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ORIGINAL ARTICLE

Effects of two *Ralstonia Solanacearum* strains on Yield of Tomato (*Lycopersicon esculentum* Mills 1768) Genotypes Planted at Three Different Planting Seasons at the Sotuba Station, Sudano-Sahelian Area of Mali

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The tomato, a genus of Lycopersicon, is cultivated worldwide for fruit. It is an important gastronomic ingredient and an important source of income for small farmers in Mali. However, its production faces a number of phytosanitary constraints that are still poorly understood. Among phytosanitary problems, bacterial wilt, caused by *R. solanacearum*, is proving to be the most dangerous and devastating of all tomato crops in Mali. The aim of this study is to contribute to the improvement of tomato production in Mali by identifying tomato varieties tolerant to *R. solanacearum* and adapted to the growing periods. To achieve this objective, trials under artificial and natural infestation conditions with 12 tomato genotypes during three periods were conducted at the Sotuba research station from December 2018 to December 2019. Analysis of variance revealed no significant difference between the two strains tested. Both strains were more severe, especially in period 2 of the experiment. The Caraïbo variety was the most susceptible to both strains, with an average severity rate of 2.8 (≈3) and the most stress-susceptibility index (0.69). The varieties Carioca and SF-83-61 were the most productive in both experimental conditions. With average yields ≥ 3.5 t/ha under artificial infestation conditions and ≥ 6 t/ha under natural conditions. In contrast, the Roma and Rossol varieties recorded the lowest yields. To minimize *R. Solanacearum* damage and improve field yields at all cropping periods, the SF-83-61 and Carioca varieties may be recommended for release in areas where *R. Solanacearum*, responsible for bacterial wilt, causes significant damage in tomato crops after confirmation tests.

Key words: Tomato, R. solanacearum, yield, period of growing, Mali

The tomato (*Lycopersicon esculentum* Mills 1768) is one of the most widely cultivated field and garden vegetable crops in the world (Salunkhe and Kadam, 1998). It is an important cash crop for smallholders and commercial farmers with modest landholdings; it is also an important source of vitamins and essential minerals in the food supply (Naika *et al.,* 2005).

The tomato is in great demand throughout the world in all seasons (Freeman *et al.,* 2011), and is an essential condiment in the gastronomy of many countries, particularly Mali. Used in cooking as a vegetable, tomatoes can be eaten raw, in salads or mixed with other ingredients (Dembélé, 1994).

Vegetable crops are attacked by a wide range of pests, often resulting in substantial crop losses each year (IPM-CRSP 2006). Pest pressure often reduces the range of crops that can be grown.

The tomato, which is the subject of our study, is the most widely cultivated fruit in Africa, yet its production is subject to a number of phytosanitary constraints during its development (Camara *et al.,* 2022). Tomato crops are subject to multiple parasitic pressures, caused by pests and diseases as well. Among diseases, bacterial wilt, caused by *R. solanacearum*, is the most dangerous and devastating for tomato crops in Mali (Thera *et al.*, 2010). Currently, there are no preventive or curative treatments for this disease, so the only solution is to respect crop rotations and use resistant or tolerant varieties (Courchinoux, 2008).

The aim of this study is to contribute to the improvement of tomato production in Mali by identifying tomato varieties tolerant to *R. solanacearum* and adapted to the different cultivation periods.

MATERIALS AND METHODS

Experimental site

The Station de Recherche Agronomique de Sotuba is located in the district of Bamako on the left bank of the Niger River, about 7 km from Bamako city center, and covers an area of about of around 265 ha. Sotuba is located between altitude 12°39 North and longitude 07°56 West at an altitude of 320m. The climate is Sudano-Sahelian, with rainfall varying from 800 to over 1,000 mm. The soil is silty clay or sandy clay.

Plant material

The plant material consists of 12 tomato varieties, all introduced. The details of the varieties are given in Table 1. Bacterial material (bacterial strains)

Two bacterial strains, K5 (Kati) and Sd (Samanko), both were obtained from the AVRDC-Mali collection (WorldVegetable) where they are being cryopreserved. Were used to prepare the inoculum. The Kati strain (k5) is irregular in shape, small in size, russet in color with numerous isolated colonies. The Samanko strain (sd) is irregularly shaped, round and grouped, dark red in color with rapid colony growth. The two strains both host tomatoes belonging to Phylotype I.

Preparation of bacterial strains

R. solanacearum strains collected at the AVRDC (World Vegetable Center) were stored in glycerol at 20-70°C before use. Then, the strains were put into pure growth by repeated streaking of a single colony on agar medium containing triphenyltetrazolium chloride (TTC) (Kelman, 1954). To prepare the inoculum, bacterial cells were grown in nutrient bouillon (Difco, USA) under agitation at 28°C during two days. They were then in suspension in distilled water and an optical density of 0.1 at 600 nm wavelength (using the spectrophotometer) of around 108 cfu/ml/ml (DO600 = 0.8) and adjusted. The inoculum was then ready for use.

Inoculation of tomato plants

The 12 tomato genotypes germinated in containers, 4 weeks old (at the stage of 3 to 4 true leaves, about 15 cm high) were infected using 5 mL of inoculum applied to the substrate after scarification of the roots with a scalpel. The plants were watered regularly to prevent the substrate from draining. A treatment without infestation with the pathogen constituted the control trial, which also included the 12 genotypes placed 2 m from the infested trial to evaluate them under the same practical and environmental conditions.

Experimental design.

To assess the severity of the two bacterial strains on the 12 genotypes, a split plot design was used with the two strains as the main factor and the 12 genotypes as the secondary factor. The main factor consisted of two strips subdivided into four blocks (replications) each. Each genotype was sown in 10-litre containers 3/4 filled with compost. Each container constituted a treatment and the 12 containers constituted a replicate, i.e. 48 containers for a block. A total of 96 containers made up the two blocks. To limit cross-contamination, the two plots were placed two metres apart and 20 cm was between the containers in which the different genotypes were sown. A non-infested control plot was set up not far (2 m) from the infested plot in a simple Fischer block design with four (4) replications. The trial was conducted during all three periods using the same design.

Data collection

- Observation of tolerance parameters

Observations of tolerance parameters began 15 days after inoculation: the severity of symptoms was observed 15 days after inoculation. Plants were observed weekly according to the development of symptoms of wilting caused by *R. solanacearum* on a scale of 0 to 5, a descriptive key for measuring the severity of the disease based on a scale developed by Winstead and Kelman, (1952).

0 = 0% Healthy plant with no visible symptoms

1 = < 5% On single leaf "fully or partially" wilted

2 = 5 - 25% 2 to 3 wilted leaves

3 = 25 - 50% All leaves wilted except 2-3

4 = 50 - 75% Total wilting of the plant

5 = 75 - 100% Dead plant.

- Observation of agronomic parameters

For the trial under artificial infestation, the observations concerned yield and some yield components, such as the mean height of the tomato plants, the mean number of fruits per plant and the mean weight of a fruit, in order to identify correlations between yield and these parameters under artificial infestation. In the control plot, grown under natural conditions, only the yield per hectare was observed in order to estimate stress indices.

- Method of calculating stress indices

Six stress indices and the percentage reduction in yield were calculated on the basis of yield under infested and non-infested conditions. These parameters were calculated using the following formulae:

Tolerance index (TOL) (Hossain *et al.,* 1990),

$$TOL = (Yp - Ys)$$

Mean productivity (MP) (Hossain *et al.,* 1990),

$$MP = \frac{(Yp + Ys)}{2}$$

Geometric mean productivity (GMP) (Fernandez, 1992),

$$GMP = \sqrt{Yp \ x \ Ys}$$

Stress susceptibility index (SSI) (Fischer and Maurer, 1978),

$$SSI = \frac{[1-(Ys)/(Yp)]}{SI}$$

where SI is the stress intensity and is calculated as follows:

$$SI = [1-(\bar{Y}s)/(\bar{Y}p)]$$

Stress tolerance index (STI) (Fernandez, 1992) as:

$$STI = \frac{(Yp)\times(Ys)}{(Yp)^2}$$

Reduction percentage (Red%) (Choukan *et al.,* 2006).

$$Red\ (\%) = \frac{(Yp - Ys)}{Yp}$$

Where Ys and Yp are the yields under infested and non-infested conditions and $\bar{Y}s$ and $\bar{Y}p$ are the mean yields of all genotypes under infested and non-infested conditions.

Statistical analysis of data

Data was input into Excel. Analysis of variance (ANOVA) was performed using R i386 3.1.2. software. The effects of replicates and blocks were considered to be random, whereas those of genotypes were considered to be fixed. Means were separated by the least significant difference (LSD).

RESULTS

Experimental conditions

During the first experimental period, the minimum and maximum temperatures were almost constant during the first two months (December 2018 and

January 2019) of the experiment; we noted a slight increase in these minimum and maximum temperatures during the last two months of the experiment (February 2019 and March 2019). In contrast to temperatures, there was a decrease in minimum and maximum humidity in the last two months of the experiment.

The average monthly temperature and humidity during the first period are shown in Figure 1a. During the second experimental period, the minimum and maximum temperatures are high for the first two months (April 2019 and May 2019), then decrease for the last two months of the experiment. There was an almost exponential increase in minimum and maximum humidity towards the last two months of the experiment. The average monthly temperature and humidity during the second period as shown in Figure 1b. During the third experimental period, the minimum temperature decreased slightly in the last two months of the experiment (June 2019 and July 2019), while the maximum temperature increased slightly in the same months. There was also an almost exponential drop in minimum and maximum humidity levels towards the last two months of the experiment. The average monthly temperature and humidity during the third period is illustrated in Figure 1c.

Trials under artificial infestation conditions during the three experimental periods at the Sotuba station.

Analysis of variance (ANOVA) of the squares of the means of the various traits studied in the trials infested with two bacterial strains of *R. solanacearum* during the three periods.

The results of the analysis of variance of the means squared for the different traits studied are presented in Table 2. The analysis reveals a highly significant difference ($p<0.01$) between the periods for all the traits studied. A significant difference ($p<0.05$) was observed between strains only for yield. Except for plant height and fruit weight, a highly significant difference was observed between varieties for all the other traits studied. The effects of interactions between periods and strains were highly significant for the number of fruits per plant and yield. Interactions between periods and varieties were significant at $p<0.05$ and <0.01 for strain severity, height, number of fruits per plant, fruit weight and yield. Interactions between strains and varieties were significant ($p<0.05$) for fruit weight and yield.

Analysis of the results of the means of the various traits studied by strain and by experimental period under artificial infestation conditions

In the interpretation of the results, Strain 1 represents the Kati strain (K5) and Strain 2 represents the Samanko strain (Sd).

Results of strain severity on genotypes over the three periods

The results of the mean analyses in Table 3 show that the two strains were generally moderately severe during the three experimental periods, with an overall mean of 1.7 (≈2). A minimum value of 0.6 (≈1) in period 1 and a maximum of 2.4 (≈2) during the second period (Table 3). On the other hand, the analysis reveals that several genotypes were susceptible to both bacterial strains and especially during the second trial period, with a degree of severity between 3.5 and 4.3. These genotypes are: Caraïbo, Estrella, Floradade, Roma, Rossol and UC-82. It should also be noted that strain 1 was slightly more severe than strain 2 during the 2nd trial period, with a mean of 2.6 versus 2.3.

Results of the analysis of variance of some yield components during the three experimental periods under conditions of artificial infestation.

The overall mean plant height was 55.5 cm. The results of the analysis show that the greatest plant height was recorded during the 3rd experimental period, with an average of 84.9 cm. The plants were shortest during the 2nd period (32.8 cm), when the bacterial strains were most severe. The study did not reveal any significant difference in height between the strains.

Period 3 of the experiment still produced more fruit per plant than the other two periods. The results show that the genotypes behaved differently for the same strain and the same period. During the 1st period of experimentation, the varieties SF-83-61, Estrella and Carioca were more tolerant to strain 1 than the varieties UC-82, Floradade and C-20-5. And the Estrella variety was more tolerant to strain 2 than all the other varieties during the same period. During period 2, varieties SF-

83-61, Carioca and Estrella were the most tolerant to both bacterial strains. During period 3, the varieties least sensitive to strain 1 were C-20-5, Estrella and Carioca. The varieties least sensitive to strain 2 were Estrella, SF-83-61, C-20-5, Carioca and Formosa. The varieties most tolerant to strains for fruiting were: Estrella followed by SF-83-61. The results of the statistical analysis of the mean weight of a fruit show us that the fruits harvested during the 1st period of the experiment were much heavier, followed by the 3rd period. The varieties with the highest mean of a fruit weight were Floradade and UC-82; the Estrella variety had the lowest fruit weight.

Results of the analysis of average yield per hectare over the three experimental periods under artificial infestation conditions

The results in Table 4 show that yields were highest in period 3 (4,201 kg/ha), followed by period 1 (3,287 kg/ha) and period 2 (305 kg/ha). The genotypes were much more sensitive to strain 2 during periods 1 and 2 of the experiment.

The best yields were obtained with the SF-83-61, Carioca and Buffalo varieties infested with strain 1 during period 1, with 9,626 kg/ha, 6,688 kg/ha and 6,424 kg/ha respectively; the Floradade and Buffalo varieties were better with strain 2 during the same period. Only the variety SF-83-61 had an above-average yield (3,085 kg/ha) with both strains during the 2nd period. During the 3rd period, the best yields obtained with strain 1 infestation were the varieties Mongal F1 (7,728 kg/ha), C-20-5 (6,764 kg/ha) and Carioca (6,531 kg/ha). With strain 2, the best varieties were Carioca (7,408 kg/ha), Formosa (7,279 kg/ha) and C-20-5 (6,133 kg/ha).

The best performance over the three periods and with both strains was obtained with the Carioca variety (3,938 kg/ha), while the lowest performance was observed with the Roma variety (1,292 kg/ha). Several genotypes died before the production period, which may be due to the severity of the strains linked to the production period.

Correlation analysis between the different traits studied under artificial infestation conditions during the three periods.

The analysis in Table 5 shows a negative and highly significant correlation ($p<0.01$) between the degree of severity and all other variables. This means that as the value of the degree of severity increases, the value of all the other traits (yield, height, number of fruits, etc.) decreases, and vice versa.

Trials under natural infestation conditions (controls) during the three periods

Control (non-infested) trials were conducted at the same time as trials infested with two bacterial strains of *R. solanacearum.*

Results of the analysis of the mean yield (kg/ha) of the genotypes during the three experimental periods under non-infested conditions.

The results show that the best production of the genotypes was achieved during the 3rd period of the experiment (Table 6). The most productive varieties were, on average, SF-83-61, Carioca and Estrella, with yields per hectare: 7,459 kg/ha, 6,084 kg/ha and 5,888 kg/ha respectively. Analysis of yields and stress indices correlated with the tolerance of genotypes to *R. solanacearum*

Analysis of yields (kg/ha) and stress indices

Various indices were calculated on the basis of yields under infested and non-infested conditions. The results are shown in Table 7. The varieties Roma, Rossol, Caraïbo and UC-82 obtained the highest values for the stress susceptibility index (SSI) and percentage yield reduction (Red %). With yield reductions of over 60% (Table 7) due to the incidence of stress induced in the above varieties. The results showed that these four varieties also had the lowest stress tolerance indexes (STI), which explains their higher susceptibility to bacterial strains. The Carioca variety recorded the lowest Stress Susceptibility Index (SSI) value and percentage yield reduction, and was the most tolerant variety with the highest Stress Tolerance Index (STI) value. Variety SF-83-61 showed the best values for geometric mean productivity (GMP), mean productivity (MP) and tolerance index (TOL). This explains the tolerance of SF-83-61 to bacterial strains.

Correlation analysis between yields and stress indices

The results in Figure 4 show a highly significant and positive correlation at p<0.01 and equal to 1 between the stress susceptibility index (SSI) and percentage yield reduction (Red%). These two variables had a significant negative correlation at p<0.05 or p<0.01 with all the other variables except the tolerance index (TOL). This means that as the values of SSI and Red% increase, the values of the other variables will decrease and vice versa, except for TOL. Significant positive correlations at p<0.05 or p<0.01 were recorded between the variables: yield in non-infested conditions (Yp), yield in infested conditions (Ys), geometric mean productivity (GMP), mean productivity (MP) and stress tolerance index (STI). The tolerance index showed no significant correlation with the other variables, except for the stress tolerance index (STI), with which there was a significant negative correlation at p<0.05. (Figure 2).

Table 1: List and some characteristics of the different tomato varieties used in the study.

Ord N°	Variety	Origin	Type genetics	Growth type	Cycle planting maturity 1st Harvest	Color of fruit at maturity
1	SF 83-61	Taiwan	Pure line	Determinate	90 DAP	Red
2	Formosa	Cap Vert	Pure line	Determinate	90 DAP	Red
3	Carioca	Martinique	Pure line	Determinate	70 to 75 DAP	Red
4	Mongal F1	France	Hybrid	Determinate	65 DAP	Bright red
5	Caraïbo	Martinique	Pure line	Determinate	75 DAP	Red
6	Rossol	France	Pure line	Determinate	75 à 80 DAP	Red
7	C-20-5	France	Pure line	Determinate	90 DAP	Red
8	Roma	Italie	Pure line	Determinate	70 à 80 DAP	Red
9	Floradade	France	Pure line	Determinate	75 à 80 DAP	Red
10	Estrella	Cap Vert	Pure line	Determinate	90 DAP	Red
11	Buffalo	France	Pure line	Semi-Determinate	70 to 75 DAP	Red-orange-gold
12	UC-82	USA	Pure line	Determinate	70 to 80 DAP	Red

DAP = Day After Planting. (Source : Catalogue régional. 2017 ; Aïssa *et al.,* 2014)

Table 2: Results of analysis of variance of agronomic parameters observed in trials infested by two bacterial strains during the three periods at the Sotuba station.

Source of variation	d.f	Severity	PLH (cm)	NF/PL	WF (g)	Yield (kg/ha)
Period	2	93,764**	68457.8**	1573,07**	3045,2**	3,99E+08**
Strain	1	0,222	913.8	18,00	2,4	2,69E+07*
Variety	11	7,836**	1343.8	171,79**	167,6	1,76E+07**
Period*Strain	2	1,514	285.1	271,95**	3,4	6,21E+07**
Period*Variety	22	4,711*	1387.0*	49,01**	211,3**	1,22E+07**
Strain*Variety	11	3,093	840.8	25,77	198,8*	1,33E+07*
Residual	216	2,868	838.9	19,42	104,6	6,00E+06
CV %		**100,8**	**52,2**	**85,4**	**131,9**	**94,3**
SE		**1,7**	**28,96**	**4,4**	**10,2**	**2449,2**

d.f. = degree of freedom, **PLH (cm)** = Plant height, **NF/PL** = Number of fruits per plant, **WF (g)** = Weight of a fruit, **CV % =** coefficient de variation**, SE =** Standard error.

Table 3: Results of strain severity analysis on the different genotypes over the three periods under artificial infestation conditions.

Variety	Period 1		Period 2		Period 3		Overall mean
	Strain 1	Strain 2	Strain 1	Strain 2	Strain 1	Strain 2	
Buffalo	0,3	0,5	3,0	2,5	2,8	2,5	1,9
C-20-5	0,0	0,3	2,5	1,8	0,8	1,3	1,1
Caraïbo	1,5	0,0	3,8	4,3	3,8	3,3	2,8
Carioca	0,0	1,0	0,0	0,8	0,3	1,0	0,5
Estrella	0,8	0,0	4,5	2,5	2,5	0,8	1,8
Floradade	0,5	0,0	3,5	1,0	2,3	1,8	1,5
Formosa	0,0	2,8	3,8	2,0	2,0	1,5	2,0
Mongal F1	1,0	1,3	2,5	2,3	0,8	1,3	1,5
Roma	0,0	0,5	1,3	1,3	3,5	3,5	1,7
Rossol	0,3	0,0	3,8	3,8	2,5	*2,5*	*2,1*
SF-83-61	0,0	1,3	1,3	2,0	1,8	1,5	1,3
UC-82	1,3	0,5	1,3	3,5	2,3	3,3	2,0
Mean strain	**0,5**	**0,7**	**2,6**	**2,3**	**2,1**	**2,0**	**1,7**
Mean period	**0,6**		**2,4**		**2,0**		
LSD	**1.7**	**1.9**	**3.3**	**3.1**	**2.0**	**2.2**	**2,4**

Table 4: Results of the analysis of the mean yield (kg/ha) of the genotypes during the three experimental periods under artificial infestation.

Variety	Period 1		Period 2		Period 3		Overall mean
	Strain 1	Strain 2	Strain 1	Souche 2	Strain 1	Strain 2	
Buffalo	6424	4080	0	0	2802	2891	2700
C-20-5	3358	1561	264	0	6764	6133	3013
Caraïbo	3806	3440	0	0	0	3985	1872
Carioca	6688	1090	1099	814	6531	7408	3938
Estrella	5930	1774	409	44	3611	5795	2927
Floradade	2828	5366	0	674	2461	5511	2807
Formosa	4831	809	0	228	4904	7279	3008
Mongal F1	4435	528	89	426	7728	3561	2794
Roma	2369	1026	0	0	1886	2470	1292
Rossol	984	1716	0	0	2159	3891	1458
SF-83-61	9626	2335	3085	198	3178	3910	3722
UC-82	2450	1436	0	0	3821	2149	1643
Mean strain	**4477**	**2097**	**412**	**199**	**3820**	**4582**	**2598**
Mean period	**3287**		**305**		**4201**		
LSD	**3536**	**3246**	**2399**	**491**	**4226**	**5208**	**3414**

Table 5: Correlation matrix between the different traits studied under artificial infestation conditions during the three periods.

	Severity	NF/PL	WF	PLH	Yield
Severity	**1**				
NF/PL	-0,389**	**1**			
WF	-0,382**	0,158**	**1**		
PLH	-0,488**	0,470**	0,292**	**1**	
Yield	-0,411**	0,748**	0,545**	0,516**	**1**

****.** Correlation is significant at **0.01, NF/PL =** Number of fruits per plant, **WF (g)** = Weight of a fruit, **PLH** = Plant height.

Table 6: Results of the analysis of the mean yield (kg/ha) of tomato genotypes during the three experimental periods under non-infested conditions.

Variety	Period 1	Period 2	Period 3	Overall mean
Buffalo	6626	2227	7525	5459
C-20-5	5138	2540	8186	5288
Caraïbo	7400	1731	5364	4832
Carioca	6954	2705	8591	6084
Estrella	7203	1914	8548	5888
Floradade	5645	1744	9109	5499
Formosa	5077	2276	9541	5631
Mongal F1	4912	1809	9672	5464
Roma	3771	2329	6711	4270
Rossol	3568	1877	8359	4601
SF-83-61	10560	3095	8721	7459
UC-82	4302	1635	6424	4120
Mean variety	**5930**	**2157**	**8063**	**5383**
LSD	**3208**	**2864**	**4321**	**3440**

Table 7: Results of yields (kg/ha) and stress indices

Genotypes	Yp (kg/ha)	Ys (kg/ha)	TOL	MP	GMP	SSI	STI	Red (%)
Buffalo	5044	2700	2344	3872	3690	0,91	0,54	46
C-20-5	5288	3013	2275	4151	3992	0,84	0,57	43
Caraïbo	4832	1872	2960	3352	3008	1,20	0,39	61
Carioca	6084	3938	2146	5011	4895	0,69	0,65	35
Estrella	5888	2927	2961	4408	4151	0,99	0,50	50
Floradade	5332	2807	2525	4070	3869	0,93	0,53	47
Formosa	5431	3008	2423	4220	4042	0,88	0,55	45
Mongal F1	5233	2794	2439	4014	3824	0,91	0,53	47
Roma	4270	1292	2978	2781	2349	1,37	0,30	70
Rossol	4601	1458	3143	3030	2590	1,34	0,32	68
SF-83-61	7459	3722	3737	5591	5269	0,98	0,50	50
UC-82	4120	1643	2477	2882	2602	1,18	0,40	60
Mean	**5299**	**2598**	**2701**	**3948**	**3690**	**1,0**	**0,5**	**52**

Yp (kg/ha) = yield under non-infested conditions, **Ys** (kg/ha) = yield under infested (stress) conditions, **TOL** = tolerance index, **MP** = Mean productivity, **GMP** = Geometric mean productivity, **SSI** = stress susceptibility index, **STI** = stress tolerance index, **Red (%)** = percentage yield reduction

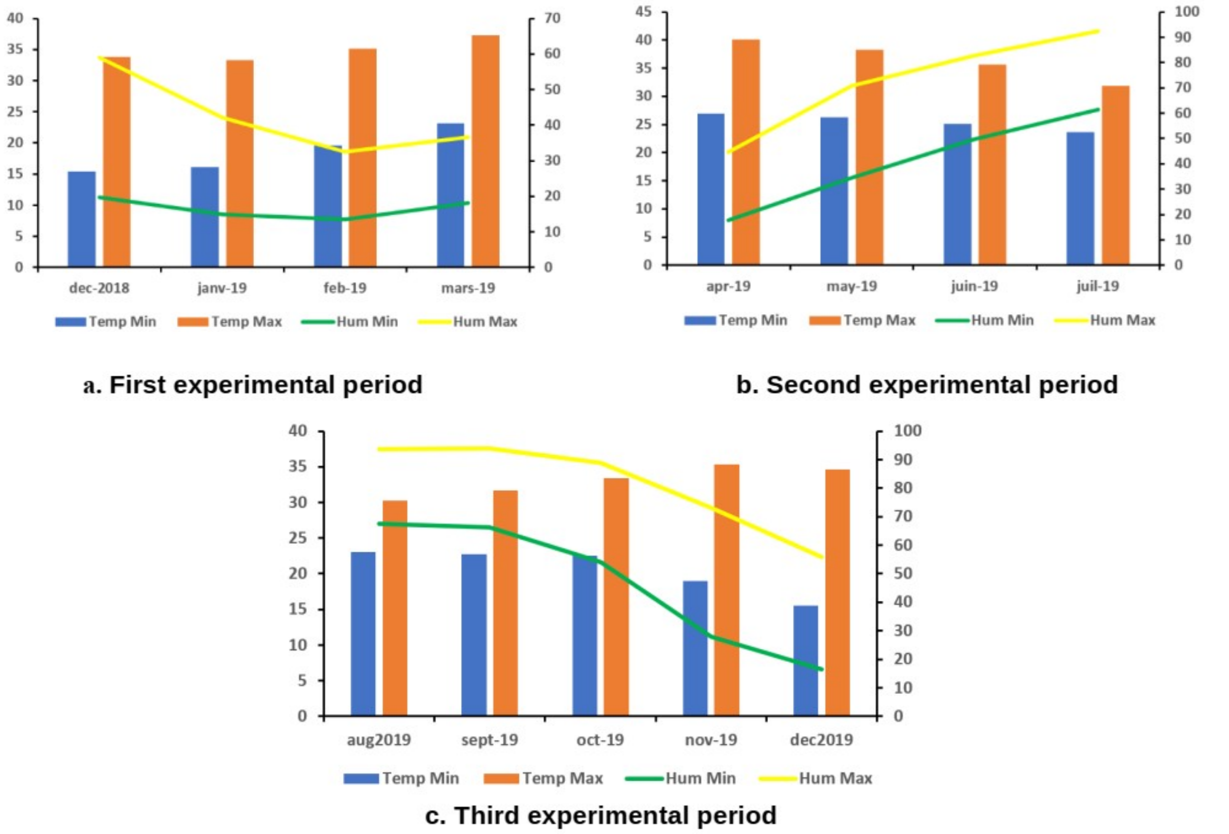

Figure 1. Monthly mean temperature and humidity (max and min). (Source: Sotuba weather station 2018 - 2019).

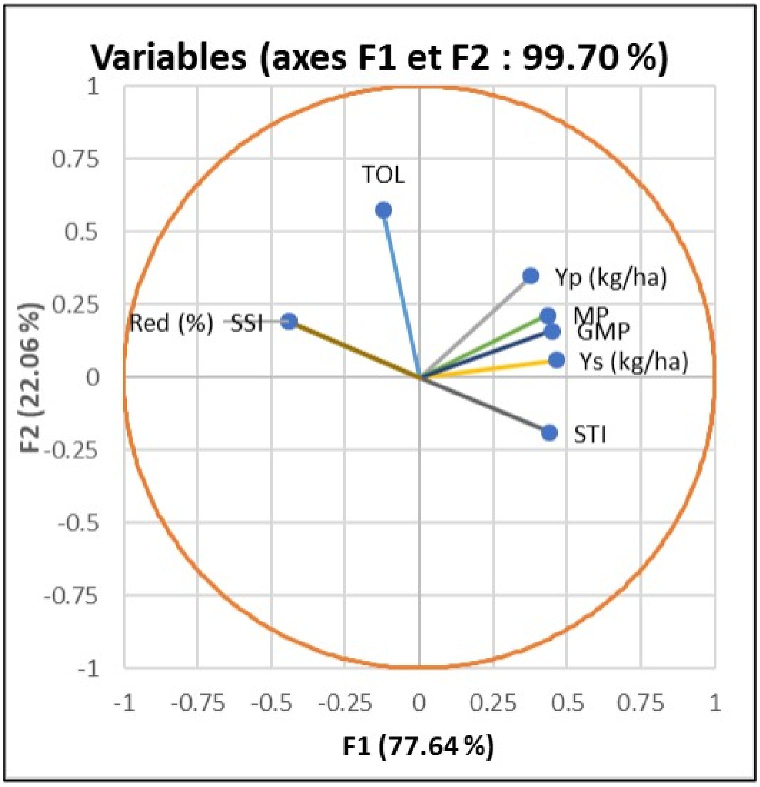

Figure 2. Correlation between yields and stress indices

Yp (kg/ha) = yield under non-infested conditions, **Ys** (kg/ha) = yield under infested (stress) conditions, **TOL** = tolerance index, **MP** = Mean productivity, **GMP** = Geometric mean productivity, **SSI** = stress susceptibility index, **STI** = stress tolerance index, **Red (%)** = percentage yield reduction

DISCUSSION

The results of the experiment during the three periods revealed that the yield and some yield components of all the genotypes improved under non-infestation conditions compared with artificial infestation conditions. This indicates the effect of the bacterial wilt agent (*R. Solanacearum*) on genotypes under artificial infestation conditions. According to Elphinstone (2005), bacterial wilt caused by *R. solanacearum* is one of the most destructive diseases of food and cash crops in the world, and one of the threats to the sustainability of agriculture. The 2nd period of the experiment (April to July 2019) has the lowest value for yield and other traits studied in the two experimental conditions. These results may be due to the effect of temperatures and high humidity during this period (hot and humid), not only on bacterial strains but also on tomato genotypes. The development of fungal diseases is strongly linked to high humidity accompanied by high temperatures (Laumonier, 1979). Tilma and Fontaine (2015) maintain that conditions favourable to the development of *R. solanacearum* are high temperatures. Other authors, such as Lallmahomed & Rakotobe (1988), Rakotondramanana & Rabehevitra (1984), support the same idea, i.e. that bacterial wilt usually occurs on crops in hot, humid periods. The best values for average yields and components under both growing conditions were obtained during the 3rd period of the experiment (August to December 2019). This is a period when temperatures generally decrease, which would be favourable for yield and its components. According to Maïga (2004), tomato cultivation gives better results in the cool, dry season (December to July). Yields for the 1st period (December 2018 to March 2019) under both conditions are also acceptable, with the genotypes probably benefits from the cool periods from December to February and the drop-in humidity from January to March. Bacterial wilt causes losses depending on the variety and the growing period (Ahmed and Sing, 1975; Sing and Rao, 1977).

The analysis did not reveal any significant difference between the two strains (K5 and Sd) for the parameters studied, except for yield per hectare and the interaction of the strains with the periods. The average yield values of genotypes inoculated with strain 1 (K5) were higher than those inoculated with strain 2 (Sd) during experimental periods 1 and 2, and low during period 3. According to Buddenhagen and Kelman (1964), the speed of appearance and intensity of the disease depend on the host (species, cultivar), the physiological stage, the nature of the strain and the quantity of inoculum, but especially on interactions with the environment.

A highly significant difference was observed between varieties and interactions between varieties and period, for the degree of severity of bacterial strains. These results were confirmed by the correlation analysis, which revealed a highly significant negative correlation between all the traits and the degree of severity of the bacterial strains.

The results of the analysis of the mean yield under non-infested conditions show that the best production of the genotypes was achieved during the 3rd period of the experiment.

Stress indices were calculated on the basis of yield in infested (Ys) and non-infested (Yp) conditions. This method of analysis is a means of identifying genotypes with better stress tolerance. A higher value of SSI, Red % and TOL indicates a relatively higher sensitivity to stress (Golabadi *et al.,* 2006). The results of the analysis identified the varieties SF-83-61 and Carioca as genotypes with better performance at different stress levels. On the other hand, Roma, UC-82 and Rossol were identified as the genotypes with the lowest yields. A number of authors both confirm and refute the results obtained in this study. Sikirou *et al.*, (2007) found in their study that the varieties Carioca and Roma were all susceptible to bacterial wilt. According to Huat and Prier (2005), the Mongal F1 and Carioca varieties were both relatively resistant to *R. solanacearum* and had the best yields in their study.

CONCLUSION

The tomato is one of Mali's most important vegetables and is adapted to a wide variety of growing conditions. Bacterial wilt is one of the main causes of tomato yield losses in the field worldwide, and in Mali in particular.

Our study confirmed that bacterial wilt, caused by *R. solanacearum*, is one of the main bacterial diseases causing damage to tomato crops in Mali at all growing seasons. But its damage is greatest during the growing season from April to July. To minimize the damage caused by *R. Solanacearum* and improve field yields at all growing seasons, the SF-83-61 and Carioca varieties can be offered for release in areas where *R. Solanacearum*, which causes bacterial wilt, causes significant damage to tomatoes after confirmation tests.

CONFLICTS OF INTEREST

The authors declare that they have no potential conflicts of interest.

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