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(Research Article)

Stability analysis and genotype X environment interaction of cotton seed and fiber yield of some cotton (*Gossypium hirsutum* L.) genotypes in multi-environment in Mali

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Abstract

Cotton is a strategically important crop for Mali. Mainly used for export, it represents 50–60 % of the value of the country's exports. Genotype by environment interaction study was carried out to identify the most stable cotton genotype(s) and the most desirable for seed cotton yield and lint yield in 35 villages across six different environments(High Valley of the Niger, New Cotton Growing Zone, North Sudan-Sahel, Old Basin, Southern Extension Zone and Zone Sikasso-Bougouni) in a dispersed block design. Where each village represented a block, giving a total of 35 blocks or replications. A combined analysis of variance showed that yields of seed cotton and fiber were significantly affected by environments ($p<0.05$), but did not reveal any significant difference between genotypes or genotype-environment interactions. The result of GGE biplot analysis method showed that the polygonal view identified three mega-environments (ME1, ME2 and ME3) with three winning genotypes: BRS 293, NTA B149 and NTA L66, respectively, for seed cotton yield. For fiber yield, the winning genotypes were CG1, NTA L65 and BRS 293, respectively. Given that all the varieties tested have a mean fiber yield within the recommended norms, the two promising varieties NTA B149 and NTA L66 with good seed cotton yields and the standard check BRS 293 can be recommended for extension in the environments to which they have been assigned.

Keywords: Cotton; Fiber; Yields; Stability; Environment; Mali

1. Introduction

Cotton (*Gossypium hirsutum* L.) is a perennial plant that grows in arid tropical or subtropical climates at temperatures between 11 °C and 25 °C. It is the most important plant fiber crop in the world today and is grown commercially in both temperate and tropical regions in more than 50 countries [1]. It is estimated that cotton is grown on around 2.4 % of the world's arable land [2]. Cotton is grown on all five continents, with different varieties and cultivation practices. In northern countries, cotton is grown over large areas, irrigated in certain areas, as in the United States and Australia, and is fully mechanized. By contrast, in the countries of the South, cotton is grown on small plots in rain-fed systems and in Africa, it is grown in rotation with food crops, so cotton plays an important role in food security [3].

Cotton represents considerable economic and social importance for the African countries that grow it, particularly the countries of the CFA (*Communauté Financière Africaine*) zone [4] *in* [5].

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In Mali, cotton growing has been known and practiced for a very long time, but it has developed particularly over the last thirty years. Its production supports four million people, around a quarter of Mali's population [6].

Malian cotton has strategic importance. Mainly destined for export (90 % of production is exported), cotton growing provides regular cash income for a significant fraction of the rural population; it accounts for around 50–60 % of the value of the country's exports [7]. Mali's cotton-growing zone, often referred to as Mali-Sud, is located between 4 ° 15 ' 00 " and 10 °15 '00 " west longitude and 10 ° 15 ' 00 " and 14 ° 15 ' 00 " north latitude. It covers an area of around 150,000 km2 and had a population estimated at 5.6 million in 2009 [8]. Administratively, the cotton-growing zone covers the whole of the third administrative region (Sikasso), the whole of the districts of Bla and Baraoueli, and a large part of the districts of Tominian and San in the fourth administrative region (Ségou); the whole of the districts of Kati, Kangaba, Dioïla and Koulikoro in the second administrative region (Koulikoro); and finally, the whole of the district of Kita in the first administrative region (Kayes) [9].

Numerous cotton seed varieties have been created locally or introduced in Mali. In both cases, a meticulous system of experimentation has been used to evaluate the performance and stability of the main characteristics of the varieties being considered for widespread release throughout the cotton-growing zone. Given the extent of the area sown with cotton in Mali, several seed varieties are often suggested to growers, which makes it somewhat difficult to multiply and supply seed. The seed varieties proposed for extension often do not behave stably in the growing area. This inappropriateness of certain seed varieties of extension seed has an impact on the production and productivity of Malian cotton, in addition to biotic and abiotic constraints.

The aim of this study was to determine the genotype x environment (GE) interaction and the stability of cotton genotypes in order to identify the most stable cotton genotype(s) and the most desirable environment(s).

2. Material and methods

2.1. Experimental site

The study was carried out in 35 villages (see appendix) in Mali's six cotton-growing zones (environments): the Old Basin, High Valley of the Niger, North Sudan-Sahel, New Cotton Growing Zone, Zone Sikasso-Bougouni and Southern Extension Zone. (Figure 1). These six locations represent different agro-ecological characteristics of cotton-growing areas in Mali.

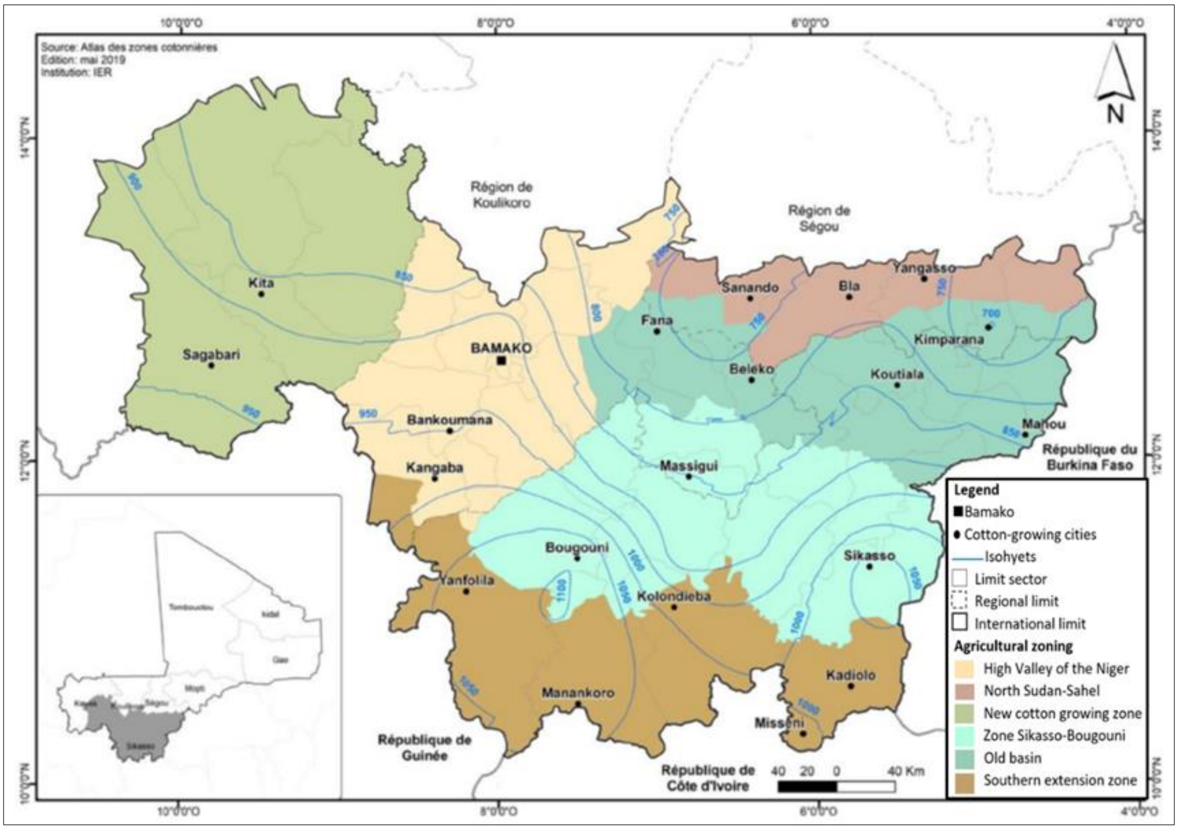

Figure 1 Présentation des six zones cotonnières du Mali (source Soumaré et al. 2020)

2.2. Plant material

The plant material consisted of seven cotton genotypes: one standard check, BRS 293; and six promising new varieties: CG1, NTA B149, NTA E154, NTA L 65, NTA L 66, NTA L 93.

2.3. Experimental design

Seven cotton varieties were evaluated in 35 villages across six different environments in a dispersed block design where each village represented a block, giving a total of 35 blocks or replications. Each genotype was sown on an elementary plot of 5 lines 20 m long. Observations were made on the three main rows and the other two were used as borders.

2.4. Data collection

In cotton improvement, the objectives have always been to achieve good productivity in the field, an adequate fiber yield at ginning and the fiber quality required by the textile industry. The first two are agronomic characteristics and the third is the technological quality of the fiber. In this study, the characteristics studied were seed cotton yield (kg/ha) and ginning fiber yield (%)

2.5. Statistical analysis

2.5.1. Analysis of variance (ANOVA)

The quantitative traits were subjected to analysis of variance (ANOVA) to estimate the existence of variations among the genotypes, the environment and genotype by environment in R Studio (a simplified version of R statistical software). The genotypes were treated as fixed variables, while the environments were considered random variables.

2.5.2. GGE Biplot Analysis

To explain the G×E interaction, the multivariate stability analysis was performed graphically based on GGE biplot using GenStat software, 15th edition, to quantify genotype by environment interaction, classification of mega-environments, characterization of testing environments, and simultaneous selection of genotypes based on stability and mean yield.

The GGE biplots is graphical images to exemplify G×E interaction and genotype ranking based on mean and stability. The graph generated is based on multi-environment evaluation (which-won-where pattern), Genotype evaluation (mean versus stability), and tested environment raking (discriminative versus representative).

3. Results

3.1. Analysis of variance

3.1.1. Seed cotton yield (kg/ha)

The analysis of variance did not reveal any significant difference between the varieties or the interaction between variety and location (environment) for seed cotton yield. This means that no one variety was statistically superior to another for the zone as a whole or in an individual zone. On the other hand, a significant difference at p<0.05 was observed between the seed cotton yield averages of the localities.

The results in Table 1 showed that the highest average seed cotton yield was obtained in the Southern Extension Zone with 1367 kg/ha of seed cotton. And the New Cotton Growing Zone recorded the lowest average value of seed cotton yield, with 913 kg/ha. Although all seven varieties were statistically equal (no significant difference), it is interesting to note the good arithmetic value of the mean seed cotton yields of the standard check BRS 293 over the whole zone (1355 kg/ha) and individually in all cotton growing zones except in the New Cotton Zone, where NTA L66 had the best arithmetic value with 1067 kg/ha (Table 1).

Table 1 Seed cotton yield (kg/ha) of genotypes in the six environments

Variety	**Cotton production zones**						**Mean all location**
	HVN	**NCGZ**	**NSS**	**OB**	**SEZ**	**ZSB**	
BRS 293	1389	981	1423	1420	1515	1286	1355
CG1	1265	1021	1185	1247	1321	1205	1225
NTA B149	1304	810	1256	1229	1454	1275	1241
NTA E154	1177	1004	1027	1220	1474	1086	1195
NTA L65	1240	749	819	1094	1293	1133	1102
NTA L66	1187	1067	1040	1230	1167	1153	1168
NTA L93	1108	760	848	1188	1344	1134	1124
Mean	1238	913	1085	1233	1367	1182	1201
CV%	60.5	34.0	43.0	41.4	42.5	26.5	42.7
Prob	ns	ns	ns	ns	ns	ns	ns
N	5	4	2	11	6	7	35

HVN = High Valley of the Niger, NCGZ = New cotton growing zone, NSS = North Sudan-Sahel, OB = Old basin, SEZ = Southern extension zone and ZSB = Zone Sikasso-Bougouni. CV% = Coefficient of variation expressed in percent, Prob = Probability, ns = not significant, N = Number of villages.

3.1.2. Fiber yield at ginning (%)

As for the seed cotton yield parameter, the analysis of variance did not reveal any significant difference between varieties or the variety-location interaction for ginning fiber yield. On the other hand, a significant difference at p<0.05 was observed between the cotton-growing zones for the ginning fiber yield means.

The best mean fiber yield was obtained in the Zone Sikasso-Bougouni, followed by the New Cotton Growing Zone, with fiber yields of 44.1 % and 40.0 %, respectively.

Table 2 Fiber yield at ginning (%) of genotypes in the six environments

Variety	Cotton production zones						Mean all location
	HVN	NCGZ	NSS	OB	SEZ	ZSB	
BRS 293	42.4	45.0	42.9	42.4	42.8	43.7	43.1
CG1	43.9	43.7	43.4	43.7	44.1	44.8	44.0
NTA B149	42.8	44.1	43.6	43.4	42.8	44.3	43.5
NTA E154	42.9	44.3	43.9	42.2	43.1	43.0	42.9
NTA L65	42.1	43.4	44.5	43.9	43.2	44.5	43.6
NTA L66	43.1	44.2	42.7	43.0	44.2	44.4	43.6
NTA L93	43.8	43.2	43.2	42.8	43.9	44.1	43.5
Mean	43.0	44.0	43.5	43.1	43.4	44.1	43.5
CV%	5.3	2.9	2.7	5.2	3.2	4.3	4.5
Prob	ns	ns	ns	ns	ns	Ns	ns
N	5	4	2	11	6	7	35

HVN = High Valley of the Niger, NCGZ = New cotton growing zone, NSS = North Sudan-Sahel, OB = Old basin, SEZ = Southern extension zone and ZSB = Zone Sikasso-Bougouni. CV% = Coefficient of variation expressed in percent, Prob = Probability, ns = not significant, N = Number of villages.

It should be noted that the CG1 variety had the best arithmetic values (44.0 %) compared with the other genotypes throughout the zone and individually in all the cotton-growing zones except in the New Cotton Growing Zone and the North Sudan-Sahel zone, where the BRS 293 and NTA L65 varieties had the best arithmetic values (45.0 and 44.5 %, respectively) (Table 2).

3.2. Stability analysis and Genotype x environment interaction using GGE Biplot method

3.2.1. Seed cotton yield (kg/ha)

The GGE biplot analysis of the seven genotypes under six environments for seed cotton yield (kg/ha) presented in Figure 2 revealed that PC1 and PC2 together explain 89.27 % of the total variation for seed cotton yield across tested environments.

The polygonal view of the GGE biplot identified three mega-environments (ME). The High Valley of the Niger (HVN), North Sudan-Sahel (NSS), Old Basin (OB) and Zone Sikasso-Bougouni (ZSB) were located in the same part of the scatter plot, implying that these environments had a strong positive correlation and therefore there was no significant difference among them so that they could be considered as one mega-environment (ME1). Only one genotype, BRS 293, produced a high yield and was therefore identified as a stable genotype in this mega-environment. The environments, the New Cotton Growing Zone (NCGZ) and Southern Extension Zone (SEZ), were located in the different quadrants, suggesting that they were significantly different and could be considered different mega-environments (ME2 and ME3, respectively).

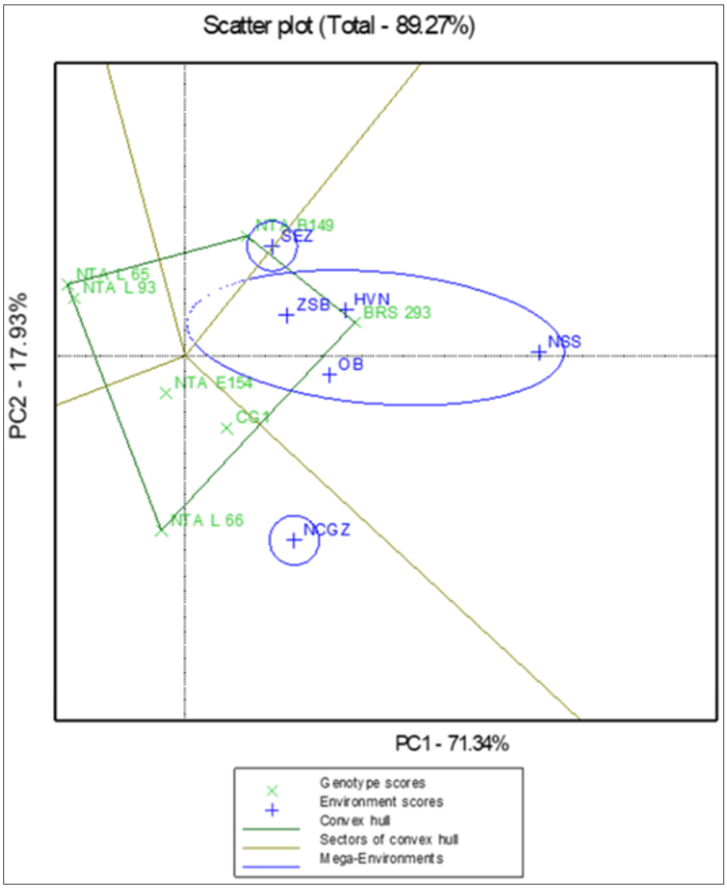

Figure 2 Polygon view of genotype by environment interaction showing which genotypes yielded best in each environment for seed cotton yield

The genotype NTA B149 is scattered in the SEZ (ME2) environment, has better adaptation and sable than other genotypes, and produces higher yields. It should be noted that the BRS 293 genotype produced the best average seed cotton yield in this zone, but it was not stable.

The genotype NTA L66 is located in the NCGZ (ME3) and exhibited high yields in this environment, indicating that it has better adaptation and stability than other cultivars in this environment. The genotypes CG1 and NTA E154 were found dispersed in the same environment (Figure 2). These genotypes also produced high seed cotton yields in NCGZ.

The genotypes NTA L65 and NTA L93 are not scattered in any environment, which explains why they are not stable in any of the six environments. It should be noted that these two genotypes also recorded the lowest mean values for seed cotton yield.

3.2.2. Fiber yield at ginning (%)

The fiber yield stability of the genotypes was examined using the GGE biplot method, and the result is indicated in Figure 3. The GGE biplot analysis reveals that PC1 and PC2 together accounted for 80.06 % of the total variance for fiber yield across test environments.

The polygonal view of the GGE biplot identified three mega-environments (ME).

The High Valley of the Niger (HVN), Southern Extension Zone (SEZ), and Zone Sikasso-Bougouni (ZSB) were located in the same part of the scatter plot, implying that these environments had a strong positive correlation, and therefore there was no significant difference among them so that they could be considered as one mega-environment (ME1).

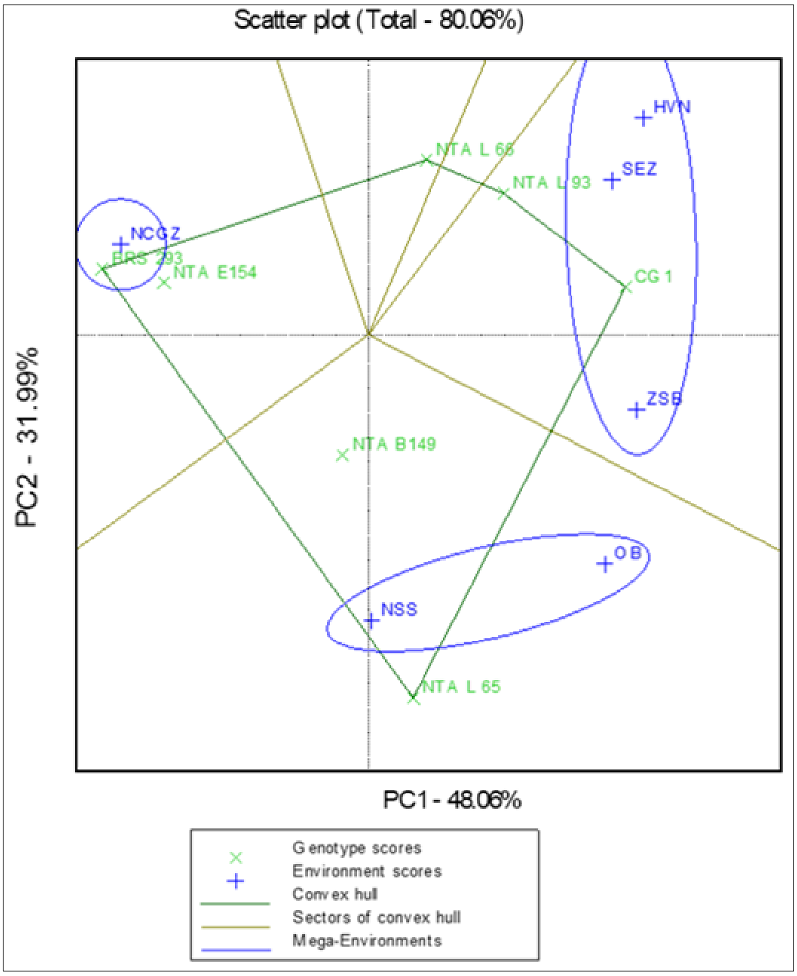

Figure 3 Polygon view of genotype by environment interaction showing which genotypes yielded best in each environment for fiber yield

The genotype CG1 produced a high fiber yield and was therefore identified as a stable genotype in this mega-environment, followed by the genotype NTA L93. The North Sudan-Sahel (NSS) and Old Basin (OB) were located in the same part of the scatter plot and fell into mega-environment two (ME2). The genotypes NTA L65 and NTA B149 were more stable and had a good level of fiber production in these environments. The New Cotton Growing Zone (NCGZ) environment is not related to any other environment and falls inside mega-environment three (ME3). The genotypes BRS 293 and NTA E154 are located in this mega-environment and exhibited high fiber yield, indicating that they have better adaptation than other genotypes in this environment.

4. Discussion

For seed cotton yield, the analysis of variance did not reveal any significant difference between varieties or the interaction between variety and location for seed cotton yield. However, a significant difference at $p<0.05$ was observed between environments. The GGE Biplot method analysis grouped the six environments into three environments: a mega-environment composed of four environments: the High Valley of Niger, the North Sudan-Sahel, the Old Basin, and Zone Sikasso-Bougouni. In these environments, the BRS 293 showed greater stability and productivity than the other varieties. The good seed cotton yield performance in multi-environment in Mali of the BRS 293 cotton variety was highlighted in the studies of [10] and [11].

The other two environments are the New Cotton Growing Zone and the Southern Extension Zone, and the varieties NTA L66 and NTA B149 proved to be much more suitable for these respective environments. Although BSR 293 was much more productive in the Southern extension zone environment, it was not stable. This result supports Dewdar [12] view that high-yielding genotypes can differ in terms of yield stability and suggests that yield stability and high average yield are not mutually exclusive. The stable genotype is defined as the genotype that exhibits relatively stable mean performance and minimal variance under different environmental conditions and has a high degree of adaptability across a wide range of environments [13]. Yield stability selection method was better than conventional selection in isolating and selecting the elite and adaptable genotypes when G x E interaction was significant [12]. The GGE Biplot method of analysis enabled us to identify ideal genotypes for each environment for seed cotton yield.

Concerning fiber cotton yield, the analysis of variance did not reveal any significant difference between varieties or the interaction between variety and location for seed cotton yield. However, a significant difference at $p<0.05$ was observed between environments.

It should be noted that the mean fiber yield at ginning (%) of all the genotypes tested was good and within the standards recommended (> 42 %) by the Mali cotton company [14].

The GGE biplot analysis method enabled us to group the six environments into three: two mega environments and one simple environment. As emphasized by Abdelmoghn, [13] the GGE biplot technique is one of the most appropriate methods for investigating the genotype x environment interaction.

The first mega-environment concerned the High Valley of the Niger, the Southern Extension Zone, and Zone Sikasso-Bougouni. The variety CG1 was identified as the most stable with good fiber productivity in this mega-environment. The North Sudan-Sahel and Old Basin composed the second mega-environment. The variety NTA L65 showed greater stability and productivity in fiber yield than the other varieties of this mega-environment. The simple environment was the New Cotton Growing Zone, and the BRS 293 and NTA E154 genotypes adapted better to this environment. As for seed cotton yield, the GGE biplot method has again allowed us to identify a stable and productive genotype for each environment (or group of environments). Yan and Rajcan, [15] indicated that the polygonal view of the GGE biplane is the best way to both identify the best genotypes and visualize patterns of interaction between genotypes and environments. The stability and desired response of genotypes in different environments are very important to plant breeders. Therefore, breeders always test their breeding material in different environments to assess the suitability of superior genotypes for wider adaptation [16].

5. Conclusion

The aim of this multi-environmental study is to evaluate cotton genotypes on the basis of their mean performance in a wide range of environments in order to identify superior genotypes with good adaptability and stability to a given environmental situation.

The result of the GGE biplot analysis method showed that the polygonal view identified three mega-environments (ME1, ME2 and ME3) with three winning genotypes: BRS 293, NTA B149 and NTA L66, respectively, for seed cotton yield. For fiber yield, the winning genotypes were CG1, NTA L65 and BRS 293, respectively.

Given that all the varieties tested have a mean fiber yield within the recommended norms, the two promising varieties NTA B149 and NTA L66 with good seed cotton yields and the standard check BRS 293 can be recommended for extension in the environments to which they have been assigned.

From seven varieties tested to determine seed cotton yield and fiber yield stability and adaptability in six cotton-growing areas of Mali using the GGE biplot analysis method, the six environments have been grouped into three mega-environments with three winning varieties.

This study provided a synthesis of cotton genotypes for the specific environment rather than simply a general adaptation of genotypes, as is generally practiced by the cotton breeding program in our country.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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Appendix

Table 3 List of villages

N° ord	Name of villages	Cotton production zones	Code of zones
1	Dabani	High Valley of the Niger	HVN
2	Karadjé	High Valley of the Niger	HVN

3	Samako	High Valley of the Niger	HVN
4	Tièlè	High Valley of the Niger	HVN
5	Djidian	New Cotton Growing Zone	NCGZ
6	Kita	New Cotton Growing Zone	NCGZ
7	Kokofata	New Cotton Growing Zone	NCGZ
8	Sébékoro	New Cotton Growing Zone	NCGZ
9	Bla	North Sudan-Sahel	NSS
10	Yangasso	North Sudan-Sahel	NSS
11	Bèlèco	Old Basin	OB
12	Dioila	Old Basin	OB
13	Fana	Old basin	OB
14	Kimparana	Old basin	OB
15	Konobougou	Old Basin	OB
16	Konséguela	Old Basin	OB
17	Kouniana	Old Basin	OB
18	Koutiala	Old Basin	OB
19	Maracoungo	Old Basin	OB
20	Molobala	Old Basin	OB
21	M'Pèssoba	Old Basin	OB
22	Karangana	Sikasso Bougouni	ZSB
23	Dialla	Southern Extension Zone	SEZ
24	Djaranidji	Southern Extension Zone	SEZ
25	Fanidiama	Southern Extension Zone	SEZ
26	M'Pièbougoula	Southern Extension Zone	SEZ
27	Nowélébougou	Southern Extension Zone	HVN
28	Winguéla	Southern Extension Zone	SEZ
29	Wokoro	Southern Extension Zone	SEZ
30	Foh	Zone Sikasso-Bougouni	ZSB
31	Garalo I	Zone Sikasso-Bougouni	ZSB
32	Massigui	Zone Sikasso-Bougouni	ZSB
33	Siani	Zone Sikasso-Bougouni	ZSB
34	Torokoro I	Zone Sikasso-Bougouni	ZSB
35	Yorosso	Zone Sikasso-Bougouni	ZSB