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Cotton (Gossypium Hirsutum L.) Yield Losses Linked To Boll Rot In The Sudano-Sahelian Zone Of Mali

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Abstract
Cotton (Gossypium hirsutum L.) is an important cash crop in Mali's national economy, contributing around 19% of gross domestic product (GDP). Yield depends on various factors, including the high (healthy) number of bolls in the field. The aim of this study was to assess the effect of boll rot on seed cotton yield. The experiment was conducted at the Finkolo station (11° 22' North, 5° 51' West) in Mali in 2020 and 2021. The plant material consisted of eight varieties of cotton planted in a Randomized Complete Block Design (RCBD) with eight replications. The results of this experiment showed no significant interaction between varieties and the total number of rotten bolls per hectare, the percentage of rotten bolls, seed cotton yield and yield loss due to boll rot. This suggests that boll rot is not a varietal problem but an environmental concern. In addition, the number of rotten bolls increased when the annual average rainfall, temperature (max and min), maximum humidity, number of plants per hectare, and seed cotton yield increased. This experiment revealed an average yield loss of around 100 kg per hectare of cotton planted in the area. As the area is one of Mali's major cotton production basins, the loss observed is too high on the scale of the area planted in particular and the country in general. It is important to take appropriate precautions to preserve the bolls in the fields in years of high rainfall and high temperatures, and to guarantee a good harvest.
Key-words: *Boll rot, cotton yield, Mali*

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I. Introduction

Cotton is the most important natural fiber produced in the world (Amrouk and Palmer, 2021). In sub-Saharan Africa, it is mainly grown in the rainy seasons by smallholders and harvested by hand. Compared with the major producing countries, where it is much more intensive, capitalistic, and often irrigated, it is very different. Cotton is of considerable economic and social importance to the African countries that grow it, particularly those in the CFA (*Communauté Financière Africaine*) zone (Berti et al. 2006).

Indeed, cotton contributes around 8% to 12% of gross domestic product (GDP), 40% of total export revenues; and 70% of agricultural export revenues in the C-4 countries: Benin, Burkina Faso, Mali and Chad (WTO, 2019).

In Mali, the cotton sector contributes to the dynamic that is essential for maintaining economic growth, taking into account its contribution to the various spheres of the economy. Cotton production gives numerous farming households access to an income that enables them to live in acceptable conditions. It gives them the opportunity to save and finance some projects during good agricultural seasons (Camara, 2016).

Mali was ranked as the continent's leading cotton producer in 2018, with 725,000 tons of seed cotton. (Maiga 2019 in Westerberg et al., 2020), from an area of more than 795,000 hectares (Maiga, 2022). Despite this ranking in Africa, cotton production in Mali is subject to a number of constraints that affect part of its production. These include boll rot, which occurs before the plants reach maturity and is often caused by biotic factors (insect bites, fungi, etc.) or abiotic factors (drought, humidity, cultivation practices, etc.). Boll rot is a problem that continues to frustrate growers. When growing conditions are favorable, the best bolls are the most threatened. Once a boll is infected, it is too late to contain the disease (Guthrie et al. 1994). Boll rot is not a constant or universal problem for cotton growers. Boll rot surveys and loss estimates reveal strong regional and seasonal variability (Guthrie et al. 1994). Between 2010 and 2011, boll rot is estimated to have caused a yield loss of between 100,153 and 182,708 bales of US cotton, and the pattern has continued since (Goldberg et al. 2010). In

Mali, the cotton industry and agricultural research institutions have no concrete statistical data on the impact of cotton boll rot on seed cotton yields.

The objectives of this study are to:
- Determine the effect of boll rot on cotton yield in the Sudano-Sahelian zone of Mali;
- Identify correlations between boll rot and some agro-morpho-physiological and climatic parameters.

II. Material and Methods

Experimentation site

The experiment was conducted at the Finkolo agricultural research station, located in the rural municipality of Finkolo (11° 22′ North, 5° 51′ West), 18 km east of Sikasso (Mali's third administrative region). The climate is Sudano-Sahelian, with average annual rainfall varying between 1,000 and 1,200 minutes in a normal rainy year. The average minimum and maximum temperatures are 19°C and 38°C, respectively.

Plant material

The plant material consisted of two varieties already released: BRS 293 from Brazil and NTA 88-6 from Mali. And four promising varieties at the final stage of experimentation: Y 331-B, LVYI N°8, both from China, FK 140 from Burkina Faso and NTA P32 from Mali.

Experimental design

The experiment was conducted during the rainy season for two years (2020 and 2021) at the Finkolo research station in a Randomized Complete Block Design (RCBD) with eight replicates. The elementary plot consisted of three lines of 10 m in length. The observations were made on the central line.

Mineral fertilizers were applied uniformly under the seed rows at the rate recommended in Mali. The cotton complex was formulated as 14N-18P2O5-18K2O +6S +1B at a rate of 200 kg/ha, i.e., 160g per 10m row at sowing and 50 kg/ha of urea (46% N), i.e., 40 g per 10m row at 40 days from emergence. For plant protection, the plot was treated every 14 days with an insecticide based on spirotetramat 15 g/ha + flubendiamide 20 g/ha.

Data collection and analysis

Data were collected for traits including: number of monopodia (vegetative branches) per plant (NM/PL), number of sympodia (fruiting branches) per plant (NS/PL), insertion node of the first sympodia (INFS), plant height (PLH), number of plants per hectare (NP/ha), days to 50% Maturity (DM50%), total number of bolls harvested per hectare (TNBH/ha), total number of rotted bolls per hectare (TNRB/ha), total number of healthy bolls per hectare (TNHB/ha), percent rotted bolls (%RB*)*, Seed cotton yield (SCY), Yield losses (YL).

For the determination of seed cotton yield, seed cotton harvested from the individual plots (central rows) was weighted to determine yield in kilograms per hectare (kg/ha).

The loss of seed cotton yield was estimated as the ratio of the total number of rotten bolls multiplied by the seed cotton yield (kg/ha) of the bolls to the total number of healthy bolls.

Analyses of variance of the data were performed to compare the means of the different parameters observed at the 5% significance level. Tukey's multiple comparison test was used for pairwise separation of different homogeneous groups for each factor.

III. Results

The results of the climate data analysis, presented in Figures 1 and 2, show that the average annual rainfall in 2021 (1253.8 mm) was higher than in 2020 (930.4 mm). The months of July, August and mid-September were the rainiest. The rainfall in July and August 2021 was still significantly higher than in 2020 (Figure 1). In terms of temperature and humidity (maximum and minimum), the annual mean and the July and August mean for maximum temperature and humidity in 2021 are still slightly higher than in 2020. And the mean minimum temperatures are practically at the same level during the two seasons.

It should be noted that July and August also coincide with the fruiting period for cotton plants in the zone. So climatic variations during these periods can have a major impact on the fruiting of the plants and their state of health.

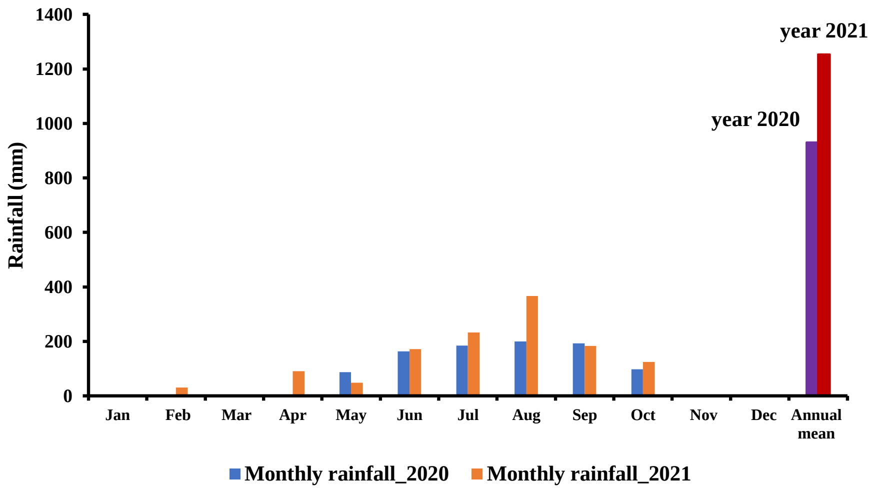


Figure 1. Mean of seasonal Rain fall (mm) of experimental site during the study period 2020 and 2021 years (Source: Finkolo weather station 2020 and 2021).

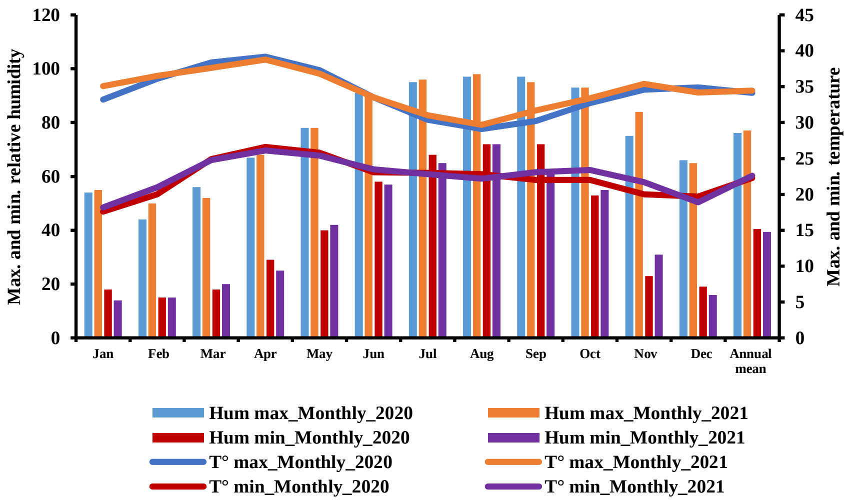


Figure 2. Mean of seasonal temperature and humidity (max and min) of experimental site during the study period 2020 and 2021 years (Source: Finkolo weather station 2020 and 2021).

Mean squares of various parameters (traits) across two years experimentation (2020 and 2021)

The results of the analyses of variance (ANOVA) for the different parameters measured are shown in Table 1. There was a significant difference ($p<0.01$ or $p<0.05$) between the varieties for all the parameters studied except the total number of rotten bolls per hectare, the percentage of rotten bolls, the seed cotton yield, and the yield loss due to boll rot. Significant differences were observed between the two experimental years for all the parameters studied, except for the number of monopodia branches. This explains why these parameters were better one year than the next. Between the variety and year interaction, there were significant differences only for two parameters: the number of plants per hectare and the 50% maturity date. This explains why, for these two parameters, the varieties behaved differently from one year to the next.

Mean of the different morpho-physiological and agronomic characteristics of varieties across two years experimentation (2020 and 2021)

The results of the analysis of variance revealed a significant difference ($p<0.01$ or $p<0.05$) between the varieties of all morphological-physiological parameters (Table 2). Several homogeneous groups between varieties were formed with the application of the Tukey test. The variety NTA 88-6 had the highest number of monopodia per plant (NM/PL) and formed the homogeneous group "a" with 2.1 monopodia. The varieties BRS 293, NTA P32 and FK 140 have the lowest number and form group "c" (table 2). The same variety, NTA 88-6, has the highest number of sympodia per plant (NS/PL) with 22.3 sympodia, the highest insertion heights of the first sympodia node (INFS) with 6.2, and the highest plant height (PLH) with 153 cm. BRS 293 always has the lowest value for these parameters (Table 2). Five homogeneous groups (a, ab, abc, bc and c) were obtained using the Tukey test for the 50% maturity date parameter. The variety NTA P32 has the longest cycle with 120 days and constitutes the homogeneous group "a". LVYI N°8 has the shortest cycle (114 days) and forms group "c".

The results of the analysis of variance revealed a significant difference ($p<0.01$ or $p<0.05$) between the varieties in relation to three agronomic parameters: the number of plants per hectare, the total number of bolls harvested and the total number of healthy bolls (table 2).

The results show the composition of three homogeneous groups for the NP/ha parameter (a, ab and b). Y 331-B had the highest NP/ha with 58,828 plants per hectare. The lowest number of plants per hectare was obtained with LVYI N°8 (49,375 plants/ha). An average of 53,945 plants per hectare was recorded (Table 2). An average of 464,987 total bolls harvested per hectare (TNBH/ha), with BRS 263 having the highest number of bolls per hectare (505,156 bolls) forming homogeneous group "a" and NTA P32 forming group "b" with a total of 404,766 bolls. The other four varieties form the "ab" homogeneous group. Three homogeneous groups (a, ab and b) were formed for the parameter total number of healthy bolls (TNHB/ha). BRS 293 recorded the highest number of healthy bolls, followed by FK 140, LVYI N°8, NTA 88-6 and Y 331-B, which form the "ab" group, and NTA P32, which forms the "b" group, with 384,688 healthy bolls (Table 2).

The analysis of variance did not reveal any significant difference ($p<0.01$ or $p<0.05$) between the varieties with regard to the other agronomic parameters, which are a total number of rotten bolls per hectare (TNRB/ha), percentage of rotten bolls (%RB), seed cotton yield per hectare (SCY) and yield loss (YL). This means that the varieties are all equivalent for these parameters. An overall mean of 20,404 total number rotted bolls per hectare (TNRB/ha), i.e., 4.3% of the total number of bolls harvested. This can be explained by the fact that boll rot is not linked to the variety but mainly to biotic and abiotic factors. An average yield of 1837 kg/ha and an average loss of 85 kg/ha were also recorded. Variety Y 331-B had the highest arithmetic mean for the number of rotten bolls and yield loss, with 24,375 rotten bolls per hectare and 103 kg/ha yield loss, respectively.

Table 1. Mean squares of various parameters (traits) across two years experimentation (2020 and 2021)

Source of variation	d.f.	NM/PL	NS/PL	INFS	PLH (cm)	NP/ha	DM50% (day)	TNBH/ha	TNRB/ha	TNHB/ha	%RB	SCY (kg/ha)	YL (kg/ha)
Variety	5	1.7427**	49.453**	1.3916**	3021.6**	1.89E+08*	68.094**	2.80E+10*	1.20E+08ns	2.81E+10*	7.768 ns	375384ns	2756ns
Year	1	0.015ns	853.83**	4.1251**	26927.3**	8.75E+09**	41.344*	3.38E+11**	6.32E+09**	2.52E+11**	130.4**	5752604**	117914**
Variety x Year	5	0.4895 ns	2.383ns	0.0496 ns	296.5ns	4.99E+08**	35.944**	1.35E+09ns	9.71E+07ns	1.86E+09ns	8.158 ns	16270ns	2194ns
Residual	84	0.4029	7.507	0.1958	276	6.72E+07	6.874	9.37E+09	1.09E+08	8.98E+09	4.204	184826	1816

d.f. = Degree of freedom, **NM/PL** = Number of monopodia (vegetative branches) per plant, **NS/PL** = Number of sympodia (fruiting branches) per plant, **INFS** = Insertion Node of the first Sympodial branches, **PLH** = Plant height, **NP/ha** = Number of plants per hectare **DM50%** = Days to 50% Maturity, **TNBH/ha =** Total Number of bolls harvested per hectare, **TNRB/ha =** Total Number of rotted bolls per hectare, **TNHB/ha =** Total Number of healthy bolls per hectare, **%RB** = *percent* rotted bolls, **SCY** = Seed cotton yield, **YL** = Yield losses, *** =** Significant at the 0.05 probability level, **** =** Significant at the 0.01 probability level, **ns =** not significant.

Table 2. Mean of the different morpho-physiological and agronomic characteristics of varieties across two years experimentation (2020 and 2021)

Variety	NM/PL	NS/PL	INFS	PLH (cm)	DM50% (day)	NP/ha	TNBH/ha	TNRB/ha	TNHB/ha	%RB	SCY (kg/ha)	YL (kg/ha)
BRS 293	1.3 b	17.3 c	5.5 b	113 c	116 bc	55234 ab	505156 a	20234	484922 a	4.0	1993	84
FK 140	1.4 b	20.3 ab	5.5 b	124 bc	118 ab	55547 ab	427891 ab	22656	405234 ab	5.2	1728	95
LVYI N°8	1.6 ab	19.7 abc	5.4 b	134 b	114 c	49375 b	497734 ab	17891	479891 ab	3.7	1850	69
NTA 88-6	2.1 a	22.3 a	6.2 a	153 a	117 abc	53906 ab	457734 ab	17188	440547 ab	3.8	1794	71
NTA P32	1.3 b	21.2 ab	5.9 ab	138 ab	120 a	50781 ab	404766 b	20078	384688 b	4.8	1629	85
Y 331-B	1.8 ab	19.0 bc	5.8 ab	126 bc	118 ab	58828 a	496641 ab	24375	472266 ab	4.9	2027	103
Overall mean	**1.6**	**20.0**	**5.7**	**131**	**117**	**53945**	**464987**	**20404**	**444583**	**4.3**	**1837**	**85**

s.e.	**0.63**	**2.74**	**0.44**	**16.6**	**2.622**	**8195**	**96780.3**	**10458.1**	**94765.6**	**2.05**	**429.9**	**42.6**
cv%	**39.8**	**13.7**	**7.7**	**12.7**	**2.2**	**15.2**	**20.8**	**51.3**	**21.3**	**47.2**	**23.4**	**50.3**

NM/PL = Number of monopodia (vegetative branches) per plant, **NS/PL** = Number of sympodia (fruiting branches) per plant, **INFS** = Insertion Node of the first Sympodial branches, **PLH** = Plant height, **DM50%** = Days to 50% Maturity, **NP/ha** = Number of plants per hectare **TNBH/ha =** Total Number of bolls harvested per hectare, **TNRB/ha =** Total Number of rotted bolls per hectare, **TNHB/ha =** Total Number of healthy bolls per hectare, **%RB** = percent rotted bolls, **SCY** = Seed cotton yield, **YL** = Yield losses
s.e. = Standard errors of means, cv% = Coefficient of variation expressed in percent. **a, b, c,** = the mean values followed by a common letter in the respective column do not differ by Least significant differences (LSD) of means (5% level).

Mean of the different morpho-physiological characteristics of varieties during 2020 and 2021-years experimentation.

The result of the analysis of variance shows that the NS/PL, PLH and DM50% parameters have a higher overall mean value in the second year of experimentation than in the first year (Table 3). On the other hand, the lowest overall mean value for INFS was recorded in year 2021. The mean values for NM/PL were the same in both years (Table 3). The analysis of variance revealed a significant difference ($p<0.01$ or $p<0.05$) between the varieties with regard to all the morpho-physiological parameters studied in years 2020 and 2021, with the composition of several homogeneous groups, except for NM/PL in year 2020 where there was no significant difference. These results are illustrated in Table 3.

Table 3. Mean of the different morpho-physiological characteristics of varieties during 2020 dans 2021 years experimentation in Finkolo recherche station.

Variety	**NM/PL**		**NS/PL**		**INFS**		**PLH (cm)**		**DM50% (day)**	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
BRS 293	1.2	1.5 bc	14.2 c	20.4	5.7 ab	5.3 b	99 c	127 b	116 a	115 b
FK 140	1.2	1.6 abc	17.1 ab	23.4	5.7 ab	5.4 b	102 c	146 ab	118 a	118 ab
LVYI N°8	1.5	1.7 ab	17.4 ab	22.1	5.6 b	5.3 b	121 ab	146 ab	111 b	117 ab
NTA 88-6	2.4	1.9 a	19.1 a	25.5	6.4 a	6,0 a	131 a	175 a	117 a	116 b
NTA P32	1.4	1.2 c	17.8 ab	24.6	6.2 ab	5.6 ab	122 ab	153 ab	119 a	121 a
Y 331-B	1.8	1.8 ab	16.3 bc	21.6	6,0 ab	5.6 ab	112 bc	141 b	118 a	119 ab
Overall mean	**1.6**	**1.6**	**17.0**	**22.9**	**5.9**	**5.5**	**115**	**148**	**116**	**118**
s.e.	**0.86**	**0.24**	**1.57**	**3.54**	**0.52**	**0.35**	**10.6**	**21**	**2.483**	**2.754**
cv%	**54.7**	**15**	**9.2**	**15.5**	**8.8**	**6.3**	**9.3**	**14.2**	**2.1**	**2.3**
Variety	**ns**	**hs**	**hs**	**ns**	**s**	**hs**	**hs**	**hs**	**hs**	**hs**

NM/PL = Number of monopodia (vegetative branches) per plant, **NS/PL** = Number of sympodia (fruiting branches) per plant, **INFS** = Insertion Node of the first Sympodial branches, **PLH** = Plant height, **NP/ha** = Number of plants per hectare **DM50%** = Days to 50% Maturity, **s.e.** = Standard errors of means, cv% = Coefficient of variation expressed in percent. **a, b, c,** = the mean values followed by a common letter in the respective column do not differ by Least significant differences (LSD) of means (5% level), *** =** Significant at the 0.05 probability level, **** =** Significant at the 0.01 probability level, **ns:** not significant.

Mean of the different agronomic characteristics of varieties during 2020 and 2021-years experimentation.

The results of the analysis of variance of the different agronomic parameters in Table 4 show that all the parameters studied have an overall average in year 2021 that is higher than in year 1. The same is also true for the average values of the parameters obtained by variety. The analysis of variance revealed a significant difference ($p<0.01$ or $p<0.05$) between the varieties in relation to only one agronomic parameter (NP/ha) studied in years 2020 and 2021, and in year 2 for TNHB. It should be noted that the Tukey test for these parameters resulted in the composition of several homogeneous groups between varieties.

The highest number of plants per hectare was recorded in year 2020 with BRS 293 and the lowest with NTA P32 with 54,844 and 35,938 plants per hectare respectively. In year 2, Y 331-B had the highest number of plants and BRS 293 the lowest, with 69,688 and 55,625 plants per hectare respectively. LVYI N°8 had the highest number of healthy bolls (541,562) in year 2021 of the experiment and NTA P32 the lowest (421,562).

For the parameters: TNBH/ha, TNRB/ha, %RB, SCY and YL the study did not reveal any significant difference ($p<0.01$ or $p<0.05$) between the varieties in relation to these parameters in either year 2020 or 2021. In particular, it should be noted that the highest mean value for each variety was observed in year 2 rather than year 1 (Table 4).

Although the analysis of variance did not determine a statistically significant difference between varieties, the variety Y 331-B obtained the highest arithmetic mean number of rotten bolls in year 1 (17,812 TNRB/ha) followed by LVYI N°8 (13750 TNRB/ha). In year 2, NTA P32 recorded the highest arithmetic mean number of rotten bolls (31,406 TNRB/ha), followed by FK 140 (31,719 TNRB/ha). As reported, yield losses were low in year 1; Y 331-B had the highest arithmetic mean loss with 73 kg/ha of seed cotton per hectare. On the other hand, losses were high in year 2; the varieties FK 140, NTA P32 and Y 331-B recorded the highest arithmetic averages with losses of 135, 133 and 133 kg/ha of seed cotton, respectively.

Table 4. Mean of the different agronomic characteristics of varieties during 2021 – 2022 years experimentation in Finkolo recherche station.

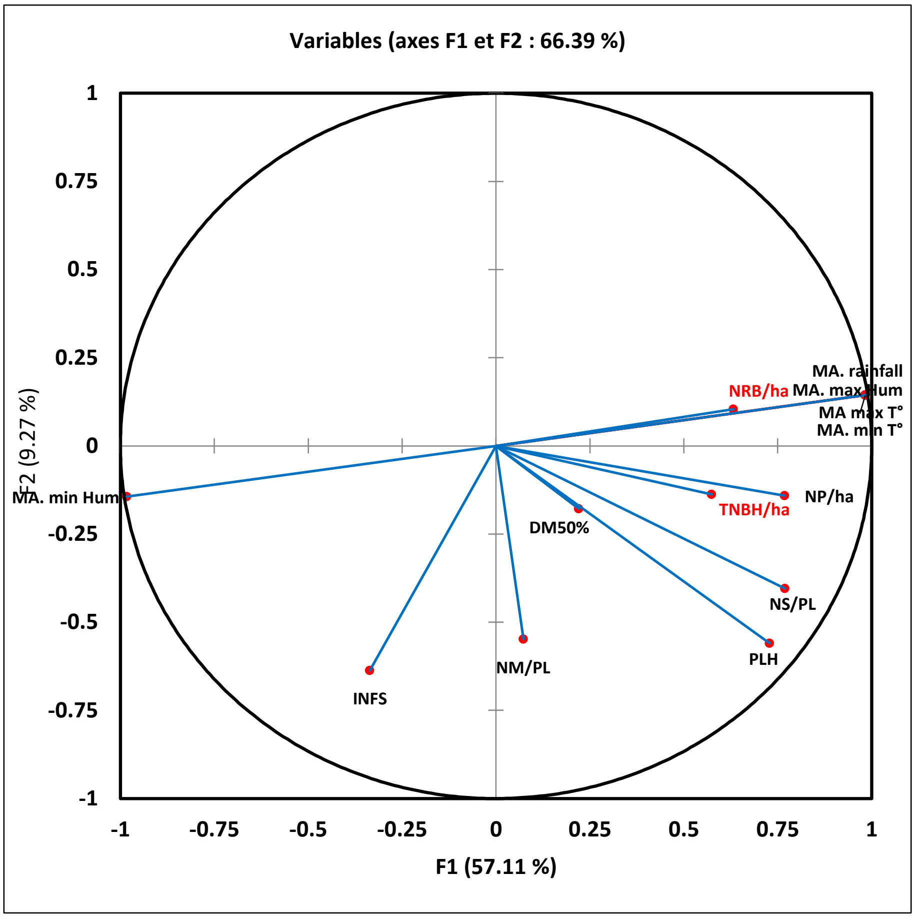
Variety	**NP/ha**		**TNBH/ha**		**TNRB/ha**		**TNHB/ha**		**%RB**		**SCY (kg/ha)**		**YL (kg/ha)**	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
BRS 293	54844 a	55625 c	457031	553281	11406	29063	445625	524219 ab	2.6	5.3	1763	2222	44	124
FK 140	46250 ab	64844 ab	357969	497812	13594	31719	344375	466094 ab	4.1	6.3	1447	2009	56	135
LVYI N°8	34062 b	64688 ab	431875	563594	13750	22031	418125	541562 a	3.5	3.9	1643	2056	55	84
NTA 88-6	47344 ab	60469 bc	397188	518281	8438	25938	388750	492344 ab	2.1	5.0	1550	2038	34	109
NTA P32	35938 b	65625 ab	356562	452969	8750	31406	347812	421562 b	2.5	7.0	1406	1852	36	133
Y 331-B	47969 ab	69688 a	433438	559844	17812	30938	415625	528906 ab	4.3	5.5	1742	2312	73	133
Overall mean	**44401**	**63490**	**405677**	**524297**	**12292**	**28516**	**393385**	**495781**	**3.2**	**5.5**	**1592**	**2082**	**50**	**120**
s.e.	**10653.2**	**4563.3**	**108103.6**	**83943.2**	**6999**	**13029.2**	**107007**	**80688**	**1.74**	**2.32**	**456.6**	**401.4**	**27.9**	**53.4**
cv%	**24**	**7.2**	**26.6**	**16**	**56.9**	**45.7**	**27.2**	**16.3**	**54.8**	**42.1**	**28.7**	**19.3**	**56.3**	**44.6**
Variety	**Hs**	**hs**	**ns**	**ns**	**ns**	**ns**	**ns**	*****	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**

TNBH/ha = Total Number of bolls harvested per hectare, **TNRB/ha =** Total Number of rotted bolls per hectare, **TNHB/ha =** Total Number of healthy bolls per hectare, **%RB** = percent rotted bolls, **SCY** = Seed cotton yield, **YL** = Yield losses, **s.e.** = Standard errors of means, cv% = Coefficient of variation expressed in percent. **a, b, c,** = the mean values followed by a common letter in the respective column do not differ by Least significant differences (LSD) of means (5% level), *** =** Significant at the 0.05 probability level, **ns:** not significant.

Correlation between boll rot and some climatic and agro-morpho-physiological parameters.

The correlation between boll rot and a number of parameters is shown in Figure 3. A highly positive and significant correlation ($p<0.01$) was observed between the total number of rotten bolls and all the climatic parameters measured, except for the average annual minimum humidity, where the correlation was significant ($p<0.01$) but highly negative.

This result confirms the high number of rotten bolls in the trial conducted in the 2021 season, as we can see from Figures 1 and 2 that it is during this year that the monthly average values for the month of August in terms of rainfall, maximum and minimum temperature, and maximum humidity are the highest compared with the month of August in the 2020 season. And August corresponds to the cotton fruiting period in the zone. A significant positive correlation ($p<0.05$) was also observed between the total number of rotten bolls and all the agro-morpho-physiological parameters measured except for the Insertion Node of the First Sympodial branches (INFS), where the correlation was significant ($p<0.05$) but negative. The analysis also revealed a highly positive and significant correlation ($p<0.01$) between the total number of bolls harvested and the number of plants per hectare.



NM/PL = Number of monopodia (vegetative branches) per plant, **NS/PL** = Number of sympodia (fruiting branches) per plant, **INFS** = Insertion Node of the first Sympodial branches, **PLH** = Plant height, **DM50%** = Days to 50% Maturity, **NP/ha** = Number of plants per hectare, **TNBH/ha =** Total Number of bolls harvested per hectare, **TNRB/ha =** Total Number of rotted bolls per hectare, **MA. Rainfall** = Mean annual rainfall, **MA. T° max =** Mean annual maximum temperature, **MA. T° min =** Mean annual minimum temperature, **MA. Hum max =** Mean annual maximum humidity, **MA. Hum min =** Mean annual minimum humidity.

Figure 3: Correlation between boll rot and some climatic and agro-morpho-physiological parameters (2020 - 2021)

IV. Discussion

The results of the two-year study did not reveal any significant difference ($p<0.01$ or $p<0.05$) between varieties in the total number of rotten bolls per hectare or in the percentage of rotten bolls. This suggests that boll rot is not a varietal problem, but is mainly due to climatic conditions (rain, temperature, humidity, etc.) and cultural practices (high density, poorly managed plots, etc.). A highly significant correlation ($p<0.01$) between the total number of rotten bolls and the average annual rainfall, maximum and minimum temperatures and maximum humidity was recorded in the correlation analysis. These conditions in themselves favour the presence of biotic factors that cause boll rot. Cotton boll rot has been associated with several fungal species, including *Fusarium*, *Diplodia*, *Alternaria* and *Phytophthora* (Guthrie et al. 1994; Pinckard and Guidroz 1973). The necrotrophic fungus *Sclerotinia sclerotiorum* this disease is favoured by cool, humid temperatures under a closed plant canopy (Hu et al. 2018). In general, the environmental factors favouring the development of phytopathogenic fungi are high hygrometry (70 to 90% humidity in the air) and mild temperatures (10 to 20°C) (SNHF, 2017). The pathogens' access to the bolls can be facilitated by insect wounds, such as the bollworm (*Helicoverpa zea*) and budworm (*Heliothus virescens*) present in poorly maintained plots or high plant population densities (Guthrie et al. 1994).

A significant difference was also observed between the two years of experimentation concerning the number of rotten bolls. This was confirmed by the variation in climatic parameters measured over the two years. The year 2021 recorded the highest average rainfall, temperature and maximum humidity values. It also had the highest seed cotton yield (kg/ha), the highest number of rotten bolls, and the highest yield loss due to boll rot. As Guthrie et al. (1994) state, the conditions favouring boll rot are heat and humidity, while the conditions favouring plant growth are also heat and humidity. Hillocks, (1992) argues that cotton loss due to boll rot varies from year to year, probably due to weather conditions, insect vector pressure, the presence of pathogens, and geographical location.

A positive and significant correlation ($p<0.05$) was also observed between the total number of rotten bolls, the total number of healthy bolls harvested per hectare, and the total number of plants per hectare. This result may be associated with the fact that a high population density of plants creates a very humid environment within the canopy, which causes rotting and therefore an increase in the number of rotten bolls per hectare (Sylla et al. 2013). Xue et al. (2015) have linked high boll retention to an increase in boll rot and a low rate of open bolls and concluded that a high population density creates shade and increases canopy humidity, making the canopy environment conducive to pest damage and disease spread.

This study also established a positive and significant correlation between the total number of (healthy) bolls harvested per hectare and the total number of plants per hectare; this is in contrast to the results obtained by Clawson et al. (2006) and Gwathmey & Clement, (2010). These authors argue that an increase in plant density reduced plant height, main stem nodes per plant, the number of bolls per plant, and the average boll weight. According to Siebert & Stewart, (2006), reducing the number of plants per hectare results in unnecessary vegetative growth, leading to undesirable fruit loss and boll rot.

A negative and significant correlation was observed between the total number of rotten bolls, the minimum moisture content and the insertion height of the first fruiting branch.

The analysis of variance did not reveal any significant difference between the varieties of terms of seed cotton production per hectare, although it should be noted that the Y 331-B and BRS 293 varieties had higher arithmetic averages than the other varieties. The good production performance of these two varieties is confirmed by the results of experiments conducted by Sissoko et al. (2020) in 2018 at the Finkolo and N'Tarla research stations. The BRS 293 variety again confirmed its good performance in seed cotton yield in another experiment conducted at the two sites during the 2019 - 2020 rainy season (Sissoko, et al., 2023).

V. Conclusion

The boll, or fruit, is the most important element in cotton production. The number of bolls per plant is an important parameter contributing to the yield of seed cotton per hectare. If we can understand how much yield is lost due to cotton boll rot in the field, many potential problems in crop management can be avoided. The result will be increased yields and profits. The results revealed that yield loss in seed cotton is much more related to environmental factors (rain, temperature, humidity, etc.) than varietal factors. The study identified an average seed cotton yield loss of around 100 kg per hectare in the area. Given that the zone is one of Mali's major cotton production basins, the loss observed is too high on the scale of the area sown in particular and the country in general, especially given that the area sown by Mali in 2021 is expected to be around 800,000 ha. It will be imperative to adopt appropriate measures to safeguard the bolls in the fields during years of abundant rainfall and elevated temperatures, thereby ensuring a satisfactory harvest.

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