

Genotype-environment interaction of sesame (*Sesamum indicum* L.) accessions in three locations in Côte d'Ivoire

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ABSTRACT

Genotype x environment interaction is a key factor in the selection of stable and high-performing accessions. The objective of this study is to determine the adaptability of high-performing sesame accessions in three locations in Côte d'Ivoire. Twenty-two sesame accessions were studied in Korhogo, Diawala, and Touba in 2022 and 2023, in a randomized complete block design with one factor (accessions) and four replicates. A combined AMMI (additive main effects and multiplicative interaction) analysis of variance was performed to evaluate the effect of genotypes, environments, and interaction. GGE-biplot (Genotype+ Genotype x Environment) methods were used to analyze the stability and performance of the accessions. The results showed that all the parameters studied were significantly influenced ($P<0.001$) by the environment, genotype, and their interaction. The genotype factor explained a small part of the variation compared to the environment and interaction. The latter indicated a differentiated response of the accessions depending on the environment. Analysis of the genotype-environment interaction revealed that accession A15 stood out for its stability and good performance in all environments, making it the best performer. Furthermore, the Diawala locality proved to be the most representative and discriminating, indicating that it is the most suitable area for sesame cultivation in the context of our study. The results obtained provide useful information for the development of future sesame improvement programs in Côte d'Ivoire. Accession A15 could thus be recommended to producers to improve sesame productivity and increase their incomes.

Keywords: Stability, sesame accessions, genotype x environment interaction, AMMI, GGE

Introduction

Sesame (*Sesamum indicum* L.) is an oilseed crop of great socio-economic importance in several regions of West Africa. Highly prized for its seeds rich in oil and bioactive compounds, it is a significant source of income for rural farmers and contributes to food security [1]. In addition to its nutritional qualities, sesame has several agronomic advantages. It has a deep root system that allows it to extract moisture from the lower layers of the soil, making it relatively drought tolerant. Furthermore, it integrates easily into crop rotation systems and can be grown as a monoculture or in association with other crops [2].

Given these many advantages, sesame cultivation has spread widely throughout the world. Between 2008 and 2017, global production increased significantly, from 5,015,600 tons to 6,314,700 tons [3]. Similarly, in Africa, production rose from 1,332,369 tons in 2009 to 3,998,148 tons in 2019, an increase of more than 50% in a decade [4].

In Côte d'Ivoire, although sesame is traditionally grown in the north and northwest, its production remains marginal and undervalued. Several constraints hinder its development, including the lack of improved seeds and, above all, the fact that the varieties grown are not well adapted to local conditions. High climate variability, soil diversity, and the specific growing conditions of each region have a significant impact on the agronomic performance of sesame [5,6].

In this context, it seems essential to identify sesame genotypes that are both productive and stable, capable of adapting to various environments. However, yield and other quantitative agronomic traits are strongly influenced by environmental factors. As a result, intensifying sesame production requires a better understanding of the genotype x environment (GxE) interaction. However, the analysis of agronomic performance is often limited to the main effect of the genotype (G), which is not sufficient to predict its behavior in variable environments [7]. Thus, the variation in yield observed between accessions grown under similar or different conditions is mainly due to genotype x environment (GxE) interaction [8]. Consequently, in order to effectively select genotypes adapted to a given environment, it is essential to conduct multi-environment trials (MET). These trials not only allow the performance of accessions to be evaluated in different locations and years, but also enable their yield and stability to be predicted under targeted conditions [9]. However, the data from these trials are rarely exploited to their full potential. Therefore, analyzing the extent of GxE interaction becomes fundamental to exploiting the adaptability opportunities of genotypes. Several statistical methods have been developed for this purpose, including AMMI (Additive Main effects and Multiplicative Interaction) and GGE biplot (Genotype plus Genotype x Environment interaction) models. These two approaches, which are both complementary and widely used, have been implemented by various authors to analyze data from multi-location trials [10].

In particular, the AMMI model combines additive effects (ANOVA) and multiplicative effects (PCA), while the more recent GGE biplot model simultaneously highlights the performance and stability of genotypes, while identifying the optimal environments for each accession [11,12]. With this in mind, the present study aims to evaluate the adaptability of several sesame accessions in three distinct agro-climatic locations in Côte d'Ivoire. Specifically, it aims to characterize mega-environments, identify the most productive and stable accessions in different environments, evaluate accessions based on the ideal genotype from one environment to another, and evaluate environments based on the ideal environment.

I. Materials and methods

1.1. Description of study areas

The trials were conducted in rural areas in three locations in Côte d'Ivoire, namely Touba, Ouangolodougou (Diawala) and Korhogo, during two consecutive rainy seasons (2022 and 2023). These localities are located respectively in the sub-humid zone in the west of the country, in the dry zone in the far north of Côte d'Ivoire, and in the sub-dry zone in the north-central region [13] (Figure 1). The geographical coordinates were recorded using GPS, while the climate data (precipitation and temperatures), available online on the METDATA platform, were downloaded from the Historical Climate (Monthly) website [14]. These areas are characterized by alternating rainy (May to October) and dry (November to April) seasons with tropical ferruginous, silty, ferruginous alteral, ferralitic, and sandy soils [15]. In Diawala, maximum temperatures reach 33.9°C with minimum temperatures ranging from 21 to 22°C. Annual rainfall was 1,271.7 mm in 2022 and 880.7 mm in 2023. In Korhogo, temperatures are comparable to those in Diawala. Rainfall was 1,249 mm in 2022 and 926.9 mm in 2023. In Touba, rainfall is higher, with 1,412.5 mm in 2022 and 1,027 mm in 2023. Temperatures there are slightly more moderate [14].

1.2. Plant material

The plant material used consisted of twenty-two (22) accessions of sesame (*Sesamum indicum* L.), five (5) of which came from Senegal and seventeen (17) were collected in Côte d'Ivoire.

1.3. Experimental design and treatments studied

The same seed source was used for all experiments. In each of the three locations, sowing was carried out in a randomized complete block design with one factor and four (4) replicates (blocks). The blocks were spaced by 1.5-meter (1.5 m) aisles. Each block consisted of twenty-two (22) elementary plots, separated from each other by one meter (1 m). Each elementary plot consisted of four rows of seedlings, each with five holes, with a spacing of 0.3 m between the rows of seedlings and 0.75 m between the holes in the row (i.e., a size of 3 m x 0.9 m = 2.7 m²). This experimental setup comprised a total of eighty-eight (88) elementary plots and measured 40.8 meters in length and 16.5 meters in width, for a total area of 673.2 m². The factor studied was accession at 22 levels.

1.4. Conduct of the trial

Plowing followed by leveling and staking was carried out a few days before the various sowings. Thinning to two plants per hole was carried out approximately 21 days after sowing (jas), followed by transplanting the thinned plants into the missing holes. Fertilization was carried out in two applications as recommended by Djima [16]. The first application was NPK (15 N-15 P-15 K) at a dose of 1.5 g/hole, or 30 g/plot on the day of thinning. The second application was urea at a dose of 0.75 g/hole, or 15 g/plot, three weeks after the first application. Insecticide treatment was carried out during periods of heavy flowering (the period most susceptible to pests) with contact insecticides in the three study locations (Sauveur 62 EC for the Korhogo location, Kapaas 80 EC for the Diawala location, and Pichen 672 EC for the Touba location).

1.5. Observations and measurements

These concerned a set of parameters related to phenology (50% flowering, maturity), plant morphology (plant height, number of branches per plant, height of 1st capsule insertion, number of capsules per plant), yield, and its components (capsule width, capsule length, number of seeds per locule, number of seeds per capsule and thousand-seed weight). These parameters were measured according to the recommendations of the sesame descriptors [17]. Phenological observations were made daily on all plants in each elementary plot. For each plot, each stage was considered effective when 50% of the plants had reached it. At maturity, the agro-morphological parameters were measured from the plants of four holes per elementary plot. At harvest, yield was determined in a yield square measuring 1.35 m² (0.6 m x 2.25 m), representing six (6) plots per elementary plot. Located in the center of each elementary plot, this yield square was thus composed of three (3) rows of two (2) plots. Yield was calculated using the ratio of dry grain weight per yield square to the yield square area.

$$Yield \left(\frac{kg}{ha} \right) = \left(\frac{PSG}{S} \right) \times 10$$

Where: PSG: Dry weight of seeds in grams (g), S: Area of the yield square in square meters (m²), 10: The factor 10 converts g/m² to kg/ha.

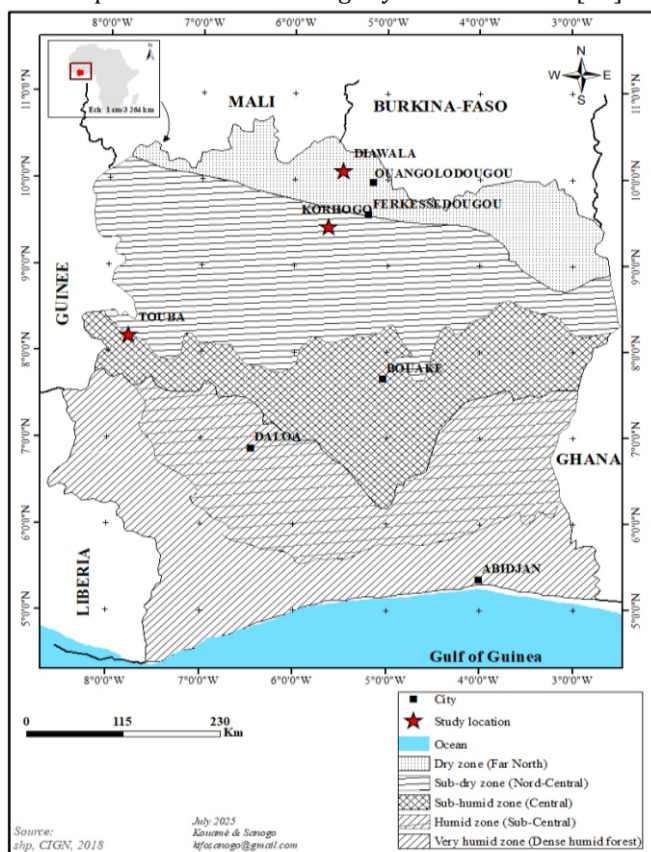


Figure 1 : Map of the study sites

1.6. Statistical analysis

In order to evaluate the interaction between genotype and environment (G×E) and their respective effects on the agronomic performance of sesame accessions, several statistical analyses were conducted. An analysis of variance (ANOVA) was first performed separately for each environment to evaluate the main effect of genotypes. Subsequently, a joint ANOVA was used to simultaneously analyze the effects of genotypes, environments, and their interactions on morpho-phenological traits. To explore the G×E interaction in depth, the AMMI (Additive Main Effects and Multiplicative Interaction) model was applied to grain yield data using the AMMI function of the Agricolae software package. The AMMI model was formulated according to the method described by Gauch [18]. The stability of sesame accessions was assessed using the percentage of ecovalence stability according to the model developed by Wricke [19]. The most favorable environments were identified using the environmental index model proposed by Annicchiarico [20]. GGE biplot analysis was then used to visualize and interpret the G×E interaction through three

essential representations: (1) the discriminatory power and representativeness of the tested environments, (2) the GGE “who wins where” pattern, (3) the ranking of the tested genotypes across all environments and the ranking of the tested environments [7]. All statistical analyses were performed using R software, based on the Agricolae and metan packages [21].

II. Results and discussion

2.1. Results

2.1.1. Analysis of variance of the effect of environments on morpho-phenological parameters

The combined analysis of variance of the morpho-phenological parameters of the sesame accessions evaluated in the different environments is presented in Table 1.

The results reveal a highly significant effect ($p < 0.001$) of environments (E), genotypes (G), and their interaction (G×E) on all traits. These results indicate that the environments tested differ significantly from one another and that accessions do not perform equally well in all environments.

Table 1: Mean squares of morpho-phenological parameters of sesame accessions evaluated in six environments

Source of variation	Environment (E)	Rep (E)	Genotype (G)	Interaction (G×E)
Degree of freedom	5	18	21	105
%CTV	53.579	4.867	5.512	20.371
50% Flowering	3345.2***	16.7***	3360.5***	231.4***
Maturity	6084.7***	0.0 ns	3656.9***	642.3***
Plant height	72345***	926***	14353***	1699***
Number of branches per plant	1812.89***	40.73***	993.92***	134.80***
Height of 1st capsule insertion	23513.2***	174.3*	15007.2***	832.3***
Number of capsules per plant	89264***	3318***	3519***	3065***
Capsule length	3.4351***	0.0234***	1.3040***	0.5152 ***
Capsule width	0.089685***	0.000582***	0.022157***	0.020848***
Number of seeds per locule	228.019***	0.915 ns	18.842***	14.685***
Number of seeds per capsule	3648.3***	14.6 ns	301.5***	235.0***
Thousand-seed weight	3.06314***	0.02237	2.91537***	0.86248***
Yield	15606309 ***	393757***	382268***	282553***

*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, ns: not significant. %CTV: percentage contribution to total variation, Rep: replication

2.1.2. Characterization of mega-environments and high-performing accessions

2.1.2.1. AMMI analysis of yield

The AMMI analysis of variance applied to the grain yield of the 22 sesame accessions is presented in Table 2. The results revealed that all sources of variation (genotypes, environments, and interaction) are highly significant ($P < 0.001$). The environment contributed the largest share of the total variation with 53.579% of the sum of squares, followed by the genotype x environment interaction (20.371%) and genotypes (5.512%). Furthermore, the effect of the IGE was broken down into two significant principal interaction component axes (IPCA). PCIA1 alone explained 55.2% of the total variation due to interaction, while PCIA2 accounted for only 21.7%.

Table 2: Analysis of variance of additive main effects and multiplicative interactions for grain yield of the 22 sesame accessions

Source of variation	DF	S.S	M.S	Contribution to the sum of squares (%)	P (>F)
ENV	5	78031543	15606309	53.579	4.2233e-09 ***
REP(ENV)	18	7087623	393757	4.867	0.0000***
GEN	21	8027623	382268	5.512	0.0000 ***
ENV: GEN	105	29668051	282553	20.371	0.0000***
IPCA1	25	16390373	655614.92	55.2	0.0000***
IPCA2	23	6431231	279618.74	21.7	0.0000***
RESIDUALS	378	22823969	60381	15.672	-

*** Significant difference at $P < 0.001$

ENV: environment, REP: replication, GEN: genotypes/accessions, IPCA: interaction principal component analysis, DF: degree of freedom, SS: sum of squares, MS: mean square.

2.1.2.2. GGE—biplot analysis of grain yield response and stability: Who won where ?

The polygons representing the best accessions for each environment are shown in Figure 2. These polygons are formed by connecting the accessions furthest from the center of the biplot, so that the other accessions are contained within them. The polygon is divided into several sectors by lines perpendicular to its sides. The accession at the top of each sector corresponds to the accession with the best yield in the environments included in that specific sector. Based on yields, the six (6) environments were grouped into three (3) mega-environments. The first mega-environment includes Diawala_1 with A15 as the best-performing accession, the second mega-environment includes Korhogo_2, Diawala_2, and Touba_1 with A7 and A9 as the winning accessions, and the third mega-environment contains Korhogo_1 and Touba_2 with A17 and A22 as the most productive accessions.

No environment was found in the sectors with vertices A1 and A2, suggesting that these accessions are not the best in any of the tested environments. Accessions A3, A6, A5, A20, A4, A14, A9, A8, A10, A13, A16, A19, A11, A18, and A21, located within the polygon, showed less responsive behavior, indicating that these accessions have variable yields from one environment to another (Figure 2A).

Two main mega-environments were identified based on the average data from the two years. The first mega-environment included Diawala and Touba with A15 as the winning accession, and the second included Korhogo, where A7 showed specific adaptability (Figure 2B).

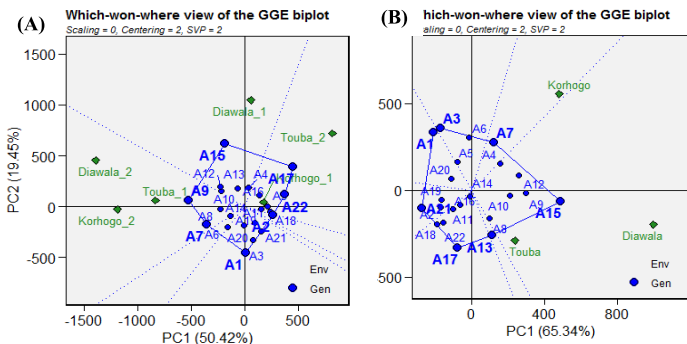


Figure 2: Which-won-where model of accession performance based on six environments (A) and two-year average data (B)

2.1.3. Identification of the most productive and stable accessions in different environments: Average vs. stability

The average performance and stability results for the six (6) environments were presented graphically using the GGE biplot model (Figure 3A) and recorded in Table 3. In the Medium vs. Stability bipot, the single arrowed line represents the medium-environment coordination axis (or AEA), which indicates the Highest average yield across all environments. With regard to stability, the markers closest to the axis indicate the most stable accessions. Table 3 presents the stability results of the accessions in the form of ecovalence percentages. An accession with an ecovalence percentage of zero or less than 1 is considered stable. In this study, the accessions were classified according to the mean tester axis (ATC abscissa). Thus, accession A15 had the highest average yield (1125.1818 kg/ha), followed by A9, A12, A10, A4, A7, A13, A8, and A14 with average yields ranging from 752.1337 to 987.5082 kg/ha. In contrast, accessions A6, A16, A5, A20, A16, A11, A17, A19, A2, A22, A18, A3, A1, and A21 had the lowest average yields (from 599.8650 to 743.5381 kg/ha).

Among the accessions with the highest yields, A15, A4, A13, A12, and A10 were the most stable in all six environments. Among the low-yielding accessions, the most stable were A20, A19, A3, A21, and A11 (Figure 3A). Based on the averages (2022 and 2023), accessions A15, A9, A4, A12, and A10 stand out for their stability and high yield, while accessions A11, A14, A16, A19, and A20 appear to be stable but low-yielding, as shown in Table 4 and Figure 3B.

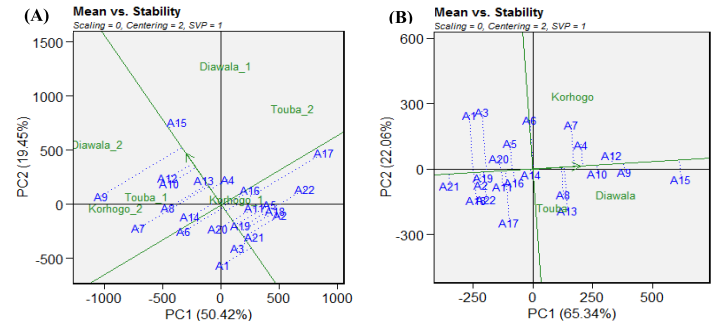


Figure 3: Biplot of mean and stability for grain yield based on six environments (A) and two-year average data (B)

Table 3: Sesame grain yield and stability parameters of accessions tested using the percentage of ecovalence stability

Accessions	Yield (kg/ha)	% Stability (Ecov_perc)	Rank	Interpretations
A17	743.5381	14.632	22	Unstable
A22	693.4228	9.280	20	Unstable
A18	599.8650	2.655	12	Unstable
A12	901.3529	0.791	8	Stable
A16	739.0051	3.585	14	Unstable
A4	882.5432	0.690	7	Stable
A6	753.7849	3.289	13	Unstable
A13	802.0453	0.647	6	Stable
A5	723.4887	6.359	17	Unstable
A21	652.9846	0.967	10	Stable
A10	896.6481	0.587	5	Stable
A15	1125.1818	0.339	3	Stable
A14	775.6955	2.386	11	Unstable
A8	779.7822	5.760	16	Unstable
A20	694.7788	0.111	1	Stable
A11	698.3405	0.506	4	Stable
A1	644.3987	6.485	18	Unstable
A3	685.4527	0.885	9	Stable
A19	695.4637	0.269	2	Stable
A2	668.2356	5.539	15	Unstable
A7	879.2243	6.881	19	Unstable
A9	987.5082	11.465	21	Unstable

Table 4: Sesame grain yield and stability parameters of the accessions tested based on the average data for the two years using the percentage of ecovalence stability

Accessions	Yield (kg/ha)	% Stability (Ecov_perc)	Rank	Interpretations
A1	644.3987	8.752	20	Unstable
A10	896.6481	0.880	8	Stable
A11	698.3405	0.654	3	Stable
A12	901.3529	0.975	10	Stable
A13	802.0453	8.144	18	Unstable
A14	775.6955	0.117	1	Stable
A15	1125.1818	0.850	7	Stable
A16	739.0051	0.704	4	Stable
A17	743.5381	8.300	19	Unstable
A18	599.8650	1.986	12	Unstable
A19	695.4637	0.903	9	Stable
A2	668.2356	2.010	13	Unstable
A20	694.7788	0.468	2	Stable
A21	652.9846	12.813	22	Unstable
A22	693.4228	4.714	15	Unstable
A3	685.4527	10.013	21	Unstable
A4	882.5432	0.811	6	Stable
A5	723.4887	1.762	11	Unstable
A6	753.7849	6.042	16	Unstable
A7	879.2243	4.027	14	Unstable
A8	779.7822	7.675	17	Unstable
A9	987.5082	0.734	5	Stable

2.1.4. Evaluation of accessions based on the ideal accession from one environment to another

The GGE biplot graph shown in Figure 4 highlights the ideal accessions selected for extension. An ideal accession is one located in the first concentric circle, or close to the first concentric circle, in the biplot. It is characterized by a high average grain yield and good stability across different environments. Accessions considered desirable are those that are close to the ideal accession and also have a satisfactory yield. Conversely, accessions far from the ideal accession are unstable and unproductive. In this study, the biplot reveals that accession A15 represents the ideal accession in all tested environments, as evidenced by its position in the concentric circle. Accessions A12, A10, and A13, which are closest to it, are thus classified as desirable accessions. On the other hand, accessions A8, A7, A14, A6, A5, A20, A16, A11, A17, A19, A2, A22, A21, A18, A1, A3, A9, and A4, which are further from the center, are considered undesirable due to their poor performance and instability (Figure 4A). Based on the average data, A15 remains the ideal accession. The desirable accessions are A12, A10, A9, A4, A7, A13, and A8. The other accessions (A14, A6, A5, A20, A16, A11, A17, A19, A2, A22, A21, A18, A1, A3) are considered undesirable due to their positions relative to the concentric circle (Figure 4B).

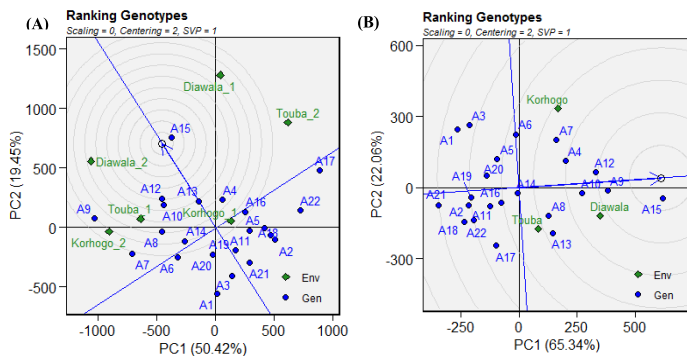


Figure 4: GGE biplot showing ideal accession based on six environments (A) and average data over two years (B)

Discriminating power and representativeness

From the point of view of discriminating power versus representativeness, the environments tested can be classified into three types. The main discriminating and representative parameters are determined by the length of the vector representing each environment and by the angle formed between this vector and the axis of the environments' mean coordinates (AEC).

The environments with short vectors and large angles to the AEC axis are classified as type I. These environments provide little useful information on the differences between accessions and are therefore not suitable for their evaluation. Type II environments, on the other hand, are characterized by long vectors and low angles to the AEC axis. They are therefore suitable for identifying accessions that are both stable and high-yielding. Type III environments feature long vectors but with large angles to the AEC axis. Like those of type I, they are not very effective for genotype evaluation. For example, the Diawala_2 environment has a long vector and a slightly smaller angle to the AEC axis than the other environments. It was therefore classified as a type II environment. Type I environments include Touba_1 and Korhogo_1. The environments Touba_2 and Korhogo_2 were grouped as type III (Figure 5A). In addition, on the basis of average data, Diawala showed good discrimination potential as well as good representational ability (Figure 5B).

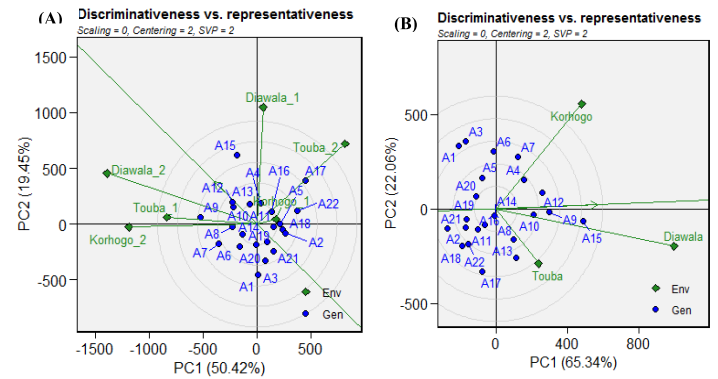


Figure 5: Biplot of discriminating power and representativeness based on six environments (A) and two-year average data (B)

2.1.5. Evaluation of environments based on the ideal environment

Figure 6 illustrates the GGE biplot centered on the ideal environment. An environment is considered ideal when it lies on or near the first concentric circle of the biplot. This environment is both representative and has the highest discriminating power.

According to the GGE biplot analysis, the Diawala_2 environment stands out as the ideal environment among the six tested. The Korhogo_2, Touba_1 and Diawala_1 environments, close to this ideal point, can also be qualified as desirable environments. On the other hand, Korhogo_1 and Touba_2, which deviate significantly from this ideal, are considered the least suitable environments (Figure 6A).

Analysis of the averages for the two years identifies the Diawala environment as the ideal environment compared with the other environments (Figure 6B). The results in Tables 5 and 6 also confirm this observation.

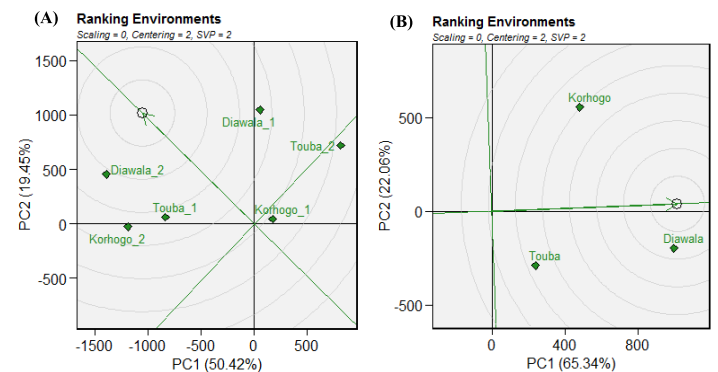


Figure 6: GGE biplot showing the ideal environment based on six environments (A) and two-year average data (B)

Table 5: Identification of the most favorable environments according to the environmental index model for the six environments

environments	Yields	Index	Class
Diawala_1	1337	563	Favorable
Diawala_2	1223	449	Favorable
Korhogo_1	326	-451	Unfavorable
Korhogo_2	746	-29.9	Unfavorable
Touba_1	402	-371	Unfavorable
Touba_2	612	-160	Unfavorable

Table 6: Identification of the most favorable environments according to the environmental index model for the average of the two years

Environments	Yields	Index	Class
Diawala	1280	505	Favorable
Korhogo	536	-238	Unfavorable
Touba	507	-267	Unfavorable

Discussion

Genotype x environment interactions refer to the way in which the effects of genes on an organism vary according to the environmental conditions in which it develops [22]. In this study, the assessment of genotype x environment interaction consisted firstly of combined analysis of variance (ANOVA). Combined ANOVA using the AMMI model revealed that the effects of genotypes, environments and their interaction ($G \times E$) were highly significant for all the traits studied. This result indicates that the performance of sesame accessions varies not only according to their genetic potential, but also according to site-specific environmental conditions such as soil type, rainfall and climate. In particular, the presence of a significant interaction between genotypes and environments suggests that certain accessions react differently depending on the environment in which they are grown. In other words, an accession that performs well in one environment may not do so in another. This finding corroborates the results of [23], who also highlighted a strong $G \times E$ interaction in sesame. Similarly, [24] reported similar behavior in relation to several agronomic traits.

In addition, AMMI analysis was used to decompose the sum of squares of the $G \times E$ interaction into two principal interaction components (IPCA), both of which are significant. The results show that the first axis (IPCA1) explains 55.2% of the interaction variance, while the second (IPCA2) explains 21.7%, for a cumulative total of 76.9%. According to [25], quoted by [23], these first two axes are generally sufficient to predict genotype performance in different environments.

Next, GGE biplot analysis was used to structure the six experimental sites into three distinct mega-environments. This structuring is essential for optimizing varietal selection, as it identifies areas where genotypes show a certain stability [7]. The grouping of sites reflects the existence of distinct agroecological units, influencing yield expression [26,27]. Thus, the first mega-environment, comprising Diawala_1, highlighted accession A15 as the best-performing, illustrating specific adaptation. The second mega-environment, comprising Korhogo_2, Diawala_2 and Touba_1, highlighted accessions A7 and A9, while the third, consisting of Korhogo_1 and Touba_2, revealed the performance of A17 and A22. This variability confirms that the $G \times E$ interaction significantly influences genotype performance depending on the environment [28,29]. In contrast, no environment was positioned in sectors dominated by A1 and A2, suggesting a low competitiveness or lack of adaptation of these accessions. This phenomenon was also observed by [30,31] in their work on AMMI and GGE models, where certain genotypes are systematically dominated. As for accessions located in the center of the biplot, such as A3, A6, A5, A20, A14, A9, A10, A13, A16, A19, A11, A18 and A21, they showed relative stability, but with average yields. According to [28], these accessions can be useful in marginal or unstable areas, although they are less suited to favorable environments where high yields are desired.

Furthermore, taking into account the average data over two years, two main mega-environments have been confirmed. One is Diawala and Touba, where A15 continues to perform well, and the other is Korhogo, dominated by A7. This inter-annual continuity reflects the consistency of $G \times E$ interactions over time, an essential criterion for selecting stable varieties [32,33]. Thus, these results reinforce the value of detecting mega-environments to guide varietal selection according to specific local conditions.

In terms of gross performance, several accessions such as A15, A9, A12, A10, A4, A7, A13, A8 and A14 showed high yields, reflecting good adaptation to different environments. For example, A15 produced an average of 1125 kg/ha, ranking it among the most promising accessions. Conversely, accessions such as A6, A16, A5, A20, A16, A11, A17, A19, A2, A22, A18, A3 and A1 produced yields generally below 750 kg/ha, probably due to their environmental sensitivity. This difference in behavior between accessions in different localities shows the effect of the interaction between genotype and environment.

[30] have clearly shown that neglecting this interaction can lead to selection errors. Indeed, [34] confirm that the AMMI and GGE models are relevant for identifying stable, high-performing accessions in several environments. They show that accessions such as A15, A12, A10, A4, A13 and A9 maintain high and stable performance, even under variable conditions, which is essential in a context of climate change. This is in line with [35], who state that for rainfed crops, it is necessary to choose varieties that are both productive and stable.

Other accessions such as A20, A19, A3, A21, A11, A14 and A16, despite their lower yields, show good stability, which can be an advantage in constrained areas (poor soils, drought, etc.). [36] notes that these accessions could serve as a genetic base for improving resilience. These observations are in line with the recent results of [37] in India and [38] in Ethiopia, who have also shown that certain sesame varieties maintain their performance in contrasting environments.

GGE biplot analysis also identified A15 as the ideal accession, thanks to its stability and high yield, in line with the findings of [28]. Other accessions such as A12, A10, A13, A9, A4, A7 and A8 are also close to this ideal profile [26,35]. Conversely, accessions A14, A6, A5, A20, A16, A11, A17, A19, A2, A22, A21, A18, A1 and A3 are less stable and less productive, limiting their use on a large scale. However, in specific contexts where stability is a priority, they may be of interest [36].

Regarding the evaluation of environments, the GGE biplot analysis designated Diawala_2 as the ideal environment among the six tested. According to [7], an ideal environment is characterized by a high discrimination capacity (long vector) and good representativeness (proximity to the AEC axis), both of which are present in Diawala_2. This makes it a prime environment for selecting stable, high-performance accessions. In addition, Korhogo_2, Touba_1 and Diawala_1, although slightly distant from the ideal point, present acceptable representativeness, justifying their use as complementary environments. On the other hand, Korhogo_1 and Touba_2, which are further away, appear less suitable, due to their low discriminating power [39,30]. In short, the combination of AMMI analysis and GGE biplot provides a better understanding of the $G \times E$ interaction, favoring targeted selection of accessions according to environments. The regular positioning of accession A15 in high-performance environments, notably Diawala, confirms its inter-annual adaptability, making it particularly useful for large-scale breeding programs [40,41].

Conclusion

In the present study, the combined ANOVA showed that the performance of sesame accessions as a function of traits of interest differed according to environment. On the basis of interaction, accessions behaved differently concerning all the traits studied, and the environment had an effect on these traits. Genotype represented the smallest case of variation, while environment and IGE explained most of the variation.

Based on yield, the AMMI and GGE models enabled the six (6) environments to be grouped into three (3) mega-environments. These models indicated that accessions A15, A9, A4, A12, A10, A14, A16, A11, A19 and A20 are the most stable. Therefore, these accessions can be considered as the superior accessions for future studies. In addition, these accessions can also be used as suitable parental lines in future sesame breeding programs. According to these models, A15 is the highest-yielding accession and the most ideal in all the environments tested. A12, A10, A13, A9, A4, A7 and A8 being close to this ideal profile could be prime candidates for selection. Diawala was identified as the ideal type II environment. This locality can be considered an ideal location for various breeding activities, such as a multiplication site, an ideal target environment for testing new varieties to obtain their full yield potential.

Declarations

Conflict of interest

The authors declare that there are no conflicts of interest.

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