2 score, with below-average yield and an IPCA1 score close to zero.

Distribution of accession effect and G×E interaction effect of 36 *C. gynandra* accessions in mega environments

The GGE biplot is presented with two principal components explaining a total of 88.28% of the GGE variation (PC1 69.97%, PC2 18.31%) (Figure 2). The first principal component is represented on the x-axis, and opposite its value is the estimated yield, that is, accessions with higher PC1 values are considered more productive. The second principal component is represented on the y-axis and shows the stability of the accessions. Thus, the Dori and Ouagadougou environments are located on the plane: they constitute a mega-environment. The Bobo-Dioulasso environment, located within the circle, is a mega-environment in its own right. The mega-environment is the most discriminating for the accessions, as indicated by the longest distance between their positions and the point of origin.

Accessions OUA3 and OUA2, positioned at the top of

Table 3. Environment classification.

Environment	Average leaf biomass yield	IPCA2	Class
Bobo Dioulasso	68.32	2.85	Favorable
Dori	26.43	-7.08	Unfavorable
Ouagadougou	72.99	4.23	Favorable

ICPA2= Second principal component of the interaction.

Table 4. Combined analysis of variance in fresh biomass yield of 36 *Cleome gynandra* accessions evaluated in the three environments.

Source of variation	ddl	SC	CM	F_test	Variation explained	G×E
Treatments	107	280429	2621	23.29**		
Accessions	35	94959	2713	24.11**	30.45	
Environments	2	141994	70997	54.43**	45.53	
Blocks	6	7827	1304	11.59**		
Interactions	70	43476	621	5.52**	13.94	
IPCA1	36	26113	725	6.45**		60.06
IPCA2	34	17363	511	4.54**		39.94
Residual	0	0				
Error	210	23634	113			
Total	323	311889	966			

Ddl: Degree of freedom; SC, sum of squares; CM, mean square; ICPA1= first principal component of the interaction and ICPA2= second principal component of the interaction; **highly significant. G×E: genotype-environment interaction.

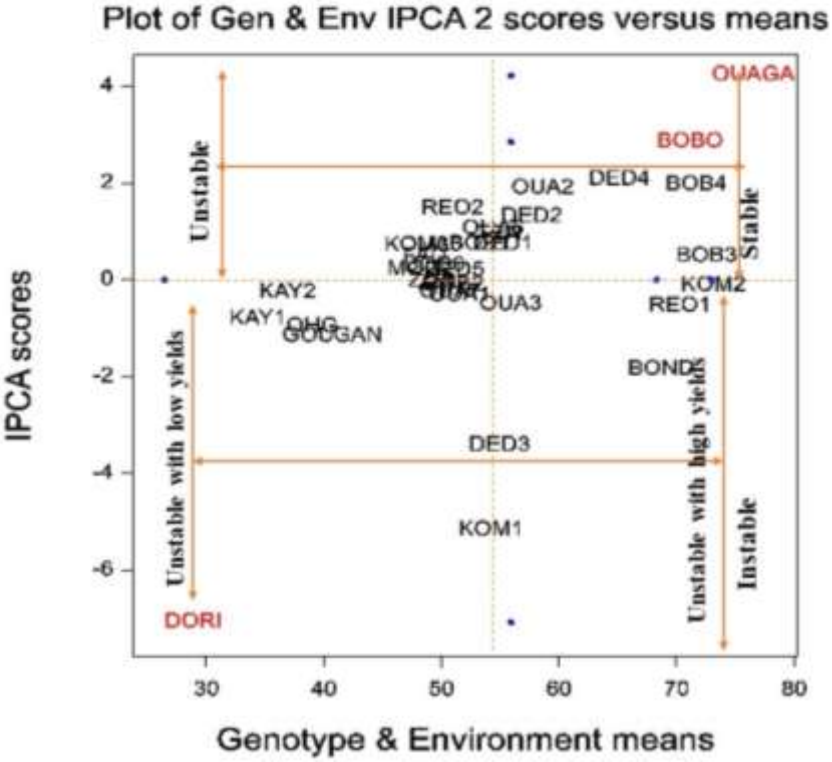

Figure 1. Distribution of the 36 accessions according to the three environments and their IPCA2 genotypic and environmental scores.

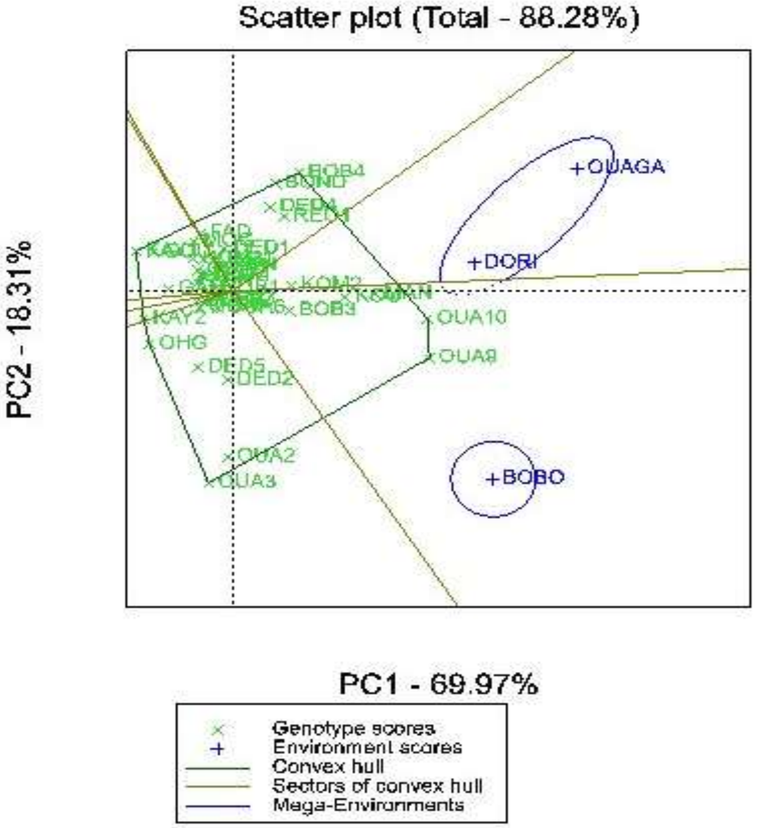

Figure 2. Polygonal view of the GGE (Genotype and genotype-environment interaction) biplot showing the effect of genotype and the effect of GxE interactions of 36 *Cleome gynandra* accessions in three environments.

the polygon and close to the Bobo Dioulasso environment, perform well in this environment. On the other hand, accessions BOB4, BOND, OUA9 and OUA10 positioned at the top of the polygon and in the mega-environment (Ouagadougou-Dori) perform well in this mega-environment. Accessions KOM2, BOB3, KOU, MAN, OUA9 and OUA10 are close to both mega-environments. On the other hand, accessions KAY2, OHG, GOU, GAN and KAY1 are different from the other genotypes in the biplot, due to their positions away from the center and on the left-hand side. They are also unstable and have low yields.

Identification of "ideal accessions" for all three sites

The results of the biplot comparison of accessions in Figure 3 showed that accessions KOU, MAN, BOB3, KOM2 and OUA1, followed by OUA9 and OUA10, which are very close to the AEC center of the concentric circles. They showed the best performance in terms of fresh biomass yield. The other accessions, namely KAY2, OHG, GOU and GAN, are far from the AEC center of the GGE biplot circle. In fact, these accessions performed poorly agronomically, making them undesirable.

DISCUSSION

The AMMI and GGE biplot models revealed significant effects for environment, genotypes and genotype-environment interaction based on leaf biomass yield. This confirms phenotypic diversity among the accessions evaluated, and that these accessions respond differently to environments. The first principal component (IPCA1) of the AMMI model, explained 60.06% of the sum of squared deviations of the interaction. The residual of the model is not significantly different from the weighted error. These results indicated that genotype and site scores on the first principal component of the interaction (IPCA1) explain more than half of the interaction present in the matrix of leaf biomass yield data submitted for analysis. The AMMI biplot of IPCA1, and average genotype and site effects show how each genotype shapes its yield (additive effect only or additive+ multiplicative), and which locality is the best suited.

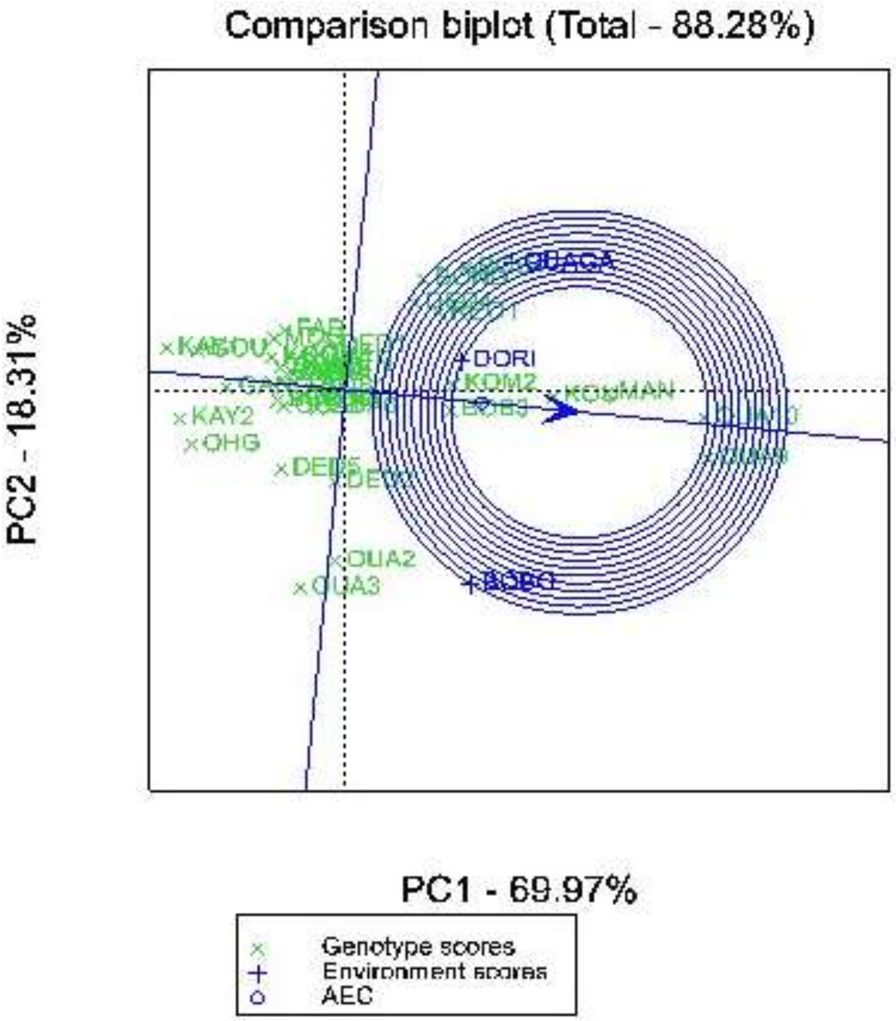

Figure 3. Comparison biplot showing the two main axes of interaction (IPCA2 vs IPCA1) of 36 accessions evaluated in three climatic zones of Burkina Faso for "ideal accessions".

According to Zobel et al. (1988), genotypes with high positive or negative scores show strong interactions. They are specifically adapted to the environment with the score of the same sign. Thus, the AMMI analysis indicated that accessions OUA2, DED4, BOB4 and DED2 were productive; while OUA9, OUA10, BOB3, KOU, MAN and KOM2 were stable in the environments tested. Furthermore, these accessions, with their lower superiority indices and positions close to the origin of the biplot, show a general adaptation to all localities. According to Lin and Binns (1988), the most interesting genotypes would be those with the lowest Pi values, most of which would be attributed to genetic distance. Furthermore, Mohammadi and Amri (2008), in a study of genotype × environment interaction in durum wheat, revealed that genotypes far from the biplot center have a high G × E interaction, while those closer to the biplot center are more stable.

The AMMI graph shows that Ouagadougou and Bobo Dioulasso, with their high scores, better discriminate between the performances of the different accessions evaluated and are a significant source of contribution to the interaction. The Dori site, on the other hand, contributes significantly less to the interaction. The GGE biplot model showed that accessions with PC1 values close to zero show greater adaptability, and genotypes with higher PC1 values are better suited to sites with PC1 values of the same sign. Thus, accessions BOB4, BOND, DED4 and DED1 are more productive in the Ouagadougou and Dori environments; while accessions OUA3 and OUA2 are productive in the Bobo Dioulasso environment. According to Mitrovic et al. (2012), performance assessment of individual genotypes can be based on their position relative to the X (high yield of accessions) and Y (stability of accessions) axes. In this case, the best accessions (OUA9, OUA10, MAN, KOU, KOM2 and BOB3) are considered those with high yield and stable performance, in all three climatic zones. Thus, they could be used in a research program for high-yielding varieties for extension in Burkina Faso's three climatic zones. Indeed, one of the major factors in the adoption of interesting varieties is superior agronomic performance (Vom Brocke et al., 2010). High yields of fresh biomass are an added value for food and nutritional security, and for market gardeners' incomes. Two mega-environments have emerged, the Bobo-Dioulasso mega-environment and the Ouagadougou-Dori mega-environment. According to Kendall et al. (2019), for studies conducted in different environments, if there is no difference between two or more environments, they are in the same circle and referred to as a mega-environment. It is then recommended to work in one of these environmental groups in subsequent studies. In this case, for future studies on *C. gynandra,* the Dori and the Ouagadougou sites constitute a single environment.

Conclusion

The AMMI biplot and GGE biplot offered three possible alternatives for the breeder. The first is to adopt stable, high-performance accessions such as OUA10, OUA9, MAN, KOM2, KOU, and BOB3. The second alternative is to use the interaction positively, through the choice of accessions. The third alternative is to assign a specific genotype to each site. Under this scenario, we select accessions OUA9, OUA10, BOB4, MAN, DED4, KOU, REO1, BOND, KOM2, and BOB3 for the Ouagadougou site, and accessions OUA9, OUA10, OUA2, OUA3, MAN, KOU, DED2, BOB3, KOM2 and DED5 for the Bobo Dioulasso site, and accessions OUA10, MAN, KOU, KOM1, OUA9, BOND, DED3, REO1, KOM2 and BOB3 for the Dori site. The best accessions identified for each climatic zone and for all three climatic zones could be used to develop high-performance of *C. gynandra* varieties in Burkina Faso.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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