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Full Length Article

Identification of Suitable Genotypes for Pearl Millet (*Pennisetum glaucum*) Production in Senegal

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Abstract

In Senegal, pearl millet is the most important cereal crops in terms of cultivated areas. Nevertheless, the production is very low compared with the potential of released improved varieties. Thus, the identification of high-performing varieties adapted to the different agroecological zones is crucial for sustaining pearl millet production. Ten improved varieties were evaluated in 6 environments and the effects of the genotype–environment interaction (GEI) and stability performance on the grain yield were investigated during the rainy seasons of 2021 and 2022. In each environment, the trial was established using a randomized complete block design with three replications. Collected data on grain yield were analyzed using the additive main effects and multiplicative interaction (AMMI) and GGE biplot models. Results showed that the grain yield parameters was affected by genotype (44%), environment (35%) and their interaction (21%). The first two PCA were significant, accounting for 55% (PC1) and 26% (PC2) of the total observed G × E interaction. The six environments were divided into two mega-environments. SL 423, IBV 8004 and SOSAT C 88 were identified as the most stable and high-yield varieties. Seeds of varieties can be produced and disseminated for pearl millet production in Senegal.

Keywords: Pearl millet; Grain yield; Stability; Senegal

Introduction

The highest population growth rate is noted in Western Africa countries (FAO 2023). Therefore, food demand will probably increase in these countries and pearl millet is expected to play a significant role in improving cereal production for achieving food security.

Pearl millet is a major cereal crop in dry areas where other cereals will not yield correctly (Serba *et al.* 2017). In addition, this crop has high potential for fighting malnutrition in dryland areas because of its high protein, vitamins, iron and zinc contents when compared to other cereals (Govindaraj *et al.* 2011). Despite the importance of this cereal as a staple food, its production is still low in the fields of farmers in Senegal compared with its potential (DAPSA 2018; FAO 2023). This situation is mainly due to the use of inappropriate and unimproved cultivars (Kanfany *et al.* 2020). Therefore, pearl millet production in Senegal can likely be increased through the dissemination of adapted pearl varieties to the different agroecological zones where this cereal is widely grown. To identify high yielding and adapted varieties, multi-location trials need to be performed.

Multiple environment trials have been used in the past to assess the response of genotypes across different locations (Yan *et al.* 2000). Thus, high yielding and adapted cereals varieties have been identified is the past (Arshadi *et al.* 2018). Additive main effects and multiplicative interaction (AMMI) and genotype-by-environment biplot (GGE) statistical models were used to study stability and G x E interactions on grain yield (Frutos *et al.* 2014). The GGE biplot is built on genotype and environment scores and the AMMI model combines analysis of variance and principal component analysis (Gauch 2013). In pearl millet, several recent studies highlighted the use of these models for agronomic and nutritional traits (Gangashetty *et al.* 2023; Singhal *et al.* 2024). This study was conducted to identify pearl millet varieties with high yield and wide adaptability for cultivation in Senegal.

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Materials and Methods

Study sites

The trials were conducted during the rainy seasons of 2021 and 2021 at the Bambey, Nioro and Sinthiou research stations located in the central and eastern part of Senegal (Fig. 1). These agroecological zones represent the main pearl millet production areas, accounting for more than 80% of the national production. They are characterized by a highly variable rainfall pattern (Table 1).

Plant materials, experimental design and data recording

For the experiments, we evaluated ten improved pearl millet varieties (Table 2). The trials were implemented using a randomized complete block design (RCBD) with three replications. Each plot had six rows of five meters long. The spacing between rows and between hills in arrow was 80 and 50 cm, respectively. The recommended pearl millet cultivation in Senegal was followed. Grain yield data for each plot was collected.

Data analysis

The locations and years were combined to form different environments. An initial analysis of variance (ANOVA) using R studio was performed for each environment to elucidate the variety effect. A joint ANOVA was performed to elucidate the genotype, environment and their interaction effects. AMMI analysis was performed on pearl millet grain yield data using AMMI function built on Agricolae package. The AMMI model formula described by Gauch (2013) was used. The stability of pearl millet varieties was evaluated using the AMMI stability value (ASV) (Purchase *et al.* 2000). Using the rankings based on yield performance and the AMMI stability value, the yield stability index (YSI) was calculated as described by Farshadfar (2008) where YSI is the sum of Ranking based on grain yield and ranking from the ASV. Biplot graphs were drawn following the GGE biplot model defined by Yan *et al.* (2000).

Results

The combined ANOVA revealed significant differences between varieties, environments and their interaction for grain yield (Table 2 and 3). Results showed that 44% of the variation was due to genotype while 35% and 21% were attributable to environment and genotype-by-environment interaction, respectively. The first two IPCAs were significant and contributed to more than 80% of the total genotype by environment variation.

The biplot analysis provided a reliable visualization of the data. Indeed, it captured 92% of the total variation presented in the pearl millet yield data (Fig. 2). The environments were divided into two sectors with different winning varieties. SL28 showed the highest yield in the mega-environment of Nioro 2021, Sinthiou 2021 and Bambey 2022 while the second mega-environment composed of Nioro 2022, Sinthiou 2022 and Bambey 2021, Souna 3 was the winning variety. ICTP 8203 and Chackti were not suitable for any of these mega-environments.

The performance of the varieties across the six environments differed significantly. SL28 presented the highest grain yield (2 590 kg ha^{-1}), whereas ICTP 8203 (1153 kg ha^{-1}) and Chackti (1158 kg ha^{-1}) had the lowest

Table 1: Rainfall, temperature and relative humidity in each experimental environment during the growing season between July and October (2021 & 2022)

Location	Rainfall		Temperature (°C)		Relative humidity (%)	
	mm	days	min	max	min	max
Sinthiou 2021	696.4	44	23.7	34.7	60.7	96.1
Sinthiou 2022	900.3	47	23.0	33.9	63.3	98.1
Bambey 2021	541.3	37	24.3	35.2	58.9	94.9
Bambey 2022	533.2	52	24.8	34.6	58.1	94.2
Nioro 2021	816.9	45	23.5	33.3	62.1	95.5
Nioro 2022	949.5	49	23.4	33.4	64.2	98.1

Table 2: List of pearl millet varieties

Genotype	Year of release	Origin	Yield potential (t ha^{-1})
Souna 3	1972	Senegal	3.5
IBV 8004	1987	Senegal	2.5
SOSAT C 88	1994	Mali	2.0
Thialack 2	2010	Senegal	2.5
Gawane	2010	Senegal	2.5
ISMI 9507	2010	Senegal	2.5
ICTP 8203	2016	Togo	3.0
Chackti	2018	Niger	2.0
SL 28	2021	Senegal	2.5
SL 423	2021	Senegal	3.0

Table 3: Additive main effects and multiplicative interaction analysis of variance for the pearl millet grain yield of the varieties across six environments

Source	df	SS	MS	Contribution to the SS (%)
Environment (E)	5	31886119	6377224***	35
Genotypes (G)	9	40571385	4507932***	44
G x E	45	18966512	421478**	21
IPCA1	13	10446551	803580.84***	55
IPCA2	11	5005480	455043.62*	26
IPCA3	9	1886460	209606.60^{ns}	0.1
Residuals	108	21864302	202447	-

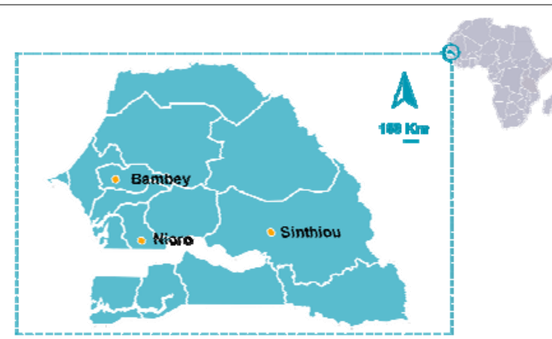

Fig. 1: Map of Senegal showing the different sites where the experiments were conducted

grain yield (Table 4). In terms of the ASV, Gawane, followed by IBV8004 and Thialack 2 were the most stable varieties for grain yield. The least stable genotype was ICTP 8203, followed by SL 28 and Chackti. The best genotype that combined high grain yield and stability (lower YSI) was IBV 8004, followed by Gawane, SL 423, SOSAT C 88, Souna 3 and Thialack. ICTP 8203 and Chackti had the highest YSIs and were considered low-yield and unstable genotypes.

The patterns of the mean performance and stability of the ten varieties across the six environments were also graphically presented using the GGE biplot model (Fig. 3). Principal components 1 and 2 accounted for 82% and 09% of the total variation, respectively. In terms of average-environment coordination (AEC), SL 28, followed by Souna 3, SL 423, SOSAT C 88, IBV 8004 and Thialack 2 were the varieties with the highest yields. The varieties with the lowest yields were ICTP 8203 and Chackti. Among the varieties with the highest yields, IBV 8004, SL 423 and SOSAT C88 were the most stable across the six environments.

Discussion

In Senegal, farmers have used improved pearl millet varieties without considering the environment in which these genotypes were bred. This study identifies high-yield and stable varieties for pearl millet cultivation in the different agroecological zones of Senegal. The results revealed that the pearl millet yield significantly differed among the ten tested genotypes. The ANOVA results also revealed significant differences across environments in terms of grain yield, which means that genotype ranks changed across the six environments. Similar results on grain yield were reported for pearl millet (Gangashetty *et al.* 2023) and other cereals, such as rice and maize (Katsura *et al.* 2016; Mafouasson *et al.* 2018).

In our study, SL28 showed the highest performance across the different environments. The grain yield of this variety is greater than the national average grain yield of pearl millet but is like its grain yield potential (FAO 2023). It is among the three open pollinated varieties released in 2020 and is mainly recommended for pearl millet production in the central part of the country where the Bambey research station is located (Faye *et al.* 2023). ICTP 8203 and Chackti presented the lowest grain yields across different locations. This could be due to the earliness of these two varieties when compared with that of other varieties, which are thus subjected to bird attacks (Gangashetty *et al.* 2023). However, ICRISAT and their partners are disseminating them across several countries to fight against food insecurity because of their high iron and zinc contents (Rai *et al.* 2012). In Senegal, despite economic growth, food insecurity remains a concern, especially in rural areas. According to the 2022 National Food Security Survey, approximately 27% of households are food insecure, with 2.1% in a severe situation and 13.4% in a moderate situation (SECNSA 2023). Thus, these varieties can be disseminated, but farmers should be aware of their earliness and grow them later during the rainy season.

Table 4: Pearl millet grain yield performance and stability parameters of the tested genotypes

Genotypes	Grain yield (kg ha^{-1})	IPCAg1	IPCAg2	ASV	YSI
Chackti	1158	-18.6333287	-5.8336986	28	17
Gawane	1948	-0.8681186	2.4951125	3	9
IBV8004	2257	-6.2572212	-3.7657851	10	7
ICTP 8203	1153	-29.0603224	1.0668658	42	20
ISMI9507	2124	9.6152207	-6.1324182	15	11
SL 28	2590	2.1239926	28.707349	29	10
SL 423	2347	14.3662603	9.7456195	23	9
SOSAT C 88	2342	10.7918863	-3.0360389	16	9
Souna 3	2372	14.1589299	-11.626974	24	9
Thialack 2	2211	3.7627011	-11.620032	13	9

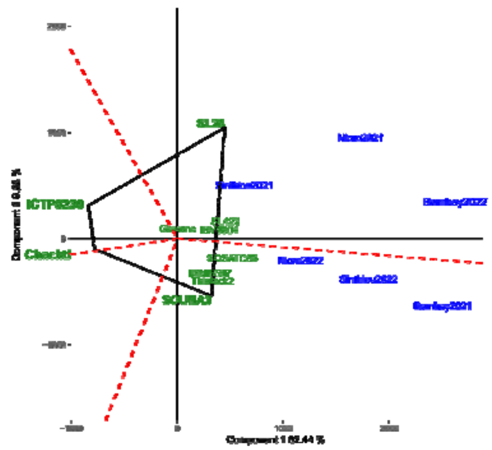

Fig. 2: The which-won-where GGE biplot

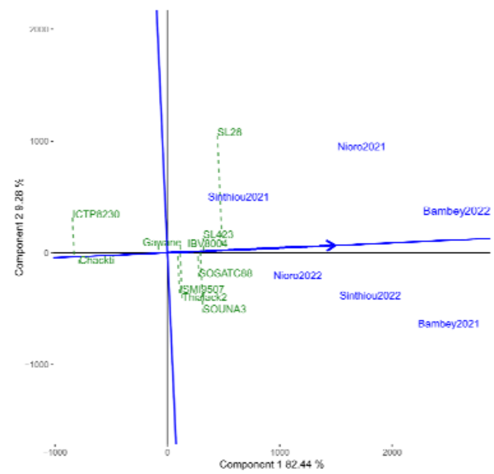

Fig. 3: The average-environment coordination (AEC) biplot

In plant breeding, defining the number of mega-environments is complicated and requires the consistency of winning genotypes in each given mega-environment over several years (Yan *et al.* 2007). However, which won where analysis allows a breeder to identify the best genotypes for a given mega-environment (Yan *et al.* 2000). The six environments were divided into two mega-environments. Bambey 2021 and Bambey 2022, Sinthiou 2021 and Sinthiou 2022, as well as Nioro 2021 and Nioro 2022, did not fall in the same mega-environment. This situation could be due to the variability observed in the weather conditions during the two rainy seasons. Differences in rainfall among the testing environments generated variable genotypic responses across locations and seasons. The rainfall was greater in Nioro and Sinthiou during the rainy season of 2022 and in Bambey during the rainy season of 2021 than in the other testing environments. Our study revealed that ICTP 8203 and Chackti did not perform in these environments. However, these varieties can be disseminated in the northern part of the groundnut basin, which is considered a Sahelian zone with a rainfall pattern of less than 400 mm year^{-1}. These varieties mature early (60 days from sowing to harvest) and have high iron and zinc contents (Gangashetty *et al.* 2023). Our study identified SL 423, IBV 8004 and SOSAT C 88 as the most stable with high grain yield across the six environments. This information is useful for farmers located in the groundnut basin and Eastern part of Senegal and will guide them in determining which varieties to grow in their fields to increase pearl millet production.

Conclusion

This study identified SL 423, IBV 8004 and SOSAT C 88 as high yielding and stable genotypes for pearl millet production is Senegal. The disseminated of these varieties across pearl millet production zones in Senegal will contribute to the national production and reduce food insecurity. These varieties could be used as parents for the genetic improvement of cultivated elite varieties.

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Author Contributions

GK, YABZ, OD, OS conceived and designed the study; GK, YD, SDM, EMS and OD performed the research. GK and YABZ wrote the manuscript. OS and MS reviewed the paper.

Conflict of Interest

There are no competing interests to declare.

Data Availability

The data used to support the 3ndings of this study are available from the corresponding author upon request.

Ethics Approval

Not applicable

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References

Arshadi A, E Karami, A Sartip, M Zare, P Rezabakhsh (2018). Genotypes performance in relation to drought tolerance in barley using multi-environment trials. *Agron Res* 16:5–21

DAPSA (2018). *Resultats Definitifs de la Campagne Agricole* 2013/2014

FAO (2023). *FAO Database*. Statistiques Agricoles. http://faostat.fao.org

Farshadfar E (2008). Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. *Pak J Biol Sci* 11:1791–1796

Faye A, TM Akplo, ZP Stewart, D Min, AK Obour, Y Assefa, PVV Prasad (2023). Increasing millet planting density with appropriate fertilizer to enhance productivity and system resilience in Senegal. *Sustainability* 15:4093

Frutos E, MP Galindo, V Leiva (2014). An interactive biplot implementation in R for modeling genotype-by-environment interaction. *Stochastic Environ Res Risk Assess* 28:1629–1641

Gangashetty PI, CB Yadav, M Riyazaddin, A Vermula, PA Asungre, I Angarawai, LAJ Mur, RS Yadav (2023). Genotype-by-environment interactions for starch, mineral, and agronomic traits in pearl millet hybrids evaluated across five locations in West Africa. *Front Plant Sci* 14:1171773

Gauch HG (2013). A simple protocol for AMMI analysis of yield trials. *Crop Sci* 53:1860–1869

Govindaraj M, B Selvi, S Rajarathinam, P Sumathi (2011). Genetic variability and heritability of grain yield components and grain mineral concentration in India's pearl millet (*Pennisetum glaucum* (L) R. Br.) accessions. *Afr J Food Agric Nutr Dev* 11:4758–4771

Kanfany G, O Diack, NA Kane, P Gangashetty (2020). Implications of farmer perceived production constraints and varietal preferences to pearl millet breeding in Senegal. *Afr Crop Sci J* 28:411–420

Katsura K, Y Tsujimoto, M Oda, KI Matsushima, B Inusah, W Dogbe, JI Sakagami (2016). Genotype-by-environment interaction analysis of rice (*Oryza spp.*) yield in a floodplain ecosystem in West Africa. *Eur J Agron* 73:152–159

Mafouasson HNA, V Gracen, MA Yeboah, G Ntsomboh-Ntsefong, LN Tandzi, CS Mutengwa (2018). Genotype-by-environment interaction and yield stability of maize single cross hybrids developed from tropical inbred lines. *Agronomy* 8:62

Purchase JL, H Hatting, CSV Deventer (2000). Genotype × environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: II. Stability analysis of yield performance. *S Afr J Plant Soil* 17:101–107

Rai K, M Govindaraj, AS Rao (2012). Genetic enhancement of grain iron and zinc content in pearl millet. *Qual Assur Saf Crop Food* 4:119–125

SECNSA (2023). *Rapport de L'enquête de Sécurité Alimentaire de Nutrition (ESAN)*. Cabinet du Premier Ministre, Republique du Senegal

Serba DD, R Perumal, TT Tesso, D Min (2017). Status of global pearl millet breeding programs and the way forward. *Crop Sci* 57:2891–2905

Singhal T, CT Satyavathi, SP Singh, M Sankar, M Mallik, R Thribhuvan, S Yadav, C Bharadwaj (2024). Elucidating genotype × environment interactions for grain iron and zinc content in a subset of pearl millet (*Pennisetum glaucum*) recombinant inbred lines. *Crop Pasture Sci* 75:555–560

Yan W, MS Ma, B Kang, S Woods, PL Cornelius (2007). GGE biplot *vs.* AMMI analysis of genotype-by-environment data. *Crop Sci* 47:643–653

Yan W, L Hunt, Q Sheng, Z Szlavnics (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Sci* 40:597–605