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# Genotype × environment interaction on tuber yield of Tiger Nut (*Cyperus esculentus* L.) grown in West Africa

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**ABSTRACT:** The performance of most crop genotypes is strongly influenced by genotype-environment interactions. Thus, finding good-performing and adapted nutsedge genotypes is necessary for growers to improve their productivity. Consequently, the aim of this study is to understand the effect of genotype x environment interaction (GEI) on tuber yield and to select high-yielding genotypes specifically or broadly adapted to production. 36 genotypes were evaluated in three environments, following an alpha lattice design of 18 genotypes × 2 blocks in four replications. The combined AMMI analysis of variance indicated that the main effects due to environments, genotypes and genotype x environment interaction were significant. The contribution of environment (E), genotype (G) and genotype × environment interaction (G×E) to the total variation in tuber yield was 36.81%, 10.80% and 6.77% respectively. The genotypes × environments interaction was represented using the GGE-biplot method. The PCA1 and PCA2 axes accounted for 47.67% and 39.49% respectively of the total variability due to the G + G×E effect. Genotypes B32 (2.21Tonnes $ha^{-1}$), P123 (1.71Tonnes $ha^{-1}$) performed best specifically in environment 1, genotypes C65 (4.69Tonnes $ha^{-1}$), B43 (4.21Tonnes $ha^{-1}$) in environment 2 and genotypes K25 (3.17Tonnes $ha^{-1}$), M5 (3.10Tonnes $ha^{-1}$) in environment 3. Genotype C69 was the ideal genotype and genotypes P181, B44, C65 and B43 were the desirable genotypes for tuber yield in all three environments. The high-performance genotypes C65, B43 could be popularized for nutsedge production in the Soudano-Sahelian zone and the high-performance genotypes K25, C69 for the Soudanian zone in Burkina Faso.

**KEYWORDS:** *Cyperus esculentus* (L.), interaction, performance, stability, Burkina Faso.

## 1 INTRODUCTION

Tiger Nut or Yellow Nutsedge (*Cyperus esculentus* L. var. Sativus Boeckeler) also known as ground fine, sweet fine is the cultivated species [1] worldwide because of its many uses. In Africa, Tiger nut is mainly grown in the western part of the continent, in Côte d'Ivoire, Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal and Togo, where it is used as a side dish for many meals [2]. Yellow nutsedge tubers are very rich in starch, oil, sugars, proteins, dietary fiber, minerals and vitamins E and C [1]. Tiger nut milk is highly nutritious for infants and nursing mothers [3]. They are also used as livestock feed [4]; [5].

Although nutsedge has been widely cultivated and used in recent years, its adaptation on varied environments remains a challenge for research to reveal. Agro-morphological characterizations of a collection of genotypes from Burkina Faso, Togo and Mali were carried out in the Sudano-Sahelian zone in 2024. This study has established the morphological and phenological variation of nutsedge.

However, it is not sufficient to provide farmers with high-performance varieties capable of adapting to different environments. Variation in a genotypic trait can be highly dependent on the environment [6]. Phenotypic expression is the combined result of genotype, environment and genotype x environment interaction [7]. Thus, different agroclimatic zones require high-performance, stable varieties to guarantee production [8]. Multilocation trials are best suited to studying the performance, stability and adaptability of cultivars in different environments [9]. Thus, [10] demonstrated the usefulness of the GGE method in their study to find potential yielding genotypes associated with stable performance under various environmental conditions. The GGE plot model provides breeders with a comprehensive visual assessment of the data, creating a biplot that simultaneously represents performance and stability, environment-specific genotypes and identifies mega-environments. This method is best suited to obtaining reliable results.

The aim of the present work is to (i) determine the effect of environment, genotype and genotype x environment interaction on tuber yield of yellow nutsedge, (ii) identify high-performance genotypes for each agroclimatic zone and (iii) identify ideals genotypes for all agroclimatic zones of Burkina Faso.

## 2 MATERIAL AND METHODS

### 2.1 MATERIAL

#### 2.1.1 PLANT MATERIAL

The plant material consisted of 36 genotypes of cultivated strains. These genotypes came from four West African countries, including five genotypes from Togo, four genotypes from Mali and twenty-seven from Burkina Faso (Table 1).

***Table 1. List of genotypes and their provenance***

| N° | Genotypes | Provenance | N° | Genotypes | Provenance |
|---|---|---|---|---|---|
| 1 | B132 | Burkina Faso | 19 | K28 | Burkina Faso |
| 2 | B135 | Burkina Faso | 20 | K32 | Burkina Faso |
| 3 | B13 | Burkina Faso | 21 | K35 | Burkina Faso |
| 4 | B32 | Burkina Faso | 22 | K3 | Burkina Faso |
| 5 | B43 | Burkina Faso | 23 | K43 | Burkina Faso |
| 6 | B44 | Burkina Faso | 24 | K53 | Burkina Faso |
| 7 | B45 | Burkina Faso | 25 | K7 | Burkina Faso |
| 8 | B90 | Burkina Faso | 26 | P123 | Burkina Faso |
| 9 | B911 | Burkina Faso | 27 | P181 | Burkina Faso |
| 10 | B95 | Burkina Faso | 28 | M1 | Mali |
| 11 | C60 | Burkina Faso | 29 | M3 | Mali |
| 12 | C64 | Burkina Faso | 30 | M4 | Mali |
| 13 | C65 | Burkina Faso | 31 | M5 | Mali |
| 14 | C69 | Burkina Faso | 32 | T1 | Togo |
| 15 | K10 | Burkina Faso | 33 | T3 | Togo |
| 16 | K243 | Burkina Faso | 34 | T4 | Togo |
| 17 | K24 | Burkina Faso | 35 | T5 | Togo |
| 18 | K25 | Burkina Faso | 36 | T6 | Togo |

#### 2.1.2 STUDY SITES

Environment 1 (E1) and Environment 2 (E2) were conducted over two successive years, 2021 and 2022, in the Soudanno-Sahelian zone at the Institute of Environment and Agricultural Research of Kamboinse (INERA/K). The station is located about 12 km north of Ouagadougou, the capital of Burkina Faso. The station's geographic coordinates are 12°28' north latitude and 1°32' west longitude, at an altitude of 296 m. According to [11] (Guinko, 1985), the station belongs to the north Sudan type of climate, as it lies between isohyets 600 and 900 mm. Kamboinsé soils are classified as leached ferruginous soils, underlain by deeper sandy material, and low-humus hydromorphic soils.

In 2021, the station recorded 775.6 mm of water in 51 days during the 2021 crop year, with temperatures ranging from 26.1 to 33.6°C and an average temperature of 30.02°C. July and August were the wettest months, with rainfall of 198.3mm and 267.7mm respectively. Rainfall of 749.9mm was recorded during the nutsedge production cycle (July to November). In 2022, August and September were the wettest months, with 395.6mm and 268.2mm respectively. Rainfall of 756.8mm was recorded during the nutsedge production cycle (July to November).

Environment 3 (E3) was the trial planted in Bobo-Dioulasso, located in the Sudanian zone during the 2022 cropping season.

It was carried out at INERA's Farako-Bâ research station, located 10 km south-west of the town of Bobo-Dioulasso on the Bobo-Banfora axis (Route Nationale n°7). The geographical coordinates of the station are 40°20' West Longitude, 11°06 North Latitude and 405 m altitude. Farako-Bâ's soils are red, slightly ferralitic (northern and western plots) and ferruginous in the south, with a 2% slope [11] (Guinko, 1985). They are highly permeable and sensitive to erosion. Their low clay and organic matter content weakens their cation exchange capacity. The station recorded 1262.4 mm of water during the 2022 rainy season, from January to September 2022 in 59 rainy days and minimum and maximum temperatures of 20.6°C and 33.6°C respectively. August and September were the wettest months, with rainfall of 316.6 mm and 299.1 mm respectively. Rainfall of 616.16 mm was recorded during the nutsedge production cycle.

## 2.2 METHODS

### 2.2.1 EXPERIMENTAL DESIGN AND TRIAL CONDUCT

The genotypes were sown in an alpha Lattice layout of 2 blocks × 18 genotypes in four replications. Each block measured 9.5 m by 3.8 m and was separated from each other by 1 m. The genotypes were each sown on a 1.4 m long ridge with a 0.5 m spacing between consecutive ridges, and a 20 cm spacing between bunches on the ridge. During ridge preparation, organic manure consisting of well-decomposed stable manure was applied at a rate of 4.5 t/ha. Maintenance mineral manure consisting of NPK (14-23-14) was applied at a rate of 200 kg/ha on the $15^{th}$ day after sowing (DAS). Maintenance operations such as weeding were carried out as required.

### 2.2.2 DATA COLLECTION

Quantitative variables were collected from emergence to harvest. The variable of interest was tuber yield. Tiger nut tubers are the vegetative organs most commonly used for consumption or processing.

### 2.2.3 STATISTICAL ANALYSIS

Data were analyzed using R software version 4.5.0. Combined analysis of variance AMMI (Additive Main Effect and Multiplicative Interaction) and GGE biplot (Genotypes + Genotypes × Environments interaction) are the main methods used to analyze genotypes × environments interaction. The discrimination and representativeness capabilities of the GGE biplot make it more sophisticated than AMMI [12]. The advantage of the GEE model over the AMMI model is that the GEE model can be used to identify stable, high-yielding genotypes, genotypes with stable performance in several environments, genotypes that perform well in each environment, and to rank environments. But the two methods complement each other to better explain the effect of genotype × environment interactions, revealing the best genotypes and appropriate environments for plant breeding. In the GGE biplot method, yield and genotype stability were estimated using average environmental coordinate (AEC) methods [13].

# 3 RESULTS

## 3.1 COMBINED ANALYSIS OF VARIANCE OF GENOTYPES EVALUATED IN THE THREE ENVIRONMENTS

The combined analysis of variance (ANOVA) of the 36 genotypes evaluated in the three environments showed highly significant effects of genotype, environment and genotype x environment interaction on yellow nutsedge tuber yield (Table 2). Of the total variation, 6.77% was explained by genotype effect, 36.81% by environment effect and 10.80% by genotype x environment interaction. The AMMI biplots (Fig 1) showed the performance of the genotypes. The abscise axis (Fig 1) represents the main effect (mean genotype performance), while the y-axis represents the impact of the interaction (PCA scores). Thus, genotypes K3, B90, T4, B45, K32, B45 closer to the origin of the figure indicate that they recorded near-zero scores on the PCA1 axis. While genotypes C69, T6, T1 and B43 were far from the origin. Genotypes presented on the same line parallel to the ordered axis showed similar performance. In terms of genotype performance, the genotypes to the right of center in Fig 1 recorded the highest yields. On the other hand, genotypes to the left of center performed poorly. Genotypes B13, B44, C65, B43, P123, C69, P181, B32, B95, B132, K10, K25, M5 and B135 produced tuber yields above the overall average.

*Table 2. Combined analysis of variance with the AMMI model*

| Source | Ddl | SS | MS | VE | G×E |
|---|---|---|---|---|---|
| Genotype (G) | 35 | 52.233 | 1.492*** | 6.77 | |
| Environment (E) | 2 | 283.7 | 141.85*** | 36.81 | |
| G×E | 70 | 83.145 | 1.187*** | 10.8 | |
| PC1 | 36 | 53.544 | 1.487*** | | 64.4% |
| PC2 | 34 | 29.6 | 0.870*** | | 35.6% |
| Residual | 315 | 78.7 | 0.249 | | |
| Total | 501 | 770.511 | 1.537 | | |

*Ddl: degree of freedom, SS: sum of squares, MS: mean square, VE: explained variance, G: genotype, E: environment, G×E: genotype-environment interaction, ***: very highly significant, %: percentage*

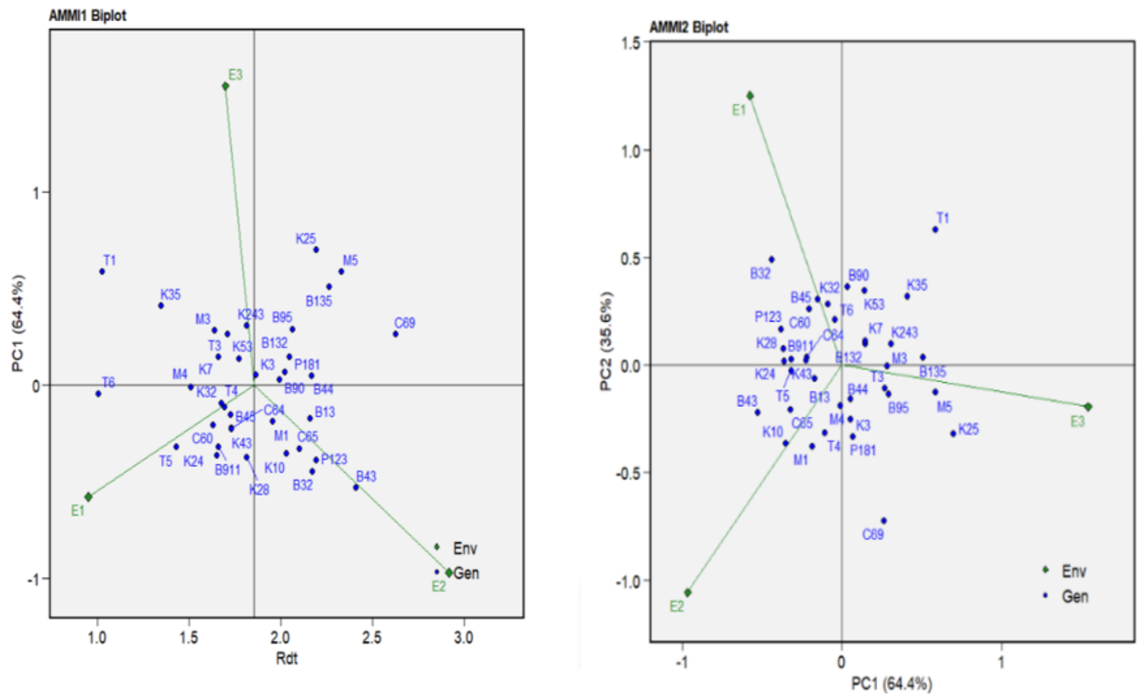


***Fig. 1. AMMI 1 and AMMI2 biplot of genotype-environment interactions for tuber yield***

### 3.2 AVERAGE PERFORMANCE AND STABILITY OF GENOTYPES IN TESTED ENVIRONMENTS

The “which-won-where” polygon (Fig 2) was used to show genotype performance as a function of environment, and to identify mega-environments. The biplot GGE is represented by two components (PC1 47.67% and PC2 39.49%) explaining a total of 87.16% of the variability (Fig 2). The polygon is divided into six sectors, and the environments are divided into two sectors. Genotypes B43 and B32 are positioned at the top of the polygon in the sector oriented towards environments E1 and E2, followed by genotypes K10, P123, C65 and K28 (Fig 2). Genotype K25 is positioned at the top of the polygon in the sector oriented towards environment E3 (Fig 2). It is followed by genotypes B135 and M5. Environments E1 and E2, positioned in the same sector, form a mega-environment, while environment E3 is a separate environment. The Fig 3 shows the GGE biplot, divided in two by the ordered axis to separate high-yielding and low-yielding genotypes. Genotypes positioned with short vectors are the most stable.

Genotypes C69, K25, B135, M5, B95, B132, B43, K10, C65, P123, B32, B13, M1, P181, B44 and K3 performed well in tuber yield. Genotypes P181, M4, B90, T4, B132, B44 and K3 showed short vectors in the biplot. These genotypes were the most stable in the environments tested (Fig 3).

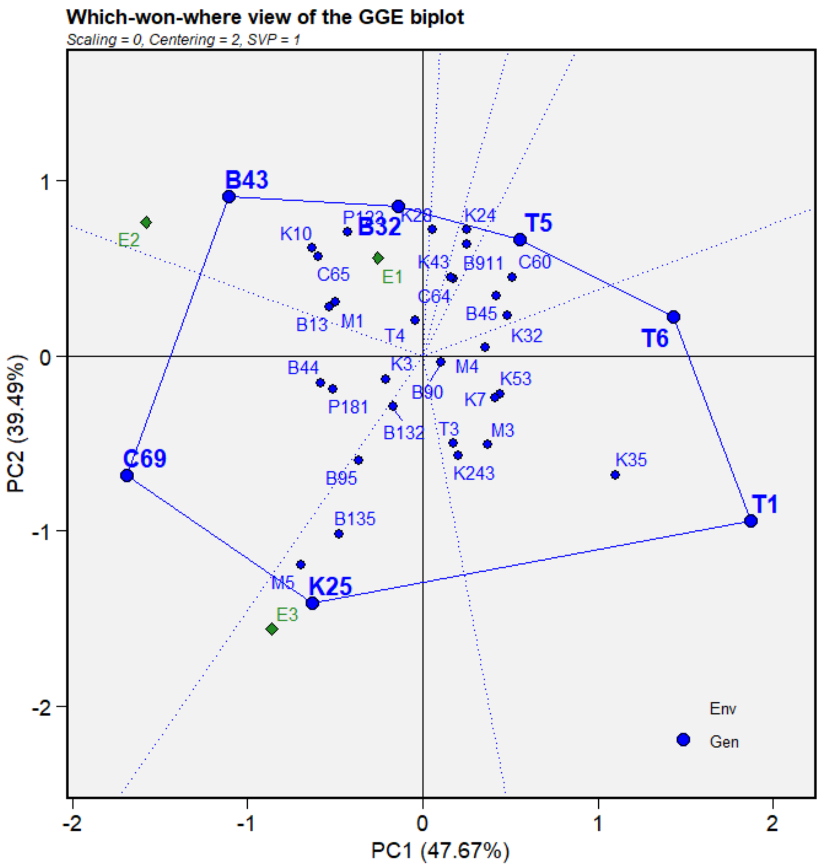


*Fig. 2.* *Which -Won- Where, performances of genotypes in environments*

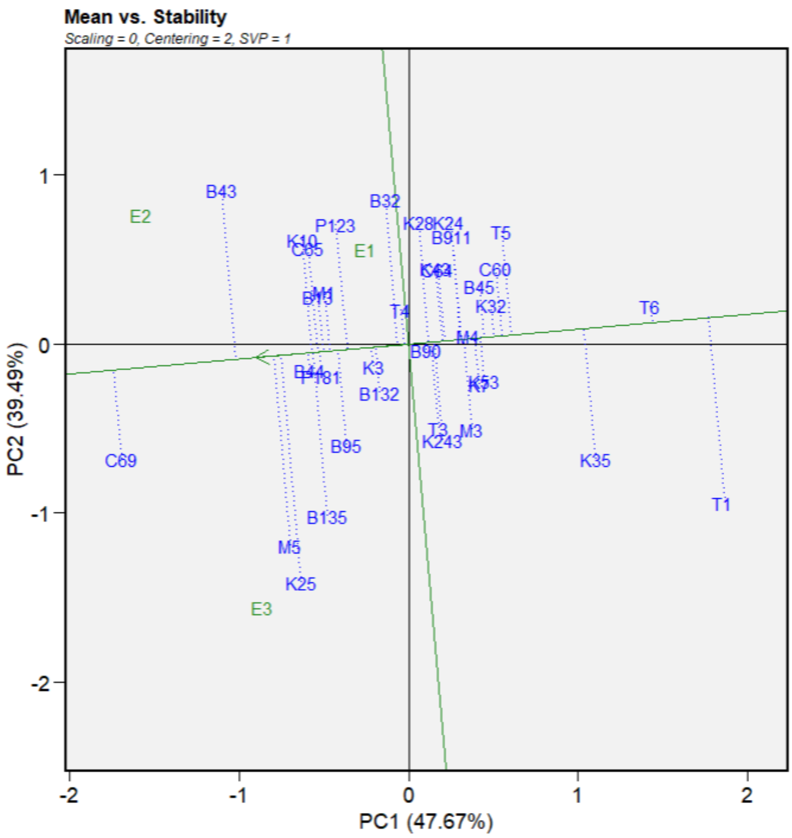


*Fig. 3.* *Stability of genotypes in tested environments*

### 3.3 Identification Of Ideal Genotypes By Environment

The ranking of genotypes is shown in figure 4. The biplot enabled us to identify the ideal genotype from among the genotypes tested. An ideal genotype has the highest average performance for a given variable, and is the most stable from one environment to the next. It is located at the center of the first concentric circle and oriented by the arrow on the x-axis. It is defined by a projection on the mean-environment axis equal to the longest vector of genotypes with above-average mean yield, and by a zero projection on the perpendicular line (zero variability between environments). Desirable genotypes are those located close to the ideal genotype. Thus, starting from the middle of the concentric circle pointed by an arrow, concentric circles have been drawn to visualize the distance between the ideal genotype and the desirable genotypes. Genotype C69 was very close to the center of the average environmental coordinates (AEC) of the concentric circles, followed by genotypes P181, B44, B43, B13, M1, K10, and C65 (Fig 4).

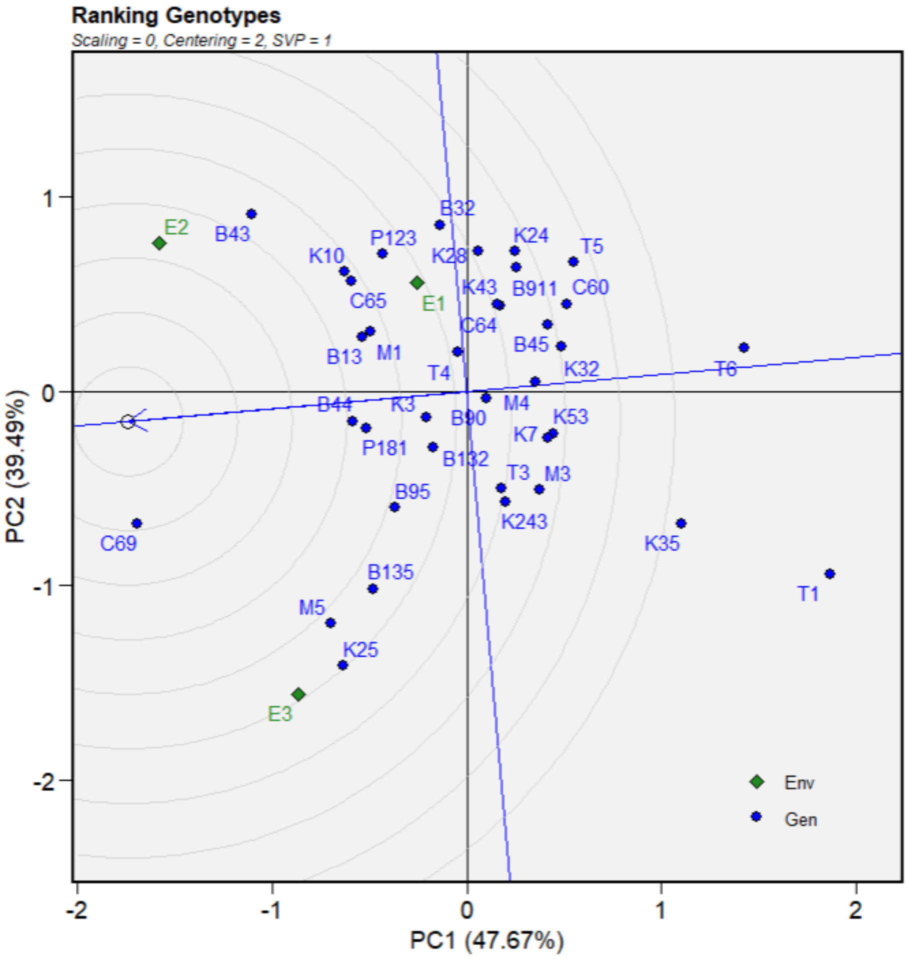


*Fig. 4. Identification of ideal genotypes*

## 4 Discussion

To guarantee food security, we need to increase crop productivity through plant breeding and improvement programs. Multi-environment experiments, commonly referred to as genotype-environment interactions, are important stages in breeding programs. The combined AMMI analysis of variance showed very highly significant effects of environment, genotypes and genotype × environment interaction ($P \leq 0.001$) on tuber yield of yellow nutsedge.

The significant effect of genotypes showed that the tuber yield of genotypes depends on the genetic potential of the genotypes, while the significance of environment revealed that environments varied and positively influenced genotype yield. The 36.42% environmental effect shows that environmental conditions had a greater influence on genotype performance for tuber yield. Some authors [14]; [15]; [16] and [17] have also shown through studies on various crops that the high percentage of variance in the effect of environment is an indication that the major factor affecting genotype performance for yield is the growing environment.

The highly significant effect of the genotype x environment interaction (GEI) means that the environment must be taken into account in varietal selection programs. The AMMI model allows us to understand the interrelationship between genotypes and the environments involved. The AMMI1 model biplot is one of several AMMI versions for identifying high potential yield and stability [18]. The "which-won-where" polygon GGE biplot revealed which genotypes performed well in each environment. The GGE biplot showed that genotypes were well adapted to each environment and confirmed the presence of differentiation through interaction between genotypes and environments. Genotypes at the top of the polygon have been identified, indicating their performance and adaptability in their environments. Genotypes C65, B43 were the best performing with a yield of 4.21Tonnes $ha^{-1}$ for genotype B43, followed by 3.69T/ha for genotype C65 in environment 2, while genotypes B32 with a yield of 2.13Tonnes $ha^{-1}$and P123 (1.71Tonnes $ha^{-1}$) were the best performing in environment 1. Tiger nut genotypes could be specifically adapted to the Sudano-Sahelian zone of Burkina Faso. On the other hand, genotypes K25 and C69, followed by M5 and B135 were the best performers, with the highest yields of 3.17Tonnes $ha^{-1}$for genotype K25 and 3.01Tonnes $ha^{-1}$ for genotype C69 in environment 3. These genotypes would be best suited to the production of high-yielding tuberous nutsedge in the Sudanian zone of Burkina Faso. Similar results were found by [19]; [20] and [21] on sweet potato genotypes in Burkina Faso and Ethiopia. GGE biplot results showed that genotypes P181, M4, B90, T4, B132, B44 and K3 were identified as stable.

## 5 Conclusion

From these results, the main factors influencing tiger nut yields are the environment and genotype, but the environment is the most decisive factor in tiger nut yield potential. Genotypes C65 and B43 performed best and were specifically adapted to both environments E1 and E2 belonging to the Sudano-Sahelian zone. While genotypes K25 and C69 perform best in the Sudanian zone, genotypes P181 and B44 were the most stable genotypes in all three agroecological zones.

The ideal genotype C69 is the most stable, with average tuber yield performance in all three test environments. The high-performance genotypes specific to each zone could be used as the best tiger nut genotypes to be promoted for these two agroclimatic zones in Burkina Faso. The best genotypes identified for each agroclimatic zone and for both agroclimatic zones could be used to develop high-performance of Tiger nut varieties in Burkina Faso.

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