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Effects of planting date and density on cotton cultivars in sub-Saharan Africa rainfed conditions: A case study in Mali

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Abstract

Mali is among Africa's three biggest cotton (*Gossypium hirsutum* L.)-producing countries, and cotton growing is the principal driving force behind Mali's agricultural sector. Cotton production is rainfed on small-scale family farms as a commercial crop alongside staple crops grown for subsistence. Cultivar choice, planting date, and planting density are critical elements for seed cotton yield that should be optimized. This study aimed to understand the interactions between planting dates and planting densities for the optimal production of four cotton cultivars in Mali. Two trials were set up in two seasons at the Finkolo and N'Tarla research stations. A split-plot design with four replications was used, with planting dates (early and delayed by 3 weeks) as the main plots and planting density (41,666; 83,333; and 166,666 plants/ha) and cultivar (Malian NTA MS334, Togolese STAM 129A, Australian SIOKRA L23, and Brazilian BRS 293) as the subplots. In 2021, seed cotton yield was 1263 kg/ha for early planting versus 361 kg/ha for late planting. Medium and high planting densities produced the same yield level, higher than the low planting density. Regardless of the planting density, early plantings' average capsular weight and seed index were higher than those of late plantings. The African cultivars (STAM 129A and Malian cultivar NTA MS334) were the most productive. Due to significant interactions on fiber percentage and to optimize cotton yields in Mali, planting should be early, with planting densities higher than 41,666 plants/ha, and either of the African cultivars tested should be used.

1 | INTRODUCTION

Cotton (*Gossypium hirsutum* L.) fiber is the most widely used natural raw material in the textile industry and plays a vital role in the global economy (Qin & Zhu, 2011). In West Africa, rainfed agriculture is a significant economic sector but the most vulnerable to climate change (Roudier et al., 2011). Sub-Saharan Africa has climatic, agronomic, and socioeconomic limiting factors of cotton production (Traoré et al., 2021). For example, an appropriate planting time is critical to optimize cotton yield (Afzal et al., 2020), and the optimal planting window depends on the timing of the rainy season onset, which is likely to be postponed by climate change in West Africa (Gaetani et al., 2020).

Along with Benin and Burkina Faso, Mali is Africa's biggest cotton-producing country (FAO, 2024). In Mali,

Abbreviations: %F, percentage of fiber in seed cotton; AWB, average seed cotton weight per boll; SCY, seed cotton yield; SI, seed index.

cotton is the main cash crop (Lambert et al., 2018; Sanogo et al., 2010) and is rainfed and cultivated by small-scale family farmers (Yattara, 2014). Cotton contributes significantly to food security by boosting the yields of subsequent cereal crops (Ripoche et al., 2015). However, water stress is one of the most limiting environmental factors for agricultural production (Montaud, 2019). An appropriate planting time is critical to optimize cotton yield (Afzal et al., 2020). However, cotton is often planted late in Mali, which reduces seed cotton yields (SCYs) (Ali et al., 2011). Consequently, farmers should use adapted cultivars and practice better crop management (Amigues et al., 2006).

After the planting date, the second key crop management is planting density for a profitable SCY in Mali (Ali et al., 2011). For instance, in China, planting density has accounted for 46% of observed yield variability, ahead even of climate (Li et al., 2020), and increased density above 45,000 plants/ha has been a critical step in improving yield (Feng et al., 2022). A quantitative synthesis with normalized cotton lint yields has identified a threshold of 35,000 plants/ha below which cotton lint yield was affected (Adams et al., 2019). Optimal cotton density depends on the environment; suitable density could be as high as 300,000 plants/ha (Feng et al., 2022). However, it could be low for the region with the lowest yields in southern China (Feng et al., 2022), where SCY is lower than Mali's.

In Mali, planting is generally carried out by hand or with seed drills with 0.8 m between rows and 0.3 m between holes and two plants per hole, leading to a stand of 83,333 plants/ha. However, poor emergence, dry spells at the start of the season, and poor cultivation practices (weeding and ridging) can lead to low densities. In addition, there have been interactions in SCY between cotton cultivars and seeding rates (L. Zhang et al., 2008). The impact of cultivars, planting dates, and planting densities cannot, therefore, be decoupled, and the best possible combinations in the African rainfed conditions of Mali have yet to be discovered. African cotton cultivars have already displayed improved performance compared to American or Australian ones for SCY under early planting conditions (Traoré et al., 2023) and to European ones for the percentage of fiber content in the seed cotton (Tsaliki et al., 2024). This study aims to understand the interaction between planting date and planting density of African, Brazilian, and Australian cultivars on SCY and fiber content under rainfed conditions in Mali. The findings of this study can inform cotton research and development in similar contexts in sub-Saharan Africa.

> **Core Ideas**
>
> - Cotton cultivars from three continents were compared in 24 cropping situations in two sites and 2 years.
> - There was no interaction between cultivar, planting date, and planting density on seed cotton yield.
> - There was an interaction between planting date and cultivar on fiber content (percentage of fiber in seed cotton [%F]).
> - The %F of African cultivars was high and was not affected by late planting dates.
> - African cultivars performed better than others under early and late planting conditions.

2 | MATERIALS AND METHODS

2.1 | Location and rainfall patterns

The trials were set up in 2021 and 2022 at two experimental stations in Mali's cotton-growing zone: Finkolo (11°22′ N and 5°51′ W) and N'Tarla (12°35′ N and 05°42′ W). The total rainfall was 1254 mm in Finkolo in 2021, 1236 mm in 2022, 978 mm in N'Tarla in 2021, and 1176 mm in 2022 (Figure 1). In 2021, the cumulative rainfall available from planting to harvest was 969 mm in Finkolo for early planting and 887 mm for late planting. In N'Tarla, it was 686 mm for early planting and 609 mm for late planting. In 2022, it was 803 mm from planting in Finkolo, while it was 824 mm in N'Tarla. In 2022, the planting date factor could not be studied, as late planting failed due to massive jassid (*Amrasca biguttula*) attacks on seedlings.

2.2 | Experimental setup and the factors studied

In each location and for each year, the experimental design was set up as a split-plot with three factors repeated four times. The main plots were the planting dates, and the subplots were the combination of planting densities and cultivars randomly distributed in the large plots. Each small plot was 56 m^2 and corresponded to seven rows of 10 m with 0.8 m between two successive rows.

Three factors were studied: planting period, planting density, and cultivar. First, the planting period factor had two levels: early and late (about 3 weeks after early planting). In 2021, planting occurred in Finkolo on June 17 and July 10 and in N'Tarla on June 23 and July 13. In 2022, planting occurred on June 27 at Finkolo and June 29 at N'Tarla.

Second, the planting density factor had three levels. Planting was performed by hand. In order to be consistent with standard practice in Mali, two cotton plants were kept in each hole at the thinning time for all three levels, with a row spacing of 0.80 m. Only the distance between two successive holes on the same row varied between levels. Low density (D1) was planted every 0.60 m, aiming for a plant density of around

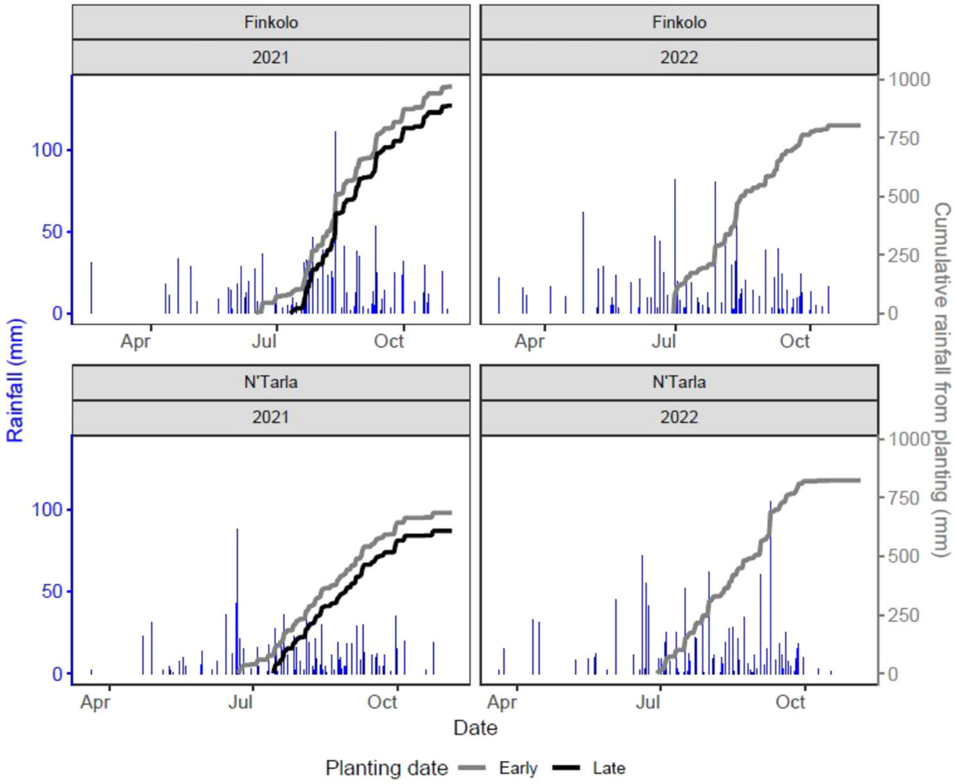

FIGURE 1 Rainfall pattern in Finkolo and N'Tarla in 2021 and 2022.

TABLE 1 Description of cultivars.

Cultivar	Origin	Seed cotton yield potential (kg/ha)	Cycle duration (days)	Traits
STAM 129A	Togo	3000	120–150	Cultivated in rainfed conditions of West Africa
SIOKRA L23	Australia	3800	130–155	Drought-tolerant and okra-leaf
BRS 293	Brazil	4600	160–170	Sensitive to diseases
NTA MS334	Mali	5000	130–150	Cultivated in rainfed conditions of West Africa

41,666 plants/ha; recommended density (D2), every 0.30 m, aiming for a plant density of around 83,333 plants/ha; and high density (D3), every 0.15 cm, aiming for a plant density of around 166,666 plants/ha.

Third, the cultivar factor had four levels. The four cultivars come from different geographical origins. NTA MS334 comes from Mali, STAM 129A from Togo, BRS 293 from Brazil, and the okra cultivar SIOKRA L23 from Australia. These cultivars were selected based on their morphology, productivity, and specific technological fiber characteristics (Table 1).

2.3 | General crop management

Plowing was carried out at Finkolo with an animal-drawn plow and at N'Tarla with a tractor. Plots were fertilized with 200 kg/ha of complex fertilizer 14 N-18 P2O5-18 K2O + 6S + 1B after the first weeding and 50 kg/ha of 46% N urea at the time of ridging. The fertilization provided 51 kg N/ha, 36 kg P/ha, 36 kg K/ha, 12 kg S/ha, and 2 kg B/ha. For the phytosanitary protection of cotton plants, the first two treatments were carried out using alternative products to pyrethroids, and the others using binary products against caterpillars and sucking pests (Table 2).

2.4 | Observations and measurements

Yield components and SCY were measured on the two central rows of each plot. On the day of harvest, the number of bolls was counted, and the harvested seed cotton was weighed to calculate SCY and average seed cotton weight per boll (AWB). After harvesting, the seed cotton was ginned with a laboratory saw ginning machine to determine the percentage of fiber in the seed cotton (percentage of fiber in seed cotton

TABLE 2 Insecticide applications in the experiment.

Year	Product composition	Rate (L/ha)	Finkolo	N'Tarla
2021	Spirotetramat 75 g/L + flubendiamide 100 g/L	0.20	July 25	Aug. 6
	Spirotetramat 75 g/L + flubendiamide 100 g/L	0.20	Aug. 8	Aug. 16
	Bifenthrin 120 g/L + acetamiprid 32 g/L	0.25	Aug. 22	Aug. 27
	Bifenthrin 120 g/L + acetamiprid 32 g/L	0.25	Sept. 5	Sept. 13
	Bifenthrin 120 g/L + acetamiprid 32 g/L	0.25	Sept. 19	Sept. 28
	Bifenthrin 120 g/L + acetamiprid 32 g/L	0.25	Oct. 3	Oct. 11
	Bifenthrin 120 g/L + acetamiprid 32 g/L	0.25	Oct. 17	Oct. 27
2022	Profenofos 500 g/L	1.00	July 21	Aug. 3
	Profenofos 500 g/L	1.00	July 26	Aug. 12
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Aug. 11	Aug. 19
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Aug. 26	Aug. 27
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Aug. 30	Aug. 29
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Sept. 6	Aug. 31
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Sept. 10	Sept. 6
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Sept. 15	Sept. 9
	Cypermethrin 120 g/L + profenofos 600 g/L	0.25	Sept. 20	Sept. 13

[%F]) and seed index (SI). The %F obtained corresponds to the weight of lint over the weight of seed cotton. The SI is the weight of 100 seeds, measured from a sample of 500 seeds.

2.5 | Data analysis

All data were processed using analysis of variance with a mixed linear model estimated using R software v4.3.1. The Bonferroni test was used to separate means anytime an effect was found to be significant.

Analyses were performed by year, as the planting date factor was absent in 2022, and the dataset needed to be more balanced to be analyzed globally. The R packages used were RODBC (Ripley & Lapsley, 2023) for reading datasets directly from an ACCESS database where it is located, tidyverse (Wickham et al., 2019), data.table (Barrett et al., 2024) and plyr (Wickham, 2011) for data manipulation and graphical representation of the results (with ggplot2), and, finally, lmerTest (Kuznetsova et al., 2017), emmeans (Lenth, 2024), and multcomp (Hothorn et al., 2008) for statistical analysis.

Graphical residual evaluations based on plots of residuals versus fitted values, Quantile–Quantile plot, and histogram of residuals in addition to skewness (0 is best) and kurtosis (3 is best) values evaluation were carried out to select the type of dependent variable transformation (square root, log, square, or no transformation) to be performed to guarantee compliance with the validity conditions of the analysis. The mixed models used are described in the following section. The random effects to structure the error are italicized, and the fixed effects are not. In the description of the models, the star (*) represents all the main effects and the interaction between them, and the column (:) represents the interaction only.

In 2021, with the planting date factor, we have:

$$\text{Transformation\_if necessary (dependent variable)} \sim \text{planting date} \times \text{planting density} \times \text{cultivar} \times \text{trial} + (1|\mathit{trial}:\mathit{block}) + (1|\mathit{trial}:\mathit{block}:\mathit{planting\ date})$$

In 2022, without the planting date factor, we have:

$$\text{Transformation\_if necessary (dependent variable)} \sim \text{planting density} \times \text{cultivar} \times \text{trial} + (1|\mathit{trial}:\mathit{block})$$

3 | RESULTS

3.1 | Seed cotton yield

There was no significant interaction on SCY between the factors studied in either year, and only main effects were significant (Table 3).

Yield varied for all the factors studied in both years (Table 4). In 2021, Finkolo's yield was slightly more than twice than that of N'Tarla, with a difference of 558 kg/ha, while in 2022, the yield was greater at N'Tarla than at Finkolo, 764 kg/ha versus 271 kg/ha, that is, a difference of 493 kg/ha.

In 2021, yields under early planting conditions were 902 kg/ha higher than those obtained under late planting conditions. Yield also varied with planting density. Yields

TABLE 3 Probability of fixed effects on dependent variables measured in 2021 and 2022.

	p-values 2021				*p*-values 2022			
Factor	**SCY**	**AWB**	**%F**	**SI**	**SCY**	**AWB**	**%F**	**SI**
Planting date	**0.0001**	**0.0010**	0.3451	**0.0006**				
Cultivar	**0.0000**	**0.0059**	**0.0000**	**0.0343**	**0.0116**	**0.0183**	**0.0002**	0.4171
Planting density	**0.0003**	0.5576	**0.0021**	0.8403	**0.0032**	0.0810	**0.0249**	0.5668
Trial	**0.0434**	**0.0021**	**0.0001**	0.0862	**0.0471**	**0.0193**	0.3949	0.2117
Planting date:cultivar	0.9495	0.4882	**0.0001**	0.7140				
Planting date:planting density	0.5516	0.4532	0.7654	0.9155				
Cultivar:planting density	0.4318	0.7083	0.3207	0.4211	0.5548	0.4449	0.7996	0.2431
Planting date:trial	0.1689	0.9347	0.9606	0.2184				
Cultivar:trial	0.2708	**0.0113**	**0.0130**	**0.0010**	0.2003	0.2815	0.6949	**0.0005**
Planting density:trial	0.1081	**0.0000**	0.4825	0.7372	0.3068	0.1671	0.9489	0.7768
Planting date:cultivar:planting density	0.6429	0.7551	0.4018	0.2355				
Planting date:cultivar:trial	0.8496	0.6884	0.0510	0.7493				
Planting date:planting density:trial	0.1690	**0.0458**	0.0909	0.5768				
Cultivar:planting density:trial	0.5502	0.8316	0.0792	0.1432	0.5795	0.9190	0.2142	0.6992
Planting date:cultivar:planting density:trial	0.7870	0.0920	0.5742	0.6369				
Coefficient of variation (%)	17.7	17.2	7.6	12.9	29.2	19.3	2.1	5.3

Note: Bold numbers indicate $p < 0.05$.
Abbreviations: %F, percentage of fiber in seed cotton yield; AWB, average seed cotton weight per boll; SCY, seed cotton yield; SI, seed index.

TABLE 4 Seed cotton yield (SCY) in experiments of Finkolo and N'Tarla in 2021 and 2022.

Factor level		**SCY 2021 (kg/ha)**	**SCY 2022 (kg/ha)**
Trial	Finkolo	1047 (183)a	271 (104)b
	N'Tarla	491 (125)b	764 (175)a
Planting date	Early	1263 (156)a	
	Late	361 (83)b	
Planting density	D1: 41,666 plants/ha	639 (104)b	355 (92)b
	D2: 83,333 plants/ha	777 (115)a	526 (111)a
	D3: 166,666 plants/ha	820 (118)a	593 (118)a
Cultivar	BRS 293	719 (112)a	388 (99)b
	NTA MS334	833 (121)a	474 (110)ab
	SIOKRA L23	578 (100)b	440 (106)ab
	STAM 129A	860 (122)a	663 (130)a
Average		763	497
Coefficient of variation (%)		17.7	29.2

Note: Numbers in parentheses are standard errors. Factor levels that do not share a letter differ at the 5% threshold in comparison tests with Bonferroni correction.
Abbreviations: D1, low planting density of 41,666 plants/ha; D2, planting density vulgarized of 83,333 plants/ha; D3, high planting density of 166,666 plants/ha.

at medium (D2: 83,333 plants/ha) and high (D3: 166,666 plants/ha) densities were at the same level and higher than at low density (D1: 41,666 plants/ha). In 2021, SIOKRA L23 was the least productive cultivar, while the other three cultivars were at the same level. In 2022, BRS 293 was less productive than STAM 129A. The cultivar STAM 129A had the highest yield in both years.

3.2 | Average seed cotton weight per boll

The AWB was influenced by all single factors except planting density (Table 3). In 2021, there were also cultivar × trial, planting density × trial, and planting date × planting density × trial interactions.

In 2021, AWB was higher at Finkolo than at N'Tarla, 3.4 g versus 2.2 g, a difference of 1.2 g (Table 5). In 2021, AWB was favored by early planting with 3.2 g versus 2.4 g for late planting. No difference in AWB was observed between the planting densities. In 2021, the cultivars STAM 129A and NTA MS334 had the same AWB level at 2.9 g, while the AWB of the cultivar SIOKRA L23 was low (2.6 g). In 2022, the AWB of cultivar STAM 129A was higher than that of BRS 293.

In 2021, under late planting conditions at Finkolo, the AWB under low density (41,666 plants/ha) was higher than that under high density (166,666 plants/ha), while at N'Tarla, the AWB of high density was higher than the AWB of other two planting densities (Figure 2). Under early planting conditions, the density did not influence AWB, irrespective of the planting density.

In 2021, whatever the planting density and the experimental site, the AWB of early plantings was always higher than that of late plantings (Figure 3).

TABLE 5 Average seed cotton weight per boll (AWB) in experiments of Finkolo and N'Tarla in 2021 and 2022.

Factor	Level	AWB 2021 (g)	AWB 2022 (g)
Trial	Finkolo	3.4 (0.2)a	2.1 (0.2)b
	N'Tarla	2.2 (0.1)b	2.9 (0.2)a
Planting date	Early	3.2 (0.2)a	
	Late	2.4 (0.1)b	
Planting density	D1: 41,666 plants/ha	2.7 (0.1)	2.3 (0.1)
	D2: 83,333 plants/ha	2.7 (0.1)	2.6 (0.1)
	D3: 166,666 plants/ha	2.8 (0.1)	2.5 (0.1)
Cultivar	BRS 293	2.7 (0.1)ab	2.3 (0.1)b
	NTA MS334	2.9 (0.1)a	2.4 (0.1)ab
	SIOKRA L23	2.6 (0.1)b	2.5 (0.1)ab
	STAM 129A	2.9 (0.1)a	2.7 (0.1)a
Average		2.8	2.5
Coefficient of variation (%)		17.2	19.3

Note: Numbers in parentheses are standard errors. Factor levels that do not share a letter differ at the 5% threshold in comparison tests with Bonferroni correction. Abbreviations: D1, low planting density of 41,666 plants/ha; D2, planting density vulgarized of 83,333 plants/ha; D3, high planting density of 166,666 plants/ha.

At N'Tarla, STAM 129A and NTA MS334 had higher AWB than the other two cultivars (Table 6). No difference in AWB was observed between cultivars at Finkolo.

3.3 | Percentage of fiber at ginning

In 2021, the %F at ginning was influenced by planting density, cultivar, and trial, and there were also planting date × cultivar and trial × cultivar interactions (Table 3). In 2022, %F was only influenced by cultivar and planting density.

In 2021, the %F was higher at Finkolo (44.7%) than at N'Tarla (41.5 %). In contrast, in 2022, no difference was observed between the trials (Table 7). The planting period did not affect %F, while the low planting density reduced it. NTA MS334 showed the highest %F in both years, and SIOKRA L23 was the lowest. In 2021, STAM 129A and NTA MS334 outperformed SIOKRA L23 at N'Tarla (Table 6), while at Finkolo, all three cultivars outperformed SIOKRA L23.

In 2021, at the early planting date, cultivars BRS 293 and NTA MS334 had higher %F than SIOKRA L23 (Table 8). At the late planting date, NTA MS334 maintained the highest %F, followed by STAM 129A, higher than BRS 293 and SIOKRA L23. The planting period did not affect the %F of cultivars NTA MS334, SIOKRA L23, and STAM 129A, while it did for cultivar BRS 293, which had a lower %F under late planting conditions.

3.4 | Seed index

The SI had a different varietal response per trial for 2021 and 2022 (Table 3). In 2021, simple effects of planting date and cultivar effects affected the SI. In 2022, no single effect was detected. There was a significant cultivar-by-trial interaction both in 2021 and 2022.

In both years, no difference in SI was observed between trials and planting densities. Similarly, in 2022, there was no difference in SI for cultivars (Table 9). Early planting favored SI compared to late planting, with a difference of 0.6 g. In 2021, STAM 129A had the best SI in N'Tarla (Table 6).

4 | DISCUSSION

The SCYs under early planting conditions (Table 4) were similar to those observed under nonirrigated conditions in sub-Saharan Africa at around 1000–1200 kg/ha (Ripoche et al., 2015; Soumaré et al., 2020) but were very low under late planting. The rainfall amount available for the cotton crop (Figure 1) was considered insufficient in N'Tarla in 2021 (Traoré et al., 2023). In 2022, planting occurred at the end of June, with around 800 mm available for N'Tarla and Finkolo. Moreover, jassid attacks may have resulted in a further reduction in yield in Finkolo in 2022.

Delayed planting dates led to reduced water availability for the crop (Figure 1), induced lower SCY (Table 4), and increased %F (Table 7). This is consistent with previous findings (Iqbal & Khan, 2011; Zhao et al., 2018). Under reduced water availability, an increase of %F was also observed in Europe (Tsaliki et al., 2024). Similarly, it was found in the United States (Texas) that late planting with a similar delay in planting date of 20 days led to a significant decrease in (lint) cotton yields, cutting down yields by more than twice (Bilbro & Ray, 1973). As in Pakistan (Ali et al., 2011), the best yields were obtained with early planting (Table 4). Early planting favored SCY (Table 4), SI (Table 9), and AWB (Table 5 and Figure 3), confirming results in Ghana (Adombilla et al., 2023). If a dry spell occurs shortly after planting, early seedlings will die; fortunately, cotton seeds are not yet too costly, and Malian farmers could be able to plant again. In addition, if the planting occurs too early, the cotton bolls will crack open before the end of the rainy season, risking the fiber getting wet and rot. However, Malian cotton farmers harvest twice, so this risk is not too significant either.

SCY also varied according to planting density (Table 4), confirming the importance of planting density on yield (Li et al., 2020). Medium and high density had similar yields and had greater yields than low density, as previously observed

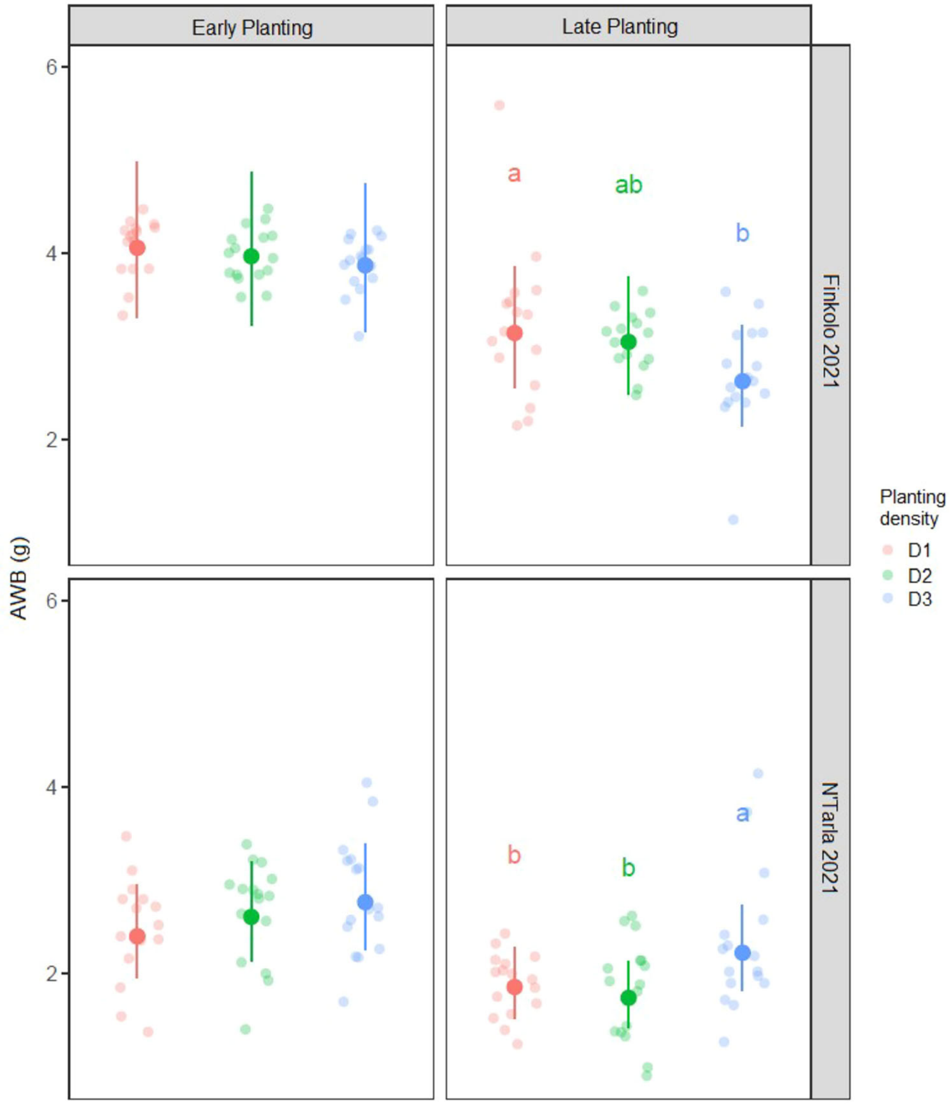

FIGURE 2 Average seed cotton weight in boll in Finkolo and N'Tarla in 2021 by planting density. Within a box, the planting densities that do not share a letter differ at the 5% threshold in comparison tests with the Bonferroni correction. AWB, average seed cotton weight per boll; D1, low planting density of 41,666 plants/ha; D2, planting density vulgarized of 83,333 plants/ha; D3, high planting density of 166,666 plants/ha.

(Zhi et al., 2016), where densities of 51,000 and 87,000 plants/ha increased yield compared with low density. A low density of 41,333 plants/ha produced lower SCY (Table 4), confirming that optimal planting densities in Malian conditions are superior to 41,666 plants/ha with a minimum 45,000–67,500 plants/ha for regular cultivars (L.-Z. Zhang et al., 2006). Similarly, previous studies identified that low densities lead to lower SCY than higher densities (Jalilian et al., 2023; L. Zhang et al., 2008). A quantitative synthesis found a threshold of 35,000 plants/ha from which a decrease in fiber yield can be observed (Adams et al., 2019). Other results differed from these, most likely due to differences in cultivars, crop management (lower row width, rainfed exclusively), and weather conditions, which were quite different from our study. In Adams et al. (2019), the lowest lint yield explored was at least two times higher than those observed in our study. Our study showed that low planting density produced a low %F (Table 7), contrary to other studies where %F decreased with density (Jalilian et al., 2023; Khan et al., 2017). In Jalilian et al. (2023), the highest density corresponded to our lowest density. In Khan et al. (2017), only one cultivar was studied, while we observed cultivar by planting date interaction on %F (Table 8). The plant density explored did not consistently impact AWB (Table 5 and Figure 2), unlike what was observed on Asian cotton under higher planting densities (Blaise et al., 2021). Our results are consistent with those of Khan et al. (2017), where no effect was observed on AWB under similar planting density. With similar AWB between planting densities, the reduction in SCY we observed under low planting density was most likely due to a reduction in the density of cotton bolls similar to previously observed (Zhi et al., 2016).

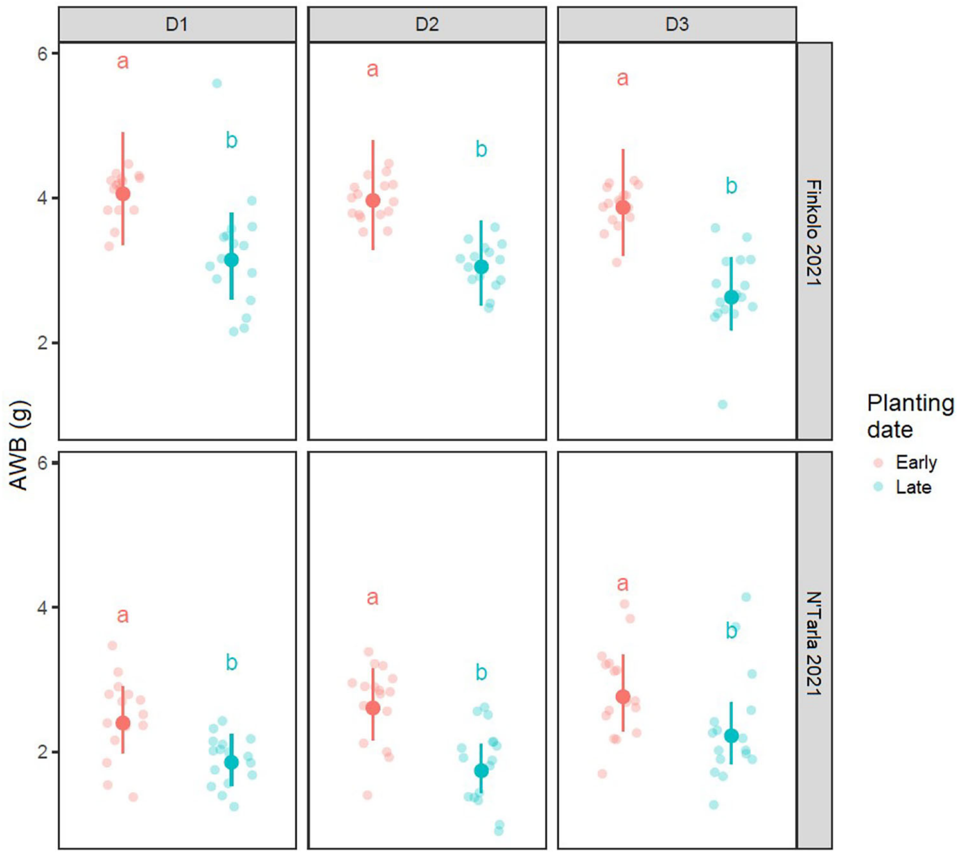

FIGURE 3 Average seed cotton weight in boll in Finkolo and N'Tarla in 2021 by planting date. Within a box, planting dates that do not share a letter are different at the 5% threshold in comparison tests with the Bonferroni correction. AWB, average seed cotton weight per boll; D1, low planting density of 41,666 plants/ha; D2, planting density vulgarized of 83,333 plants/ha; D3, high planting density of 166,666 plants/ha.

TABLE 6 Average boll weight (AWB), the fiber content in seed cotton (%F), and seed index (SI) by cultivar in 2021.

Trial	Cultivar	AWB (g)	%F	SI (g)
Finkolo	BRS 293	3.4 (0.2)	45.0 (0.4)a	7.5 (0.1)
	NTA MS334	3.5 (0.2)	45.2 (0.3)a	7.4 (0.1)
	SIOKRA L23	3.4 (0.2)	43.5 (0.4)b	7.3 (0.1)
	STAM 129A	3.4 (0.2)	45.2 (0.3)a	7.4 (0.1)
N'Tarla	BRS 293	2.1 (0.1)b	41.1 (0.4)b	6.9 (0.1)b
	NTA MS334	2.4 (0.2)a	43.3 (0.4)a	7.1 (0.1)b
	SIOKRA L23	2.0 (0.1)b	39.4 (0.4)c	7.3 (0.1)ab
	STAM 129A	2.5 (0.2)a	42.1 (0.4)ab	7.5 (0.1)a

Note: Numbers in parentheses are standard errors. Factor levels that do not share a letter differ at the 5% threshold in comparison tests with Bonferroni correction.

The cultivar STAM 129A had better SCY compared to cultivar SIOKRA L23 (Table 4) due to heavier seeds (SI, Table 6) and bolls with more seed cotton (AWB, Table 4). This result corroborates previous findings in Senegal under early planting conditions (Traoré et al., 2023). The low yield of the okra-leaved cultivar SIOKRA L23 (Table 4) can be explained by the lower light interception afforded by its leaves (Chapepa et al., 2020). The African cultivars had a high %F and high fiber quality, which is observed as one of their critical features in breeding programs (Loison et al., 2017), consistent with previous studies in Greece (Tsaliki et al., 2024). The cultivar NTA MS334 tends to have higher AWB than cultivar BRS 293 (Table 6), similar to the pattern observed in Mali (Sissoko et al., 2020). The difference in AWB between well-irrigated and stressed conditions is a good indicator of the stress tolerance index (STI) for cotton (Quevedo et al., 2022). The difference in AWB and rainfall patterns in N'Tarla and Finkolo in 2021 indicated that NTA MS334 and STAM 129A may have better STI than the other two cultivars tested due to higher values of AWB under lower water availability, yet similar AWB under better conditions in Finkolo.

There was a significant cultivar effect and interaction between cultivars and planting date effect on %F (Table 3), consistent with Bilbro and Ray (1973). We found that a cultivar reduced its %F (BRS 293) with a delayed planting date (Table 8), similar to the findings of Bilbro and Ray (1973). We found that delayed planting did not affect the %F of some cultivars (Table 8), similar to the findings of Zhao et al. (2018). There was no significant interaction between cultivar, planting date, and density on SCY (Table 3), similar to previous

TABLE 7 Percentage of fiber in seed cotton (%F) by main fixed effect in 2021 and 2022.

Factor	Level	%F 2021	%F 2022
Location	Finkolo	44.7 (0.2)a	45.4 (0.7)
	N'Tarla	41.5 (0.2)b	46.3 (0.7)
Planting date	Early	43.0 (0.2)	
	Late	43.3 (0.2)	
Planting density	D1: 41,666 plants/ha	42.6 (0.2)b	45.1 (0.5)b
	D2: 83,333 plants/ha	43.2 (0.2)ab	46.5 (0.6)a
	D3: 166,666 plants/ha	43.6 (0.2)a	45.9 (0.6)ab
Cultivar	BRS 293	43.1 (0.3)b	45.2 (0.6)b
	NTA MS334	44.2 (0.3)a	47.2 (0.6)a
	SIOKRA L23	41.5 (0.3)c	44.7 (0.6)b
	STAM 129A	43.6 (0.3)ab	46.3 (0.6)ab
Average		43.1	45.8
Coefficient of variation (%)		7.6	2.1

Note: Numbers in parentheses are standard errors. Factor levels that do not share a letter differ at the 5% threshold in comparison tests with Bonferroni correction. Abbreviations: D1, low planting density of 41,666 plants/ha; D2, planting density vulgarized of 83,333 plants/ha; D3, high planting density of 166,666 plants/ha.

TABLE 8 Percentage of fiber in seed cotton (%F) by cultivar under early or late planting date in 2021.

Planting date	Cultivar	%F
Early	BRS 293	43.7 (0.4)a
	NTA MS334	43.6 (0.4)a
	SIOKRA L23	41.7 (0.4)b
	STAM 129A	42.9 (0.4)ab
Late	BRS 293	42.5 (0.4)b
	NTA MS334	44.9 (0.3)a
	SIOKRA L23	41.2 (0.4)b
	STAM 129A	44.4 (0.3)a

Note: Numbers in parentheses are standard errors. Factor levels that do not share a letter differ at the 5% threshold in comparison tests with Bonferroni correction.

findings (Galanopoulou-Sendouka et al., 1980). There was also no significant interaction between cultivar and planting density on SCY (Table 3). Similarly, no interaction was observed between cultivar and planting geometry on lint yield (Hall et al., 2024). In contrast, Zhang et al. (2008) found some interaction between cultivar and planting density on SCY, but they used hybrids. We expected a significant interaction between cultivar and planting density on SCY, as SIOKRA L23 should have had a solid response to increasing density (Chapepa et al., 2020). However, this differed with the range of planting densities studied (Table 3). There was no significant interaction on SCY between planting dates and

TABLE 9 Seed index (SI) by main fixed effect in 2021 and 2022.

Factor	Level	SI in 2021 (g)	SI in 2022 (g)
Trial	Finkolo	7.4 (0.1)	6.2 (0.2)
	N'Tarla	7.2 (0.1)	5.7 (0.2)
Planting date	Early	7.6 (0.1)a	
	Late	7.0 (0.1)b	
Planting density	D1: 41,666 plants/ha	7.3 (0.1)	6.0 (0.2)
	D2: 83,333 plants/ha	7.3 (0.1)	6.0 (0.2)
	D3: 166,666 plants/ha	7.3 (0.1)	5.8 (0.2)
Cultivar	BRS 293	7.2 (0.1)b	5.8 (0.2)
	NTA MS334	7.2 (0.1)ab	6.0 (0.2)
	SIOKRA L23	7.3 (0.1)ab	5.9 (0.2)
	STAM 129A	7.5 (0.1)a	6.1 (0.2)
Average		7.3	5.9
Coefficient of variation (%)		12.9	5.3

Note: Numbers in parentheses are standard errors. Factor levels that do not share a letter differ at the 5% threshold in comparison tests with Bonferroni correction. Abbreviations: D1, low planting density of 41,666 plants/ha; D2, planting density vulgarized of 83,333 plants/ha; D3, high planting density of 166,666 plants/ha.

planting density (Table 3). This contrasts with the findings of Iqbal and Khan (2011), who used a much broader planting period of 2 months, which probably led to reduced productive flowering time under late planting with high density (Sekloka et al., 2007).

The attacks of jassids hindered the experiment in 2022. Therefore, the statistical analysis was conducted separately for each year. Pests are a significant issue in cotton production; hence, intercropping cotton with other crops could improve pest resistance (Chi et al., 2021). For yield improvement and economic benefit, increasing row spacing might not be a solution (Lawton et al., 2023). Conversely, decreasing row spacing is a potential solution, as it has been shown to increase the yield of *Gossypium arboreum* L. cotton (Blaise et al., 2021). Increasing population density using double rows has also increased seed cotton and lint yields (Pinnamaneno et al., 2021). In Mali, the row spacing is 0.80 m, and its reduction or double-row cultivation should be considered for seed–cotton yield improvements, even if it requires a significant modification of crop management.

5 | CONCLUSION

To optimize SCY in Mali, an experiment combining 2 years of studies at two sites evaluated four cultivars planted at three densities and two planting periods. The best yields were obtained with early planting, at 83,333 or 166,666 plants/ha, and the cultivar STAM 129A as compared to non-African cultivars. Locally adapted African cultivars performed better than foreign germplasms. Whatever the planting density, the AWB of early plantings was higher than that of late plantings. Early planting also favored SI over late planting. The study revealed that to optimize SCY, the cultivar STAM 129A should be preferred to the Malian and the others under early planting at 83,333 or 166,666 plants/ha.

AUTHOR CONTRIBUTIONS

Elhadji Mamoudou Kassambara: Conceptualization; data curation; methodology; writing—original draft; writing—review and editing. **Romain Loison**: Conceptualization; formal analysis; investigation; methodology; software; supervision; validation; visualization; writing—original draft; writing—review and editing. **Sory Sissoko**: Conceptualization; funding acquisition; investigation; supervision; writing—original draft; writing—review and editing. **Abdou Traoré**: Investigation; methodology; writing—review and editing. **Alhousseini Bretaudeau**: Conceptualization; investigation; methodology; supervision; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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