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Interannual variability of intra-seasonal rainfall descriptors and drawbacks on the spatio-temporal dynamics of *Helicoverpa armigera* and *Jacobiella facialis* infestations on cotton in Côte d'Ivoire

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ABSTRACT: Cotton yield decrease in Côte d'Ivoire are important because of the climate change and pest infestations. The target of this survey is to analyze the spatio-temporal dynamics of Intra-Seasonal Descriptors (ISD) of rainfall and the annual mean infestation levels (MILs) of two pests, *Helicoverpa armigera* and *Jacobiella facialis,* as well as their interactions. The analysis datas are mainly constituted of annual rainfall and entomological data of *H. armigera* and *J. facialis* covering the period 1971-2016. The spatio-temporal distributions of rainfall ISDs and pest MILs were statistically analyzed, mapped, and their interactions determined using Instat+ and Surfer 11 software. Outcomes showed an interannual variability in rainfall ISDs, with coefficients of variation exceeding 30%. For *H. armigera,* MIL peaks shifted from the South and Center (1995–2000) to the Center-East and North-East (2011–2016), with an overall declining trend in MILs, attributable to the adoption of the Insecticide Resistance Management Program (IRMP) in 1999. However, a recent increase in peak levels suggests that climatic conditions particularly reduced cumulative rainfall and fewer rainy days favor its development. Regarding *J. facialis,* MILs increased from 3 to 16 infested plants per 30 plants, due to the IRMP's limited focus on this pest, with the infestation hotspot shifting from the North (1995-2000) to the North-East and Center-East (2011-2016). These results demonstrated the relevance of integrating climatic conditions into pest management strategies.

KEYWORDS: Cotton, rainfall descriptors, variability, pests, Côte d'Ivoire.

1 INTRODUCTION

Cotton production stands for a significant source of income for the Ivorian agricultural economy. Especially grown in the northern and central parts of Côte d'Ivoire, cotton ranks fourth among agricultural exports after cocoa, rubber and cashews. Cotton production accounts for 7% of export earnings and contributes 1.7% to Côte d'Ivoire's gross domestic product (GDP) ([1], [2]).

However, the last two decades have been marked by a general downward trend in seed cotton yields. Indeed, cotton cultivation in Côte d'Ivoire is mainly carried out under rain-fed conditions. Yet, climate change and its consequences, including reduced and irregular rainfall, shorter rainy seasons and increased prevalence of pests and diseases, are exacerbating the decline in yields and leading to poor harvests [3]. For example, yields fell from 1,380 kg/ha (1999/2000 season) to 952 kg/ha (2016/2017 season) according to [4]. These declines may be linked to the variability of Intra-Seasonal Descriptors (ISDs) of the effective rainy season, such as start and end dates, cumulative rainfall, and number of rainy days [5], as well as attacks by pests such as *Jacobiella facialis* and *Helicoverpa armigera* ([6], [7]).

According to [8], due to climate variations, some pests may cause major yield losses, either directly through damage or indirectly through the introduction and spread of diseases affecting crops such as cotton. However, interactions between climate and pests remain insufficiently studied in West Africa, particularly in Côte d'Ivoire. In this context, it is relevant to investigate whether relationships exist between certain intra-seasonal rainfall descriptors and the mean infestation levels (MILs) of two cotton pests, *Helicoverpa armigera* and *Jacobiella facialis*.

This study aims to analyze the spatio-temporal dynamics of Intra-Seasonal Descriptors (ISDs) of rainfall and the annual mean infestation levels (MILs)

2 MATERIALS AND METHODS

2.1 STUDY SITES

The study area is located between 5°75' and 10°75' north latitude and between 3°5' and 8°5' west longitude. It covers an area of approximately 20,000 km^2. It spans 13 regions: Folon and Kabadougou, Béré, Bafing and Worodougou, Haut-Sassandra and Marahoué, Poro, Tchologo and Bagoué, Hambol and Gbèkè, and Bélier. This area is bordered to the north by Mali and Burkina Faso, to the west by Guinea and the Mountain District, to the south by the Gôh-Djiboua District, to the south-east by the N'zi and Iffou regions, and to the east by the Zanzan District (Figure 1)

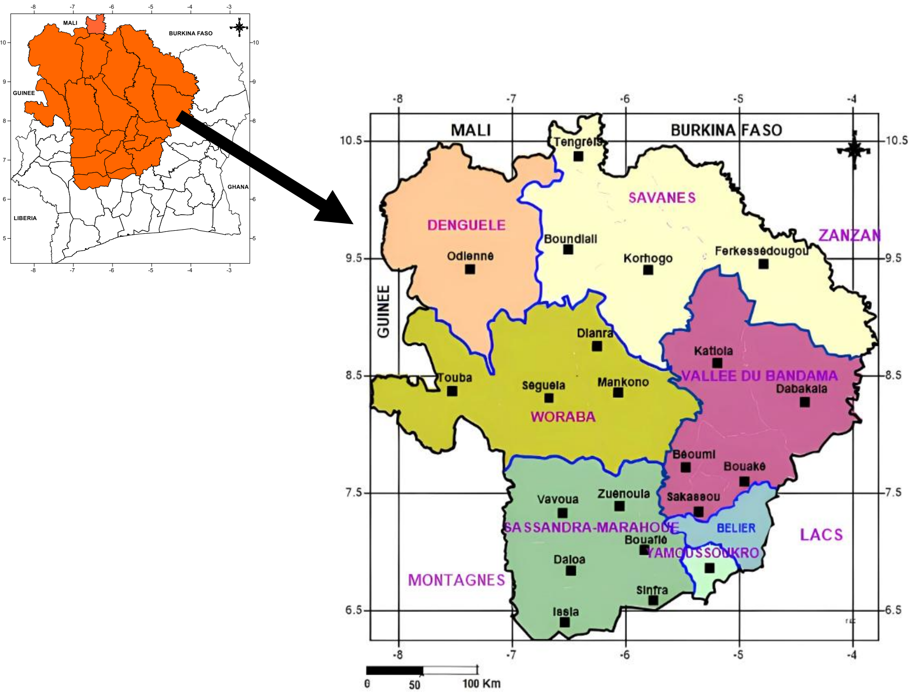

Fig. 1. Map showing the location of the study area

2.2 RAINFALL DATA

Daily rainfall data for the period 1971-2000 (30 years) were considered for this study. These data, reviewed and validated by the "Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique (SODEXAM) " were supplemented by data from the database of Central Laboratory, Soils, Water and Plants (LCSEP) of the National Center for Agronomic Research (CNRA). A dozen stations that complied with the 30-year series were selected (Table 1).

Table 1. of Words

Station Name	Station Type	Longitude	Latitude	Rainfall Pattern
Béoumi	Rainfall station	-5.57	7.67	Bimodal
Bouaflé	Rainfall station	-5.75	6.98	Bimodal
Bouaké	Synoptic station	-5.07	7.73	Bimodal
Boundiali	Rainfall station	-6.47	9.52	Unimodal
Dabakala	Rainfall station	-4.43	8.38	Bimodal
Katiola	Rainfall station	-5.1	8.13	Bimodal
Korhogo	Synoptic station	-5.62	9.42	Unimodal
Mankono	Rainfall station	-6.18	8.05	Unimodal
Niakaramandougou	Rainfall station	-5.28	8.67	Unimodal
Odienné	Synoptic station	-7.57	9.5	Unimodal
Ouangolodougou	Rainfall station	-5.15	9.97	Unimodal
Vavoua	Rainfall station	-6.47	7.37	Bimodal

2.3 ENTOMOLOGICAL DATA COLLECTION

Two species of pests were targeted for this study. The first species is the larvae of *Helicoverpa armigera* Hübner (Noctuidae), one of the most feared pests of cotton plants in Africa and around the world. This polyphagous caterpillar attacks flower buds, flowers and capsules, which empties from the inside, leaving a clean entry hole [9]. The second species of interest is the cotton leafhopper, *Jacobiella facialis* Jacobi, 1912 (Cicadellidae), a piercing-sucking insect of cotton. Its feeding punctures on plant organs cause yellowing along leaf margins, which may even lead to growth cessation or shedding of reproductive organs [6].

2.4 INTERANNUAL CHARACTERIZATION OF INTRA-SEASONAL DESCRIPTORS (ISDS) OF THE RAINY SEASON

As part of this study, a list of eight variables likely to influence rain-fed agriculture was selected as Intra-Seasonal Descriptors (ISDs) of the rainy season (Table 2). The characterization of ISDs first consisted of their determination. This determination, based on agronomic criteria, has been used in the work of several authors in Africa ([10], [11], [12], [13]). The criteria considered were adapted to the climatic conditions of Côte d'Ivoire ([14]; [15]). Thus:

Onset of the Rainy Season (ORS) was defined as the first day, from March 15 onwards for the unimodal rainfall regime, on which at least 20 mm of rainfall was recorded over two consecutive days, with no dry spell longer than 7 days during the subsequent 30 days. For the bimodal regime, the onset of the long rainy season was defined from February 1, and for the short rainy season from August 15, while applying the same criteria.

End of the Rainy Season (ERS) corresponds to the first day after a fixed date when a soil capable of holding 70 mm of available water is completely depleted by a daily evapotranspiration loss of 4 mm. For the unimodal regime, this fixed date is October 1. For the bimodal regime, it is July 1 for the long rainy season and November 1 for the short rainy season.

Length of the Rainy Season (LRS) corresponds to the difference between the onset and end dates of the rainy season.

Seasonal Rainfall Total (SRT) corresponds to the sum of daily rainfall amounts recorded on rainy days between the onset and end dates of the season.

Number of Rainy Days (NRD) corresponds to the total number of days with rainfall amounts greater than 1 mm between the onset and end dates of the season.

Mean Daily Rainfall (MDR) corresponds to the ratio between the seasonal rainfall total and the number of rainy days during the season.

Extreme Rainfall (ER) corresponds to the highest daily rainfall amount recorded during a rainy day.

Dry Spell (DS) is obtained by counting the number of consecutive days without rainfall observed between two rainy days.

To characterize the interannual variability of the ISDs, a descriptive analysis was carried out on all the determined variables using the Instat+ software.

Table 2. Intra-Seasonal Descriptors (ISDs) of the Rainy Season

Variable Acronym	Descriptors Name	Unit
ORS	Onset of the Rainy Season	date
ERS	End of the Rainy Season	date
LRS	Length of the Rainy Season	day
STR	Seasonal Rainfall Total	mm
NRD	Number of Rainy Days	days
MDR	Mean Daily Rainfall	mm/day
ER	Extreme Rainfall	day
DS	Dry Spell	day

2.5 SPATIO-TEMPORAL DISTRIBUTION OF MEAN INFESTATION LEVELS

The pest data were first analysed using Excel 2013 to highlight the mean infestation levels of pests. Then, spatial distribution maps of these levels were generated for the two study periods (1995-2000 and 2011-2016) using the Surfer 11 mapping software.

2.6 RELATIONSHIP BETWEEN MEAN INFESTATION LEVELS AND INTRA-SEASONAL DESCRIPTORS

To assess the strength of the relationship between Mean Infestation Levels (MILs) and the various Intra-Seasonal Descriptors (ISDs) of the Rainy, the Bravais-Pearson linear correlation coefficient was calculated. The significance of the correlations between the different series was then determined using the Bravais-Pearson test at a 95% confidence level.

3 RESULTS

3.1 MEAN CHARACTERISTICS OF INTRA-SEASONAL DESCRIPTORS OF THE RAINY SEASON

3.1.1 UNIMODAL ZONE

The mean characteristics of the Intra-Seasonal Descriptors (ISDs) of the rainy season determined over the study period are presented in Table 3. On average, the rainy season begins on May 14 (±17 days) and ends around November 6 (±10 days). The mean rainfall recorded during this rainy season, which lasts on average 175 days (±19), is estimated at 1,042 mm (±259). The mean number of rainy days per season is 60 days (±9). The mean daily rainfall is 17 mm/day (±2). The mean duration of the longest dry spells is 14 days (±3). The mean number of days with rainfall exceeding 50 mm (extreme rainfall events) is 3 days (±1). Furthermore, the calculated coefficients of variation (CV) range from 3 to 33%. Except for the fine rainfall variable, the CVs of the other variables are relatively high.

Table 3. Intra-Seasonal Descriptors (ISD) of the Rainy Season

Variable Acronym	Mean	Standard Deviation	Coefficient of Variation (%)
ORS (date)	May 14	17	13
ERS (date)	November 6	10	3
LRS (days)	175	19	11
STR (mm)	1,042	259	25
NRD (day)	60	9	15
MDR (mm/day)	17	2	12
ER (day)	14	3	21
DS (day)	3	1	33

3.1.2 BIMODAL ZONE

The mean characteristics of the Intra-Seasonal Descriptors (ISDs) of the long and short rainy seasons determined over the study period are presented in Table 4.

The long rainy season begins on mean on April 5 (±19 days) and ends around July 21 (±17 days). Its mean duration is 108 days (±24) with an average rainfall of 508 mm (±169). The mean number of rainy days recorded during this season is 30 days (±8), resulting in a mean daily rainfall of 13 mm/day (±2). The longest dry spells during the season have a mean duration of 13 days (±2). The number of days with rainfall exceeding 50 mm averages 4 days (±1) during the long rainy season.

The short rainy season, on the other hand, occurs on average on August 26 (±7 days) and ends around November 8 (±11 days). It lasts 73 days (±13) with a mean rainfall of 386 mm (±121). The mean number of rainy days contributing to this seasonal total is 23 days (±7), yielding a mean daily rainfall of 17 mm/day (±3). During this short rainy season, the longest dry spells last on average 11 consecutive days (±2). The number of rainy days with rainfall exceeding 50 mm averages 1.5 days (±1). The calculated coefficients of variation (CV) range from 3 to 33% and are relatively high overall.

Table 4. Intra-Seasonal Descriptors (ISD) of the Rainy Season

Intra-seasonal Descriptors	Mean	Standard Deviation	Coefficient of Variation (%)
Long rainy season			
ORS (date)	April 5	19	20
ERS (date)	July 21	17	8
LRS (days)	108	24	22
STR (mm)	508	169	33
NRD (day)	30	8	27
MDR (mm/day)	13	2	15
ER (day)	13	2	15
DS (day)	4	1	25
Short rainy season			
ORS (date)	August 26	7	3
ERS (date)	November 8	11	4
LRS (days)	73	13	18
STR (mm)	386	121	31
NRD (day)	23	7	30
MDR (mm/day)	17	3	18
ER (day)	11	2	18
DS (day)	1.5	1	30

3.2 SPATIO-TEMPORAL DYNAMICS OF PEST MILS

The Mean Infestation Levels (MILs) of *H. armigera* ranged from 0 to 0.9 caterpillar per 30 plants during the 1995–2000 period. The highest infestation peaks were recorded in the area below the 9th parallel north, i.e., in the central and southern parts of the cotton basin. These infestation peaks ranged from 0.5 to 0.9 caterpillar per 30 plants. In the northern area, MILs were below 0.3 caterpillar per 30 plants (Figure 2A). For the 2011-2016 period, MILs ranged from 0 to 0.4 caterpillar per 30 plants. The highest peaks were 0.4 caterpillar per 30 plants, located in the central and northeastern parts of the cotton basin. The MILs peaks during 2011-2016 were lower compared to the 1995–2000 period (Figure 2B). Mapping the spatio-temporal dynamics of *H. armigera* MILs reveals a significant shift in pest pressure distribution between the two reference periods. While decreasing, the infestation peaks moved from the South and Central zones to the East-Central and Northeast zones of the cotton basin.

The MILs of *J. facialis* during 1995–2000 ranged from 0 to 4 attacked plants per 30 plants. Peaks equal to or greater than 3 attacked plants were in the North-Central part of the cotton area, above the 9th parallel north, between longitudes 6° and 7° W. The spatial distribution during this period appeared homogeneous (Figure 2b). For the 2011–2016 period, MILs ranged from 0 to 16 attacked plants per 30 plants. Infestation peaks greater than 5 attacked plants were observed in the East-Central zone, reaching up to 6 plants, and in the Northeast zone, reaching nearly 16 plants (Figure 48B). Unlike the MIL peaks of *H. armigera,* the MILs peaks of *J. facialis* during 2011–2016 were higher than those of 1995–2000. Mapping the spatio-temporal dynamics of MILs between the two periods shows a shift of the infestation focus from the North in 1995-2000 to the Northeast and East-Central zones in 2011-2016.

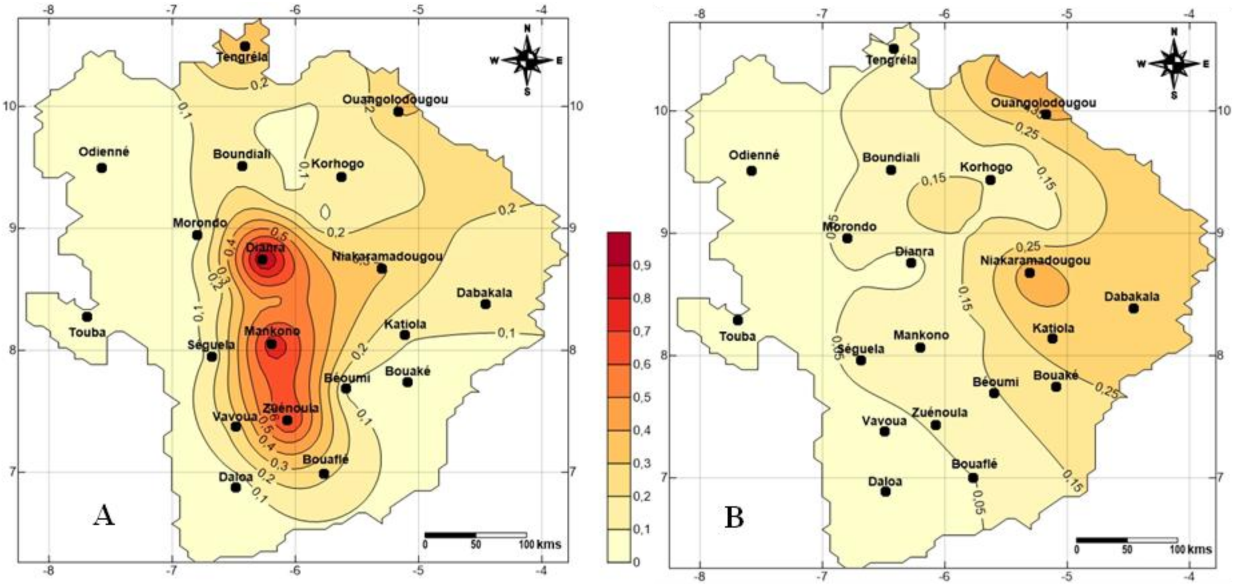

Fig. 2. Spatio-temporal dynamics of mean infestation levels of H. armigera; A: 1995-2000 and B: 2011-2016

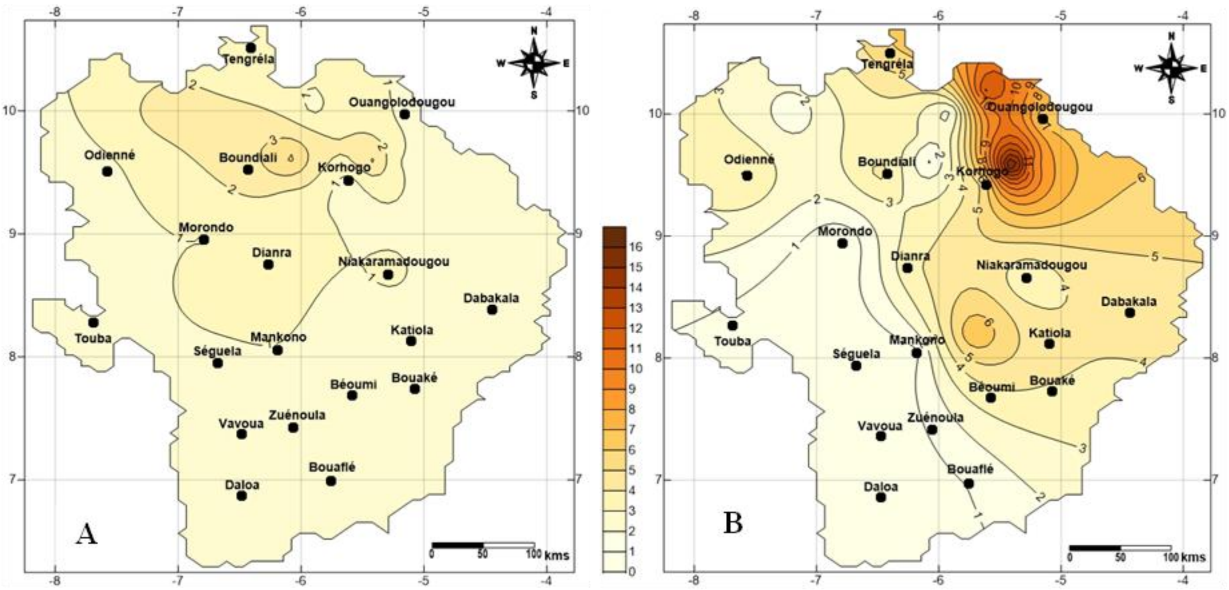

Fig. 3. Spatio-temporal dynamics of mean infestation levels of J. facialis, A: 1995-2000 and B: 2011-2016

3.3 RELATIONSHIP BETWEEN PEST MEAN INFESTATION LEVELS AND INTRA-SEASONAL DESCRIPTORS

The Table 5 presents the correlations between the Mean Infestation Levels (MILs) of the pests and the Intra-Seasonal Descriptors (ISDs) in the Ivorian cotton-growing area. For both pests, correlation analysis shows that MILs are positively correlated with ORS and HMP and negatively correlated with the six other ISDs. Moreover, the correlation coefficients (r) are all below 0.4 in absolute value.

However, for *H. armigera,* significant correlations were observed between MILs and ORS ($r = -0.27$; $p = 0.023$) and between MILs and LRS ($r = -0.29$; $p = 0.015$). Very significant correlations were found between MILs and STR ($r = -0.32$; $p = 0.007$) and between MILs and NRD ($r = -0.32$; $p = 0.006$). At a 95% confidence level, the p-values indicate that, to a lesser extent, ORS, LRS, STR, and NRD significantly influence MILs.

For *J. facialis,* the p-values indicate that the ISDs do not significantly influence MILs ($r < 0.3$ and $p > 0.05$).

Table 5. Correlation levels between pest MILs and ISDs

		MIL-ORS	MIL-ERS	MIL-LRS	MIL-STR	MIL-NRD	MIL-MDR	MIL-ER	MIL-DS
Helicoverpa armigera	Coef. (r)	**0,27***	-0,05	**-0,29***	**-0,32****	**-0,32****	0,19	-0,03	-0,01
	Prob. (p)	**0,023**	0,687	**0,015**	**0,007**	**0,006**	0,107	0,824	0,909
Jacobiella facialis	Coef. (r)	0,16	-0,17	-0,22	-0,12	-0,17	0,07	-0,03	-0,13
	Prob. (p)	0,196	0,172	0,076	0,319	0,166	0,576	0,794	0,309

***r** : correlation coefficient ; **p**: probability; * significant, ** very significant*

4 DISCUSSION

The mean onset date of the rainy season occurs in the first half of May (May 14) under a unimodal regime, and around April 5 and August 26, respectively for the major and minor rainy seasons under a bimodal regime. This gradual establishment of the rainy season from South to North is associated with the meridional shift of the West African monsoon, as suggested by several studies conducted in this region [16]. Furthermore, the dates indicated are close to those reported by [14], who found onset dates between March 20 and May 19 in the unimodal regime and between March 15 and April 29 for the major rainy season and in August for the minor rainy season under the bimodal regime. In Togo, [17] obtained almost similar results: between April 15 and May 27 in the unimodal regime, in April for the major rainy season, and in September for the minor rainy season under the bimodal regime. The mean dates marking the end of the rainy season identified in this study, 6 November for the unimodal regime, 21 July for the main rainy season, and 8 November for the short rainy season in the bimodal regime, fall within the range reported by previous authors. For instance, [14] indicated the end of the rainy season between 1 and 30 November, [18] around 9 November, and [17] between 7 October and 4 November. In the bimodal regime, the average ending dates of the main and short rainy seasons (21 July and 8 November, respectively) are consistent with the findings of [14], who reported July for the main season and between 27 October and 10 November for the short season. The different lengths of the rainy season observed in the cotton basin are consistent with those reported by [19], who estimated them between 175 and 197 days in the unimodal regime, between 115 and 129 days for the major season, and between 56 and 74 days for the minor season in the bimodal regime. The average seasonal rainfall totals associated with these lengths exceed 1000 mm in the unimodal zone, reach 500 mm for the major season, and 380 mm for the minor rainy season. The sum of the totals from the two seasons in the bimodal zone is lower than the average total in the unimodal zone. This difference could be related to the presence of major and secondary reliefs in the northwestern and southern parts of the cotton basin, respectively. Indeed, according to [20], rainfall is positively correlated with the presence of mountain ranges. The mean numbers of rainy days are 53 in the unimodal regime, and 30 and 23 for the main and the short rainy seasons in the bimodal regime. the rainfall amounts per rainy day during the short season are like those of the rainy season in the unimodal zone (17 mm/day). this result indicates higher daily rainfall amounts during the short rainy season compared to the main season. the mean dry spells are 13 and 11 days, respectively, in the main and short rainy seasons. as for extreme rainy days, they amount to 4 days in the main season and 1.5 days in the short season. The relatively high standard deviations of annual rainfall and intra-seasonal descriptors indicate their interannual variability. These results are consistent with those of [21], who showed that high standard deviations reflect strong variability within ISDs.

Pests represent one of the major factors limiting cotton yield. Indeed, they can cause yield losses ranging from 50% to 75%, depending on the country, year, and locality ([22], [23]). Therefore, characterizing the spatio-temporal dynamics of pest MILs and ISDs provides essential information for optimizing pest management in cotton cultivation and increasing producer yields. The study revealed a shift in the peak MILs of *H. armigera* from the southern and central regions during 1995–2000 to the central-eastern and north-eastern regions in 2011–2016. Moreover, MILs observed during 2011–2016 (0 to 0.4 larvae per 30 plants) showed a decreasing trend compared to the 1995–2000 period (0 to 0.9 larvae per 30 plants). This decline in MILs is likely attributable to the implementation of the Insecticide Resistance Management Program (IRMP), adopted in 1999 across all cotton-growing areas. The program requires that all farmers subject their fields to a schedule of six insecticide treatments [7]. In this context, [7] demonstrated the significantly positive impact of the IRMP on these pests. Indeed, after the IRMP implementation in 1999, MILs that had been steadily increasing to reach infestation peaks of 0.23 and 0.79 larvae per 30 plants in the northern and southern zones, respectively, significantly declined during 1999–2007, with peaks not exceeding 0.12 larvae per 30 plants in the north and 0.19 larvae per 30 plants in the south. It is observed that MILs during 1995–2000 were comparable to the pre-IRMP period (1993–1998), whereas those in 2011–2016 showed an increase compared to the post-IRMP period (1999–2007). This upward trend in MILs suggests a resurgence of *H. armigera* in recent years [24].

This resurgence could partly be explained by climatic conditions. Significant correlations were observed between MILs and certain ISDs, with ORS (r = 0.27; p = 0.023) and LRS (r = -0.29; p = 0.015), and highly significant correlations with SRT (r = 0.32; p = 0.007) and NRD (r = 0.32; p = 0.006). Delays in ORS, reductions in SRT and NRD, and shortening of LRS create favourable conditions for pest development, i.e., lower rainfall and the possibility of higher sunshine exposure. These findings align with those of [25], who showed that the life cycle of this species is closely linked to climatic conditions. The proliferation of this pest could further intensify under the climate variability observed in recent decades. Regarding *J. facialis,* the peaks in mean infestation levels (MIL) shifted from the North-Central to the North-Eastern and Central-Eastern regions. MIL peaks increased from 3 attacked plants in 1995–2000 to nearly 16 attacked plants per 30 plants in 2011–2016, showing an upward trend. These results are consistent with those of [6] for similar periods (1993–2007 and 2011–2015). This upward trend may be explained by the fact that the Insecticide Resistance Management Program (IRMP) was primarily targeted against capsule-feeding larvae, which are the main contributors to yield losses ([26], [24]). Consequently, this situation may have facilitated the emergence of previously minor pests such as *J. facialis.* Additionally, the observed reduction in rainfall in recent years may have contributed to this increase, as rainfall is one of the environmental factors influencing leafhopper proliferation in cotton cultivation [27]. Contrary to [6], who reported significant correlations between MIL and rainfall totals in June and June-July, the correlations between MIL and intra-seasonal descriptors (ISDs) in this study were not significant. However, under favourable conditions for the development of this pest (reduced rainfall and high temperature), as described by [9] and [6], MIL could increase with future disturbances in climatic parameters such as rainfall and temperature, as reported by [28].

5 Conclusion

At the end of our work, we could assert without denying there is a substantial interannual variability in intra-seasonal rainfall descriptors and a spatio-temporal modification in the damage caused by the two pests, *Helicoverpa armigera* and *Jacobiella facialis*. Moreover, the significant correlations between intra-seasonal rainfall descriptors and mean infestation levels implement the impact of climate variability in general, and intra-seasonal rainfall patterns particularly, on pest proliferation. These findings underline the significance of integrating climatic conditions into pest management strategies.

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