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Article

Abundance of Cotton Bollworms and Their Impact on Production in Cotton-Growing Areas in Côte d'Ivoire from 2021 to 2024

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Simple Summary

Pest pressure is a major constraint in cotton cultivation in Côte d'Ivoire. This study was conducted to assess the impact of bollworms *Helicoverpa armigera*, *Diparopsis watersi*, *Earias* spp., *Pectinophora gossypiella*, and *Thaumatotibia leucotreta* on production. Therefore, monitoring was conducted over four years, from 2021 to 2024. The results revealed that the damage caused by the larvae of these Lepidoptera has a significant negative impact on seed cotton yields. This highlights the need to adapt protection strategies to guarantee better yields.

Abstract

Cotton is integral to the rural economy of Côte d'Ivoire. However, it faces challenges such as pest infestations, notably carpophagous Lepidoptera. The recent incursion of the leafhopper *Amrasca biguttula* has disrupted existing plant protection strategies, resulting in the resurgence of key lepidopteran pests. This study aimed to evaluate the extent of damage inflicted by the primary species of bollworms on cotton crops within this altered context. The results indicated that *Helicoverpa armigera* remained the most prevalent exocarpic Lepidoptera species, followed by *Earias* spp. and *Diparopsis watersi*. *Helicoverpa armigera* infestations are more severe in the late planting stage, and this species is present throughout the cotton-growing region. *Earias* spp. and *Diparopsis watersi* larvae were more abundant in the northeastern cotton-growing area. Among the two endocarpic Lepidoptera species, *Pectinophora gossypiella* was more prevalent than *Thaumatotibia leucotreta*. A negative and significant correlation ($r = -0.45$; $p = 0.001$) was observed between damage by bollworms and seed cotton yield, underscoring the economic importance of these pests. These findings underscore the necessity of tailoring protection strategies to align with the specific species present, the characteristics of the production areas, and the timing of the sowing periods.

Keywords: cotton; bollworms *Helicoverpa armigera*; *Diparopsis watersi*; *Earias* spp.; *Pectinophora gossypiella*; *Thaumatotibia leucotreta*; Côte d'Ivoire

1. Introduction

In Côte d'Ivoire, cotton is a pivotal component of the rural economy, offering a stable income to over 106.000 farmers. This crop is cultivated from the central region to the northern borders, covering more than 392.000 ha [1]. However, cotton farming faces several challenges, including soil depletion [2] and climate change [3]. In addition, the productivity and quality of cotton are significantly compromised by pests. The pest spectrum is notably diverse and includes sucking insects (aphids, jassids, and whiteflies) and leaf- and carpophagous lepidopterans. The larvae of Lepidoptera (*Helicoverpa armigera*, *Diparopsis watersi*, *Earias* spp., *Pectinophora gossypiella* and *Thaumatotibia leucotreta*) are considered the most formidable pests because they directly attack cotton bolls, leading to substantial economic losses [4,5]. During the 2022–2023 cotton season, the invasive leafhopper

Amarasca biguttula biguttula Ishida [6] emerged on cotton crops in Côte d’Ivoire, causing production losses exceeding 50% [7], which disrupted plant protection strategies that were previously focused on bollworms (*Helicoverpa armigera*). Consequently, jassids have become a critical factor in plant protection programs. During the cotton season, significant attention has been devoted to managing this new threat, leading to the neglect of larvae of Lepidoptera and their subsequent resurgence [8]. This increased focus on managing *A. biguttula* may create a new imbalance within the pest complex. Indeed, specific insecticides, such as flonicamid, used on leafhoppers are not effective against Lepidoptera larvae [9]. Furthermore, in the context of *A. biguttula* invasion, there are no updated data on the abundance of Lepidopteran pests and the level of damage they cause in different cultivation areas of Côte d’Ivoire. However, this knowledge is essential for developing effective management strategies for all pests. The present study aimed to evaluate the overall impact of the damage caused by the larvae of *Diparopsis watersi*, *Helicoverpa armigera*, *Earias* spp., *Pectinophora gossypiella*, and *Thaumatotibia leucotreta* on cotton cultivation in Côte d’Ivoire, within the context of jassid (*A. biguttula biguttula*) invasion. The specific objectives were to determine the annual and spatial variations of these pests and to assess their impact on the health status of cotton bolls and seed cotton yield.

To address these objectives, a detailed study spanning various cotton-producing regions was conducted, as described in the following sections.

2. Materials and Methods

2.1. Study Area

This research was conducted in the cotton-producing region of Côte d’Ivoire, which extends from the central to the northern part of the country between latitudes 7°5 to 12° N and longitudes 3° to 8.5°W (Figure 1). This region spans both sides of the 9th parallel. The area north of the 9th parallel is characterized by a Sudanian climate featuring an extended dry season from October of one year to May of the subsequent year. Conversely, the southern area situated below the 9th parallel experiences greater precipitation and is characterized by a sub-Saharan climate with two distinct rainy and dry seasons. The rainy season occurs from March to July and from October to November, whereas the dry season occurs from August to September and from December to February. The annual rainfall in this region varies between 1300 and 1700 mm [10]. Fifty localities were selected from the entire cotton-growing region.

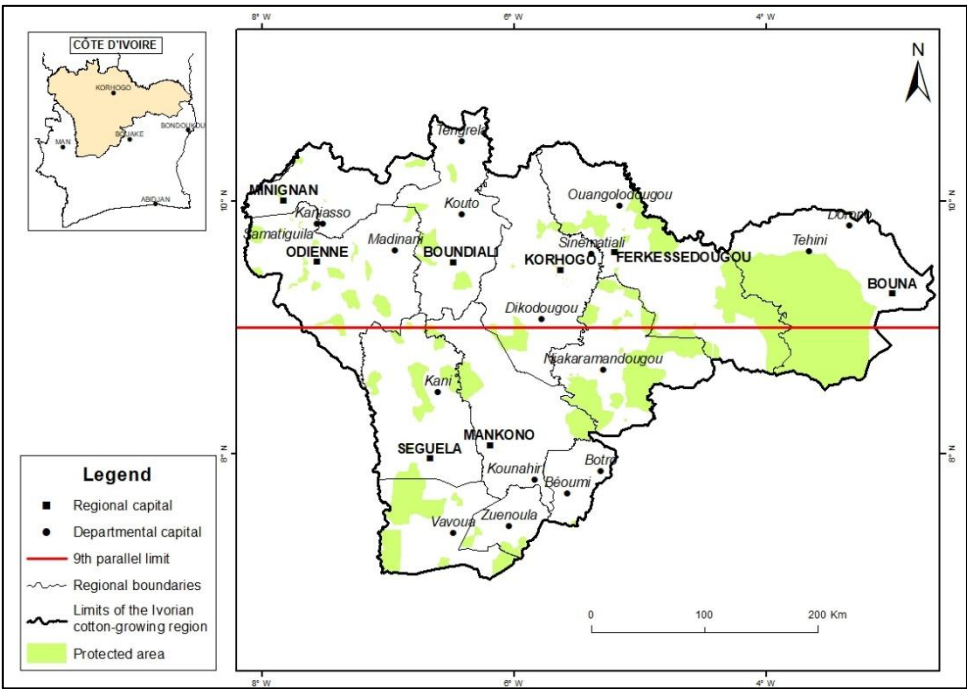


Figure 1. Study area.

2.2. Plots Selection

In each location, 10 producer plots were chosen to ensure a representative sample of local variability while remaining feasible for intensive data collection purposes. Two parameters guided the selection process: First, the North-South and East-West axes were considered to ensure comprehensive representation across the locality. The second parameter was the cotton-sowing period. Initially, the sowing dates of all producers in the area were recorded and grouped into 10-day intervals, known as decades. Subsequently, 10 producers were selected from these sowing decades. The number of producers selected per decade was proportional to the overall number of producers who sowed during that period. In the northern region, most producers sowed between June 1st and June 30th, resulting in seven out of ten producers (70%) being selected during this timeframe. In the southern region, most sowing occurred between June 11th and July 10th, encompassing eight of the ten producers (80%) in the sample. After determining these allocations, a random draw was performed.

In each selected plot, a usable area of 0.25 ha was marked at the center for the purpose of data collection. This specific area size is commonly used in field trials to ensure a representative sample, and placing it in the center helps mitigate potential edge effects from surrounding non-study areas or different management practices. This allows for monitoring the evolution of the factors studied in the same portion and makes data collection easier

The local cotton variety used in this study was Gouassou Fus. In addition to being tolerant to Fusarium wilt, this variety has good agronomic and technological characteristics [11].

2.3. Sampling and Observations

- Counting of bollworms on cotton plants

Weekly direct observations were conducted on the plants from the 30th to the 122nd day after planting. Each observation involved 30 cotton plants on 30 cotton plants within an observation area of 0.25 ha. These plants were selected in six groups of five consecutive plants along a diagonal transect of the field [12], as shown in Figure 2 to ensure representativeness. In addition, the diagonals were changed weekly to better cover the fields.

Each plant was meticulously examined to count *Diparopsis watersi*, *Helicoverpa armigera*, and *Earias* spp. larvae. These species are classified as exocarpic because the larvae inhabit and develop external bolls on the cotton plant.

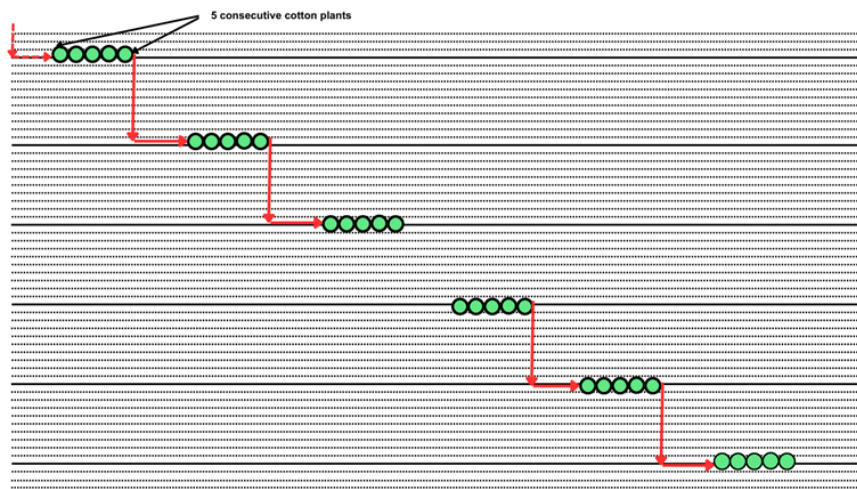


Figure 2. Method for selecting six groups of five plants along the diagonal.

- **Sanitary analysis of green bolls**

P. gossypiella and *T. leucotreta* larvae develop within bolls and are thus categorized as endocarpic. Consequently, a sanitary analysis of bolls is imperative for their detection. Starting on the 80th day after sowing, five health evaluations were conducted on days 80, 87, 94, 101, and 108. During each evaluation, 50 green capsules were randomly sampled from within the 0.25 ha plot, with only one boll taken from each plant. However, the cotton plants in the four central rows were spared as they were reserved for yield estimation. These bolls, which were approximately the same age, were sampled from the middle of the plant and close to the main stem. After collecting, the bolls were examined and categorized into several classifications: healthy, perforated bolls, and bolls that appeared healthy but had internal damage.

During the sanitary analysis, larvae of *Pectinophora gossypiella* and *Thaumatotibia leucotreta* present into bolls were counted.

- **Harvest and estimation of cotton yield**

Harvesting was conducted in the four central rows of each plot when the bolls were fully opened. Seed cotton weighed after harvesting, and the yield was quantified in kilograms per hectare.

2.3. Statistical Analyses of the Data

Various analyses were performed on the data. Analysis of variance was performed to compare the pest averages across years, locations, and sowing periods. Correlation and regression analyses were performed to evaluate the relationship between bollworms, health status of bolls, and seed cotton yield. These analyses were performed using GenStat Tenth Edition software.

Spatial distribution maps were created using the ggplot2 package to assess the geographic distribution of carpophagous Lepidoptera in cotton-growing regions.

3. Results

3.1. Average Abundances of Cotton Bollworms

The mean densities of the various bollworms are listed in Table 1. For exocarpic larvae, the average numbers per 30 plants were approximately 0.038±0.011 for *D. watersi*, 0.14±0.061 for *H. armigera*, and 0.06±0.012 for *Earias* spp. In terms of endocarpic larvae, the mean densities in 100 green capsules were 0.014±0.003 for *P. gossypiella* and 0.001±0.00 for *T. leucotreta*, respectively.

Table 1 Average densities of bollworms on plants and in cotton bolls

Groupes	Species	Minimum	Maximum	Average	Standard deviation
Exocarpic	<i>Diparopsis watersi</i> (mean/30 plants)	0.000	1.000	0.038	0.011
Lepidopteran	<i>Helicoverpa armigera</i> (mean/30 plants)	0.000	2.923	0.143	0.061
larvae	<i>Earias</i> spp (mean/30 plants)	0.000	0.909	0.064	0.012
Endocarpic	<i>Pectinophora gossypiella</i> (mean/100 green bolls)	0.000	0.667	0.014	0.003
Lepidoptran	<i>Thaumatotibia leucotreta</i> (mean/100 green bolls)	0.000	0.429	0.001	0.000
larvae					

Having established baseline densities, it is important to explore their fluctuations over the study period.

3.2. Annual Variations in the Abundance of Cotton Bollworms

3.2.1. Variation of Exocarpic Bollworms

Table 2 shows the results of the statistical analyses performed to evaluate the larval population densities from 2021 to 2024.

The average larval densities ranged from 0.03 ±0.00 to 0.07 ±0.01 larvae per 30 plants for *D. watersi*, from 0.11±0.04 to 0.22±0.04 larvae per 30 plants for *H. armigera*, and from 0.05±0.01 to 0.07±0.01 larvae per 30 plants for *Earias* spp. Statistical analyses revealed significant differences between the annual averages of *D. watersi*, *H. armigera*, and *Earias* spp. In 2024, the larval density of *D. watersi* was high, exceeding twice the average recorded in 2021. In contrast, *H. armigera* showed a decline in 2022, with densities of 0.06±0.03 larvae per 30 plants compared to 0.11±0.04 to 0.22±0.04 larvae per 30 plants in 2021. However, the density doubled in 2023, reaching 0.22±0.04 larvae per 30 plants before experiencing a slight decrease in 2024, with densities ranging from 0.13±0.04 to 0.22±0.05 larvae per 30 plants. The larval density of *Earias* spp. decreased in 2022. However, the population levels returned to the same level during the following two years (2023 and 2024).

3.2.2. Variation of Endocarpic Bollworms

For *P. gossypiella*, a notable variation in average density was observed across years. The highest density was recorded in 2023, at 0.02 larvae per 100 capsules. Conversely, the lowest densities were recorded in 2021 and 2022 at 0.006 and 0.009 larvae per 100 capsules, respectively. A discernible trend of gradual population increase was evident from 2021 to 2024. In contrast, the average density of *T. leucotreta* remained very low, approaching zero, in all years. No significant variations were observed. The populations appear to be stable at a very low level throughout the 2021-2024 period

Table 2. Trends in the average densities of bollworms on cotton plants and within green bolls from 2021 to 2024.

Years	Exocarpic Lepidopteran larvae (mean/30 cotton plants)			Endocarpic Lepidopteran larvae (mean/100 green bolls)	
	<i>D. watersi</i>	<i>H. armigera</i>	<i>Earias</i> spp	<i>P. gossypiella</i>	<i>T. leucotreta</i>
2021	0.03 ± 0.00 a	0.11 ± 0.04 b	0.07 ± 0.02 b	0.006 ± 0.00 a	0.000 ± 0.00
2022	0.04 ± 0.01 ab	0.06 ± 0.03 a	0.05 ± 0.01 a	0.009 ± 0.00 a	0.002 ± 0.00
2023	0.03 ± 0.01 a	0.22 ± 0.09 c	0.06 ± 0.00 b	0.02 ± 0.01 b	0.002 ± 0.00
2024	0.07 ± 0.01 b	0.13 ± 0.05 b	0.07 ± 0.01 b	0.01 ± 0.00 ab	0.000 ± 0.00
F	3.97	31.14	3.38	5.75	0.14
p	0.008	<0.001	0.018	<0.001	0.332

3.3. Impact of the Production Area on the Larval Densities of Cotton Bollworms

3.3.1. Impact of the Production Area on Exocarpic Bollworms

Figure 3 shows notable variations in the distribution of *D. watersi* across different locations. The highest larval densities were recorded in the northeast, specifically in Ferké (0.46 larvae per 30 plants), Koumba (0.22 larvae per 30 plants), and Sikolo (0.20 larvae per 30 plants). Conversely, densities approaching 0 larvae per 30 plants were observed in Bouandougou, Boundiali, Boron, Niofoin, Odiéné, Sarhala, Sinématiali, Tienko, Tomono, Vavoua and Zuénoula. The comprehensive analysis presented in Table 3 indicates that this species predominantly inhabits northern cotton-growing areas.

Figure 4 illustrates the distribution of *H. armigera* across the various production zones. This species was prevalent in all zones. The highest density was recorded in Sordi (0.81 larvae per 30 plants). followed by Napié (0.47 larvae per 30 plants) and Diawala (0.41 larvae per 30 plants). In

contrast, lower densities were observed in localities such as Boundiali and Ouéllé. Goulia and Gbon, with averages approaching 0.00 larvae per 30 plants. The comparative analysis in Table 3 reveals a significant difference between the northern and southern regions of the cotton basin; larval density was greater in the north (0.16 larvae per 30 plants) than in the south (0.10 larvae per 30 plants).

Significant variations in the presence of *Earias* spp. were observed across different locations (Figure 5) with a notably higher prevalence in the northeastern region of the country. The average larval density was highest in Diawala, with 0.45 larvae per 30 plants followed by Ferke and Sikolo each with 0.24 larvae per 30 plants. Conversely, the lowest densities (approximately 0.00 larvae per 30 plants, were recorded in Boundiali, Bouandougou, and Sinématiali. The analysis in Table 3 revealed that the average density of *Earias* spp. in the northern region exceeded that in the southern region.

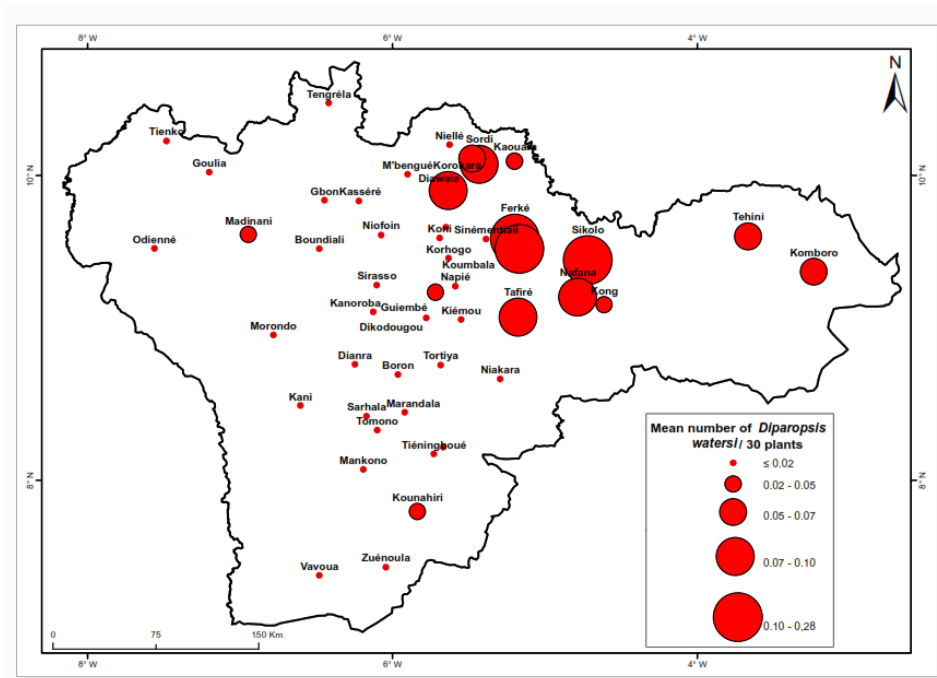


Figure 3. Spatial variation in the mean density of *Diparopsis watersii* larva within the cotton cultivation areas of Côte d'Ivoire based on a survey from 2021 to 2024.

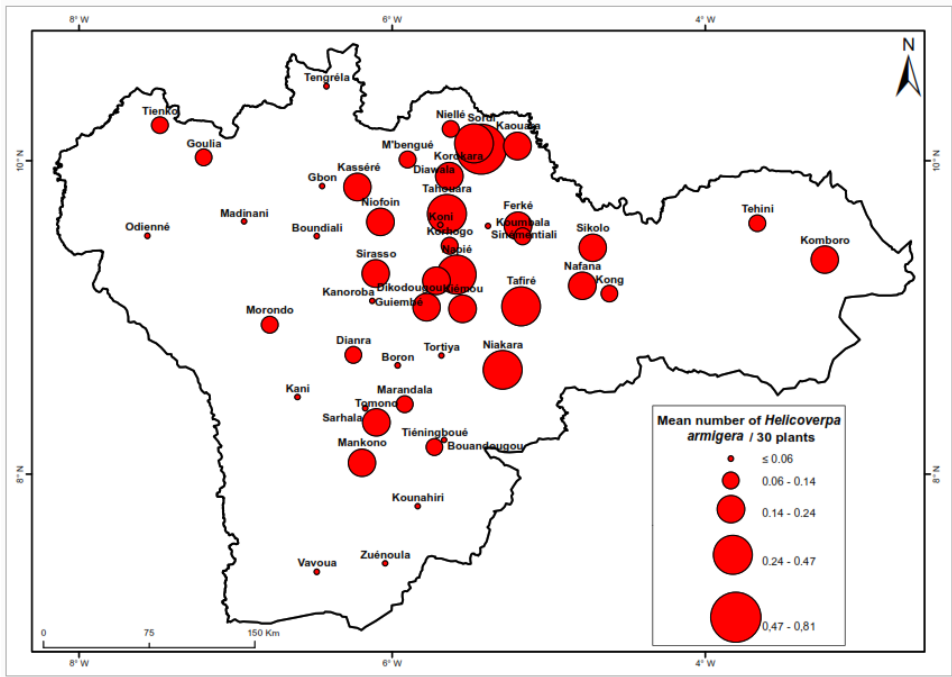


Figure 4. Spatial variation in the mean density of *Helicoverpa armigera* larva within the cotton cultivation areas of Côte d’Ivoire based on a survey from 2021 to 2024.

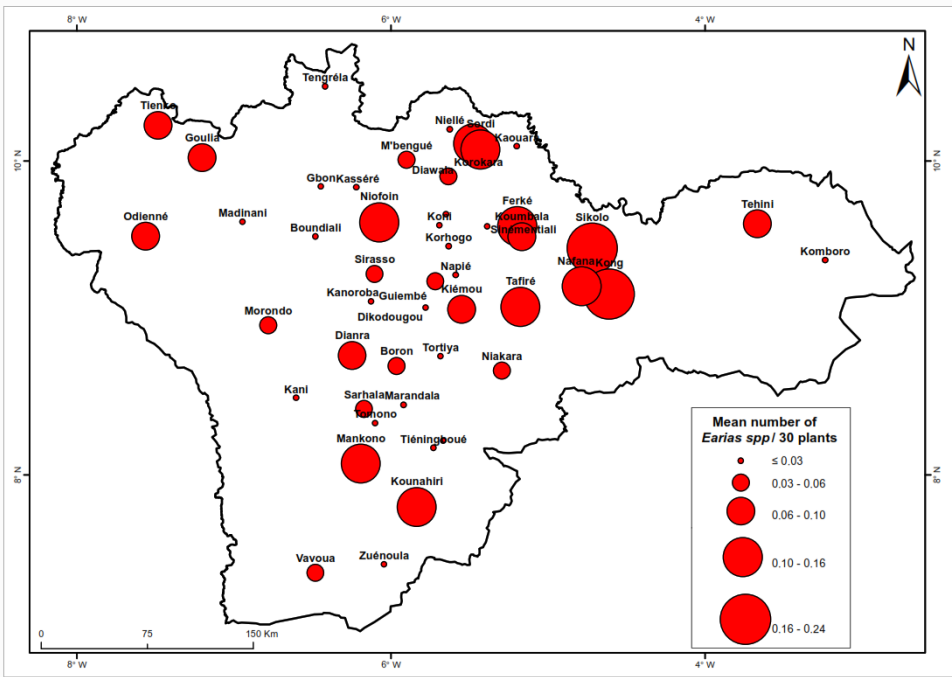


Figure 5. Spatial variation in the mean density of *Earias* spp larva within the cotton cultivation areas of Côte d’Ivoire based on a survey from 2021 to 2024.

3.3.2. Impact of the Production Area on Endocarpic Bollworms

Figure 6 illustrates the notable variation in larval densities of *P. gossypiella* across different localities. This species is predominantly observed in southern regions, specifically in the localities of Zuénoula (0.22 larvae/100 bolls), Kounahiri (0.21 larvae/100 bolls). Vavoua (0.14 larvae/100 bolls) and Koumbala (0.06 larvae/100 bolls). The analytical results presented in Table 3 suggest a higher abundance of these species in the southern cotton-growing basin.

Figure 7 depicts the overall low density of *T. leucotreta*. The highest densities were recorded in Boundiali (0.05 larvae/100 bolls) and Mankono (0.02 larvae/100 Bolls). This species did not exhibit a distinct distribution pattern between the northern and southern regions (Table 3).

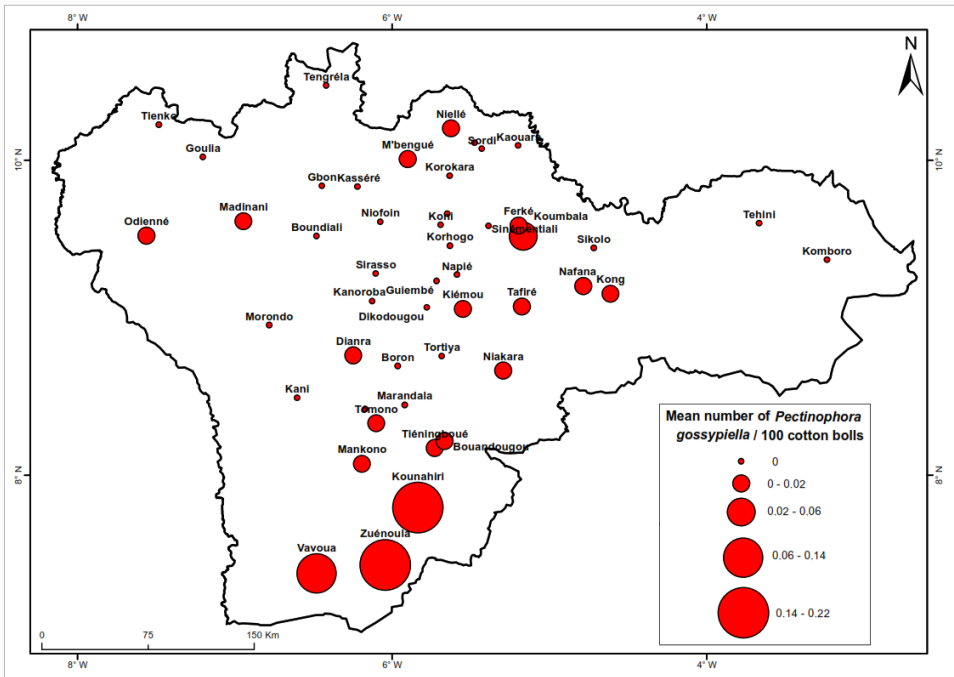


Figure 6. Spatial variation in the mean density of *Pectinophora gossypiella* larva within the cotton cultivation areas of Côte d’Ivoire based on a survey from 2021 to 2024.

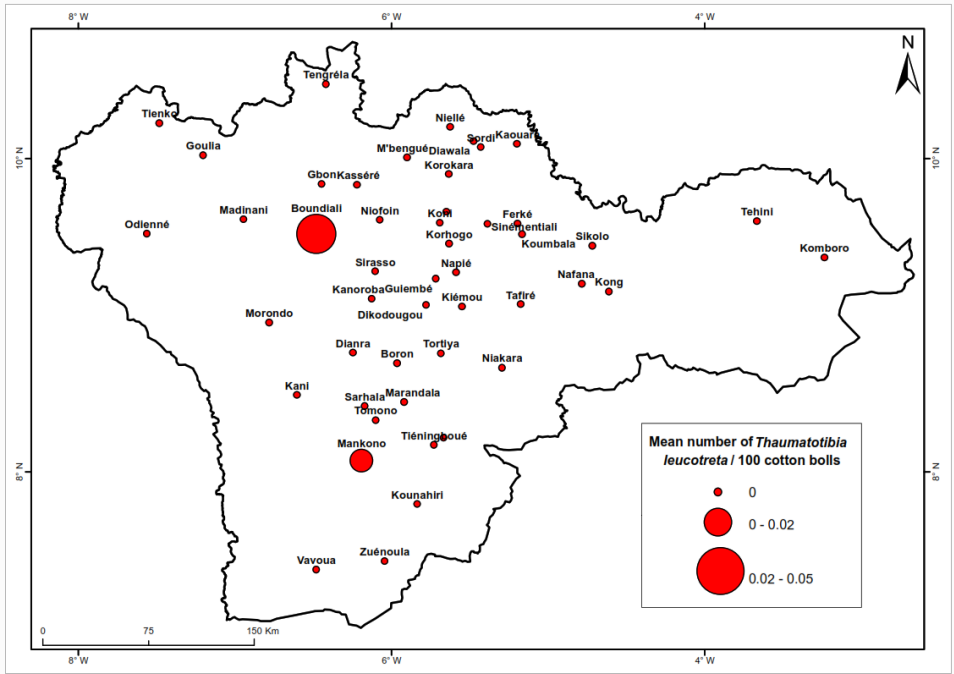


Figure 7. Spatial variation in the mean density of *Thaumatotibia leucotreta* larva within the cotton cultivation areas of Côte d’Ivoire based on a survey from 2021 to 2024.

Production area	Exocarpic Lepidopteran larvae (mean/30 cotton plants)	Endocarpic Lepidopteran larvae (mean/100 green bolls)

	<i>D. watersi</i>	<i>H. armigera</i>	<i>Earias</i> spp	<i>P. gossypiella</i>	<i>T. leucotreta</i>
North	0.06 ± 0,01	0.16 ± 0,07	0.07 ± 0.01	0.01 ± 0,00	0.00 ± 0.00
South	0.00 ± 0,00	0.10 ± 0,03	0.05 ± 0.01	0.03 ± 0,01	0.01 ± 0.00
<i>t</i>	8.51	4.35	2.64	7,55	0,75
<i>p</i>	<0.001	<0.001	0.008	<0.001	0.454

3.4. Influence of the Sowing Period on the Density of Cotton Bollworms

Table 4 presents the densities of various species of carpophagous Lepidoptera according to cotton-sowing timing.

No statistically significant differences were detected in the average densities of *Diparopsis watersi*, *Earias* spp., *P. gossypiella*, and *T. leucotreta* across the various sowing periods. In contrast, a significant variation in the density of *H. armigera* was observed depending on the sowing period. The highest density (0.18 larvae per 30 plants) was recorded during the D4 sowing period (June 21 to 30), whereas the lowest density was noted during the D1 sowing period (May 20 to 31). Overall, there was an observable trend indicating a progressive increase in *H. armigera* density from the early to the late sowing periods.

Table 4. Variation in the densities of bollworms in relation to the timing of cotton sowing in Côte d’Ivoire.

Sowing period	Exocarpic Lepidopteran larvae (mean/30 cotton plants)			Endocarpic Lepidopteran larvae (mean/100 green bolls)	
	<i>D. watersi</i>	<i>H. armigera</i>	<i>Earias</i> spp	<i>P. gossypiella</i>	<i>T. leucotreta</i>
D1 (20-31 may)	0.01 ± 0.00	0.06 ± 0.01 a	0.09 ± 0.02	0.00 ± 0.00	0.000 ± 0.00
D2 (01-10 jun)	0.03 ± 0.01	0.11 ± 0.03 a	0.07 ± 0.01	0.02 ± 0.00	0.003 ± 0.00
D3 (11-20 jun)	0.04 ± 0.01	0.13 ± 0.04 ab	0.06 ± 0.01	0.01 ± 0.00	0.001 ± 0.00
D4 (21-30 jun)	0.05 ± 0.01	0.18 ± 0.11 b	0.07 ± 0.01	0.01 ± 0.00	0.001 ± 0.00
D5 (01-10 july)	0.04 ± 0.02	0.13 ± 0.07 ab	0.07 ± 0.02	0.02 ± 0.00	0.002 ± 0.00
D6 (11-20 July)	0.04 ± 0.01	0.11 ± 0.03 a	0.03 ± 0.00	0.03 ± 0.01	0.000 ± 0.00
<i>F</i>	1.22	3.59	0.83	0.84	0.73
<i>p</i>	0.299	0.003	0.529	0.524	0.598

3.5. Influence of Bollworms on the Sanitary Condition of Green Bolls and Cotton Yield

• Influence on the rate of perforated bolls

Table 5 presents the results of multiple regressions of the mean number of perforated bolls as a function of the larval density. The analysis of variance was significant (*p* <0.001) and indicated that Lepidopteran larvae were responsible for approximately 10.5% of the prforation of bolls (*R*² = 0.105). The species with a significant influence were *D. watersi*, *H. armigera*, *Earias* spp. and *P. gossypiella*. All regression coefficients (*β*) were positive. This indicates that the rate of perforated bolls increases when larval populations are high. Furthermore, the analysis of the standardized coefficients showed that *D. watersi* had the greatest influence on the rate of perforated bolls, followed by *P. gossypiella* and *H. armigera*.

• Influence on the rate of internal damage in cotton bolls

The results of the regression analysis of bolls with internal damage are presented in Table 6. The regression was significant and indicated that 3% of the variations in this parameter were due to the larvae of carpophagous Lepidoptera (*R*² = 0.3; *p* <0.001). An examination of the coefficients (*β*) showed

that the rate of bolls with internal damage increased when the larval populations of *P. gossypiella* and *T. leucotreta* were high. Conversely, this rate decreased when the larval populations of *D. watersi*, *H. armigera*, and *Earias* spp. were high. The analysis of the standardized coefficients (β std) showed that *D. watersi*, *P. gossypiella*, and *T. leucotreta* were the most influential.

Figure 8 illustrates a significant negative correlation ($r = -0.45$) between seed cotton yield and the percentage of damaged green bolls. Approximately 20% of yield losses are related to damage caused by bollworms ($R^2 = 0.20$).

Table 5. Regression coefficients of the rate of perforated bolls as a function of the densities of bollworms ($F = 29.62$, $p < 0.001$).

Variables	β	SE	t	Pr > t	IC (95%)	β std
Intercept	0.82	0.069	11.791	<0.0001	[0.68 ; 0.95]	
<i>Diparopsis watersi</i> (mean/30 plants)	4.10	0.545	7.508	<0.0001	[3.03 ; 5.17]	0.21
<i>Helicoverpa armigera</i> (mean/30 plants)	0.90	0.225	4.002	<0.0001	[0.46 ; 1.34]	0.11
<i>Earias</i> spp (mean/30 plants)	1.32	0.528	2.505	0.012	[0.29 ; 2.36]	0.07
<i>Pectinophora gossypiella</i> (mean/100 green bolls)	5.40	0.942	5.724	<0.0001	[3.546 ; 7.24]	0.15
<i>Pectinophora gossypiella</i> (mean/100 green bolls)	0.80	3.210	0.248	0.805	[-5.50 ; 7.09]	0.01

$R^2 = 0,105$; SE : Standard Error; IC : Interval of confidence; β std : standardized coefficients.

Table 6. Regression coefficients for the rate of bolls with internal damage as a function of the densities of bollworms ($F = 9.94$, $p < 0.001$).

Variables	β	SE	t	Pr > t	IC (95%)	β std
Intercept	7,001	0,270	25,893	<0,0001	[6.47 ; 7.53]	
<i>Diparopsis watersi</i> (mean/30 plants)	-7,540	2,133	-3,535	0,000	[-11.73 ; -3.36]	-0,10
<i>Helicoverpa armigera</i> (mean/30 plants)	-1,843	0,878	-2,099	0,036	[-3.57 ; -0.12]	-0,06
<i>Earias</i> spp (mean/30 plants)	-3,849	2,066	-1,863	0,063	[-7.90 ; 0.21]	-0,05
<i>Pectinophora gossypiella</i> (mean/100 green bolls)	12,066	3,686	3,273	0,001	[4.83 ; 19,30]	0,09
<i>Pectinophora gossypiella</i> (mean/100 green bolls)	37,836	12,554	3,014	0,003	[13,21 ; 62.47]	0,08

$R^2 = 0,03$; SE : Standard Error; IC : Intervalle of confidence; β std : standardized coefficients.

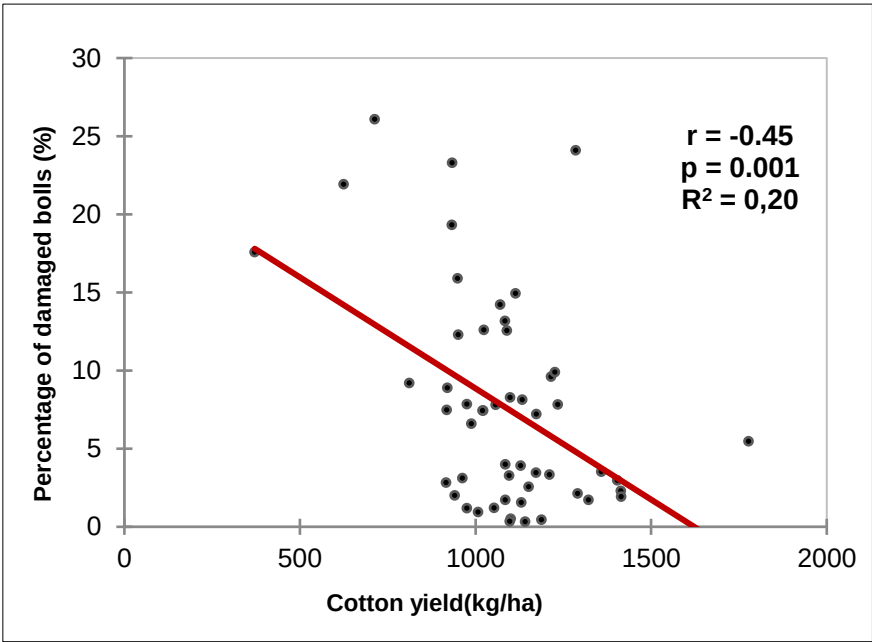


Figure 8. Variation in seed cotton yields in response to bollworms damage on green bolls.

4. Discussion

The study showed that *Helicoverpa armigera* is the most predominant exocarpic bollworm, followed by *Earias* spp and *Diparopsis watersi*. The prevalence of *H. armigera* may be due to the diversity of host plants in the production environment. Indeed, this species is found worldwide and is known to feed on more than 300 plant species belonging to over 68 families [13]. Although it is recognized as the key pest of cotton, studies have shown that several other crops are more attractive to *H. armigera*, particularly tobacco, maize, and sunflower [14]. This predisposition allows *H. armigera* to adapt easily and proliferate in various regions [15,16]. Therefore, management of this species should take several aspects into account, including relay host plants. In contrast, the *Diparopsis watersi* species does not have a wide diversity of host plants. This species enters diapause during the dry season to survive unfavorable environmental conditions, such as temperature, relative humidity, photoperiod, etc. [17–19].

Among the two endocarpic species, *Pectinophora gossypiella* was the most abundant. Indeed, previous studies have shown difficulties in controlling these two species. Previous work on *P. gossypiella* demonstrated that larval development inside the capsules greatly limits the effectiveness of insecticide products [20]. Furthermore, studies on sensitivity have revealed a strong presence of insecticide detoxification enzymes in *P. gossypiella* and levels of resistance, particularly to organophosphates [21]. It would thus be advisable to consider integrated management strategies. Alternative methods such as mating disruption [22], mass trapping [23], and integrated management strategies have been evaluated [24–26].

Regarding the spatial distribution of the studied pests, exocarpic species (*H. armigera*, *D. waersi*, and *Earias* spp.) were more abundant in areas located above the 9th parallel, whereas the densities of endocarpic species (*P. gossypiella* and *T. leucotreta*) were higher in the area situated below the 9th parallel. These results confirm previous studies [27]. This distribution may be influenced by agro-climatic conditions. Indeed, the northern zone is characterized by a Sudanian climate, with a dry season and a rainy season. The southern part is marked by a sub-Sudanian climate, with two dry seasons and two rainy seasons throughout the year [3]. In fact, climatic factors such as temperature, rainfall, and relative humidity in the different zones could determine the spatiotemporal distribution of the various pests [28,29].

From the perspective of year-to-year evolution, studies have shown fluctuations in infestation levels for all species. This could be explained not only by variations in agroclimatic factors but also by interactions with other biotic agents. Indeed, the 2022-2023 period saw the invasion of the jassid species *Amrasca biguttula*, which disrupted the composition of the insect fauna on cotton [30]. From 2023 to 2024, protection programs focused on controlling this new species, using specific products such as flonicamid. However, these products proved ineffective against fruit-feeding Lepidoptera. This situation led to a resurgence of their infestations [8,31].

The studies also highlighted the impact of bollworms on the health of the bolls and on yield. These pests are responsible for about 3 to 10% of the damage observed on the bolls, leading to nearly a 20% loss in yield, despite plant protection measures. These results confirm the status of carpophagous Lepidoptera as major pests of cotton cultivation in West Africa [4,5]. Despite the invasion of jassids in 2022, carpophagous Lepidoptera thus remain major pests. Their significance stems from their direct feeding on the reproductive organs (flower buds, flowers, and bolls) of the cotton plant. The resurgence of carpophagous Lepidoptera after the jassid invasion reflects the complexity of cotton plant protection and the need to consider other approaches.

The results generally show instability in the populations of bollworms in cotton-producing areas. This highlights the need for regular monitoring in relation to agroclimatic factors, to study the sensitivity of different species to the insecticides used by producers, and to assess the effectiveness of the pest control programs implemented.

5. Conclusions

This study conducted on cotton bollworms in Côte d'Ivoire from 2021 to 2024 revealed several significant results. It demonstrated that fruit-feeding Lepidoptera remain major pests of cotton, significantly affecting production. Then, focusing protection strategies on the invasive species *Amrasca biguttula* is likely to cause their resurgence.

These results underscore the necessity of sustaining continuous surveillance of bollworms and adjusting control strategies according to the prevailing species, geographic regions, and planting schedules. Integrated pest management, which encompasses suitable cultural practices and targeted phytosanitary interventions, is essential for mitigating yield losses attributable to these pests.

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