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Seasonal Dynamic of the Fall Armyworm, *Spodoptera frugiperda* (J.E Smith, 1797) (Lepidoptera: Noctuidae) on Maize Crop in the Sub-Sudanese Zone of Côte d'Ivoire

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Abstract

In Côte d'Ivoire, maize (*Zea mays* L) is the second most cultivated cereal after rice. Since the first report of *Spodoptera frugiperda* in Côte d'Ivoire, maize production in the northern regions has been affected resulting in maize production losses. This study aims to study the seasonal dynamic of *Spodoptera frugiperda* in maize fields in the sub-Sudanese zone, main zone of maize cultivation in Côte d'Ivoire. The study was done using pheromone trap lures. The results revealed a variation in the moth population at various growth stages during rainy and dry seasons. Notably, the highest numbers of moths were consistently trapped during the whorl stage with counts ranging from 131 ± 35.7 during the rainy season to 70.6 ± 15.01 in the dry season. The lowest numbers of moths were observed during pod maturation, with counts ranging from 30.3 ± 13.05 during the rainy season to 11.7 ± 3.05 in the dry season. Between the 7th and 21st days after sowing, the count of moths displayed a consistent upward trajectory, reaching 188 moths during the rainy season. The damages were particularly observed at whorl stage. The relationship between the numbers of moths and some climatic variables revealed a negative correlation between moths numbers and rainfall (r= −0.44) and relative humidity (r= −0.684). In contrast, there were positive relationships with temperature (r = 0.16), highlighting the significant impact of temperature changes on moth population dynamics. The research highlights the need for integrated pest management strategies that consider climatic factors and growth stages of maize to mitigate the impact of this insect pest on maize.

Keywords

Spodoptera frugiperda, Moths, Climatic Variables, *Zea mays*

1. Introduction

Maize (*Zea mays*) and its derivatives play a pivotal role in global food security and economic development, constituting a significant portion of dietary intake and livestock feed across different continents [1]. In America, maize accounts for 30% of food supply, 38% in Africa, and 6.5% in Asia, underscoring its critical role [2]. With global maize production surpassing 967 metric tons, the United States of America and China are the major producers, with the remaining produced in Latin America, southern Asia and Africa particularly in subtropical regions and tropical [3] [4]. In Sub-Saharan Africa, maize accounts for 40% of cereal production, with 80% of it serving as a primary food source, providing up to 450 g per person per day and contributing 30% of total calorie intake [5]. Maize is cultivated by both small-scale and large-scale farmers [6].

In Côte d'Ivoire, maize is the second most cultivated cereal after rice (*Oryza* spp.). Maize cultivation, originally concentrated in the north, mainly in the sub-Sudanese zone [7], has expanded to the entire national territory over the past thirty years [8]. The surface area dedicated to maize cultivation in Côte d'Ivoire is estimated at nearly 350,000 hectares, with an average annual production of approximately 600,000 tons [9]. Out of this, 60% is contributed by Sub-Sudanese zone, with a yield of 1.9 tons per hectare [10]. Maize serves as a staple food for rural populations, particularly for those in the North, and it also plays a crucial role in livestock feed [9]. Additionally, maize serves as a raw material in various industries, including brewing, soap making, and oil production [8]. Nonetheless, maize cultivation in this zone faces a multitude of challenges that hamper production and often fail to meet local demands. These challenges include issues related to low soil fertility, as well as losses attributed to pathogens, weeds, diseases, and pests [11].

Spodoptera frugiperda, commonly known as the fall armyworm, stands out as the most significant insect pest attacking cereal crops. This pest is native to tropical and subtropical regions of the Americas but, due to global trade and its dispersal capabilities, has made its way to other continents in recent years [12]. It was first reported on the African continent in January 2016 [13]. Subsequent studies have revealed that this pest is now present in almost all of sub-Saharan Africa, where it causes significant damage, especially in maize fields and, to a lesser extent, in sorghum and other crops. It attacks more than 80 plant species belonging to 27 families [14], making it one of the most harmful polyphagous crop pests. Depending on the stage of development, damage can be seen on all plant components of maize. Bigger caterpillars completely section the stem base of maize plantlets, acting as cutworms [15]. Constant feeding during the vegetative phase of maize produces extensively windowed whorls laden with larval frass and skeletonized leaves [16]. Larvae on mature maize plants also target reproductive organs by burrowing into the ears or feeding on tassels [17].

Since the first report of *Spodoptera frugiperda* in Côte d'Ivoire [15] [18], maize production in the northern regions have been particularly affected, experiencing an infestation rate of 45%, resulting in a 60% loss of maize yield [7]. Yield losses continue to escalate, underscoring the need for the development of effective integrated management strategies to combat *Spodoptera frugiperda*. This necessitates a comprehensive understanding of *Spodoptera frugiperda* seasonal dynamic in maize fields, including its relationship with some climatic variables, particularly in Sub-sudanese, main zone of maize cultivation in Côte d'Ivoire.

2. Material and Methods

2.1. Study Area

The study was conducted in sub-Sudanese zone at the National Centre of Agronomic Research (CNRA) of Ferkessedougou of Côte d'Ivoire located between latitudes 9˚35' North and longitudes 5˚12' West, during 2020 and 2021 from January to March for the dry season and June to August for the rainy season. The climate is sub-Sudanese type [19]. It characterized by two main seasons [15]. A long rainy season, from April to September and a long dry season, from October to March [20]. The soil is ferralitic type with a shallow topsoil (40 - 60 cm) limited by indurations [21]. The physical properties of these soils, according to [20] are generally poor and present development constraints (shallow indurated soils)

The mean temperature, mean rainfall and mean relative humidity of Ferkessedougou during the study were obtained from SODEXAM (Airport Aeronautical and Meteorological Operation and Development Company) meteorological station of Côte d'Ivoire.

2.2. Methods

Setting up Experiment Plots

Three plots of 300 m^2 were delimited and separately for at least 5 km. The improved variety of maize, EV 87/28-SR, was utilized. The grain had a three-months cycle and was yellow in colour. Scrubbing and clearing were done quickly and efficiently. They involved mowing the grass but leaving the stumps standing, enabling in this instance a shifting cultivation to guarantee prompt regrowth or recruitment in the event that the plot is abandoned. Sowing was done with three seeds by hole. Approximately 15 days after germination, excess plants were removed to achieve the desired density. Also weeds, especially during the vegetative phase of the crop, were pulled out manually (weeding). Compound fertilizer (N-P-K) was applied at rate of (60-60-60 kg/ha as N, P_2O_5 AND k20) ten days after planting and top-dressed with of urea six weeks after planting. During dry season, watering was done manually with a 20 m connection to a modern borehole. The frequency was every three days until the plants were two weeks old and two days during the rest of the vegetative cycle.

2.3. *Spodoptera frugiperda* Moths Traps

The study was done by using pheromone lure trap. It was composed of catcher bucket, and *Spodoptera frugiperda* female sex pheromone lure prepared by Russell IPM, UK with catch number 72/1936, labelled with the trade name *Spodoptera frugiperda* PH-869-1PR. The pheromone lure was hanged in cage at the top of catcher bucket and one strip of Dimethyl 2,2-DichloroVinyl Phosphate (DDVP) was placed at the bottom in the bucket as killing agent to knocked male moths entering through vents on the sides of the bucket. Traps were mounted at field level, after emergence of plant maize. One trap hanged on a pole was put in the centre of each delimited areas at height of 1.5 m from the ground. The pheromones were replaced every 3 weeks while the strips 2 months. Each week, the traps were emptied and the *Spodoptera frugiperda* moth males were counted.

2.4. Damages

After emergence of maize, each plot was sampled weekly on the same day of the emptied moths trap to score the damage. In each field, as preconized by [17], 20 plants were selected randomly in 'w' pattern for a total of 100 plants. The damage was assessed by visually estimating the area of damaged leaves on the maize plants and assigning an index from 0 to 5 from the rating scale proposed by [17]:

0 = no visual damage;
1 = up to 10% of foliar damage;
2 = foliar damage between 10 to 25%;
3 = foliar damage between 25 to 50%;
4 = foliar damage between 50 to 75%;
5 = foliar damage between up to 75%.

The percentage of damaged leaves was calculated as the ratio of the number of damaged leaves to the total number of leaves multiplied by one hundred.

2.5. Data Analysis

Data analysis was implemented in R software 3.6.3. One way analysis of variance was performed to detect difference on moths and damages among maize phenological stages follow by post hoc Turkey test. Before each analysis, the normality and homogeneity of variance were verified. Pearson's correlation analyses were performed to determine relationship between moths and climatic variables (temperature, relative humidity and rainfall). Alpha (α) less than 0.05 was considered as statistically significant.

3. Results

3.1. Average Numbers of Adult Moths According to Phenological Stages

The study revealed a variation in moth population at various growth stages during rainy and dry seasons. Notably, the highest numbers of moths were consistently trapped during the whorl stage, with this stage outperforming tasselling and maturation stages in terms of moth captures. In the year 2020, moths were most abundant during the early whorl stage, with counts ranging from 131 ± 35.7 during the rainy season to 70.6 ± 15.01 in the dry season. Conversely, the lowest numbers of moths were observed during pod maturation, with counts ranging from 30.3 ± 13.05 during the rainy season to 11.7 ± 3.05 in the dry season (**Figure 1**). A similar pattern emerged in 2021, with the highest moth numbers occurring at the early whorl stage, ranging from 106 ± 72 during the rainy season to 74.3 ± 35.9 in the dry season. Once again, the lowest moth counts were documented during pod maturation, with numbers ranging from 49.3 ± 3.78 during the rainy season to 16 ± 1.03 in the dry season (**Figure 1**).

The statistical analysis of variance further underscored the significance of these findings, revealing notable differences in the mean moth numbers at various phenological stages during both 2020 (F = 111.08; ddl = 3; P < 0.001) and 2021 (F = 53.81; ddl = 3; P < 0.0001).

3.2. Average Numbers of Adult Moths According to Days after Sowing

The average number of adult moths trapped in relation to the days after sowing

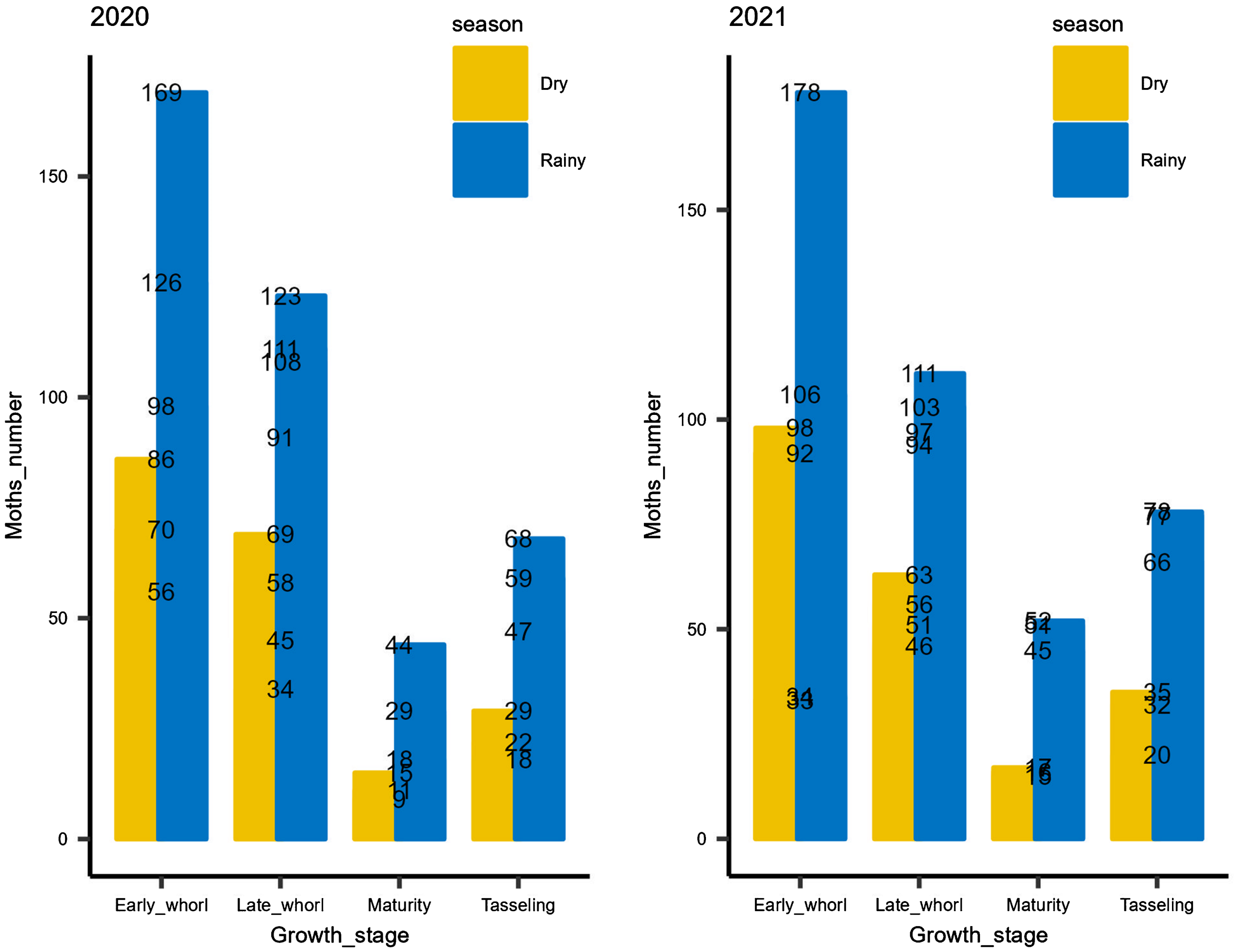

Figure 1. Number of moths according growth stage during rainy and dry season.

exhibited noteworthy variations, surpassing the numbers captured during the dry season in both years. In the year 2020, at the 7-day after sowing, there was a remarkable disparity, with 102 ± 67.9 moths observed during the rainy season as opposed to 58 ± 21.7 in the dry season. This divergence in moth numbers continued to intensify, culminating in a peak of 158 ± 35.8 moths during the 21st day of the rainy season. However, as time progressed, the moth numbers began to gradually decline, ultimately reaching their lowest point by the 90th day. In the subsequent year, 2021, a similar trend emerged. Between the 7th and 21st days after sowing, the count of moths displayed a consistent upward trajectory, reaching 188 ± 77.3 moths during the rainy season and 52 ± 36.9 moths during the dry season. Subsequently, there was a steady decrease in moth numbers as the days advanced, mirroring the patterns observed in the previous year and persisting until the 90th day in both the rainy and dry seasons (**Figure 2**).

3.3. Damages

During rainy season, in 2020, the average percentages of damaged leaves and damage indices increased progressively from 14th to 35th days after sowing. The highest average percentage of damaged leaves and damage indices were recorded at 21st after sowing (late whorl stage). These percentages were 94.65% ± 1.48% and 4.04 ± 0.04 indicating that the percentage of destruction of the plant leaf

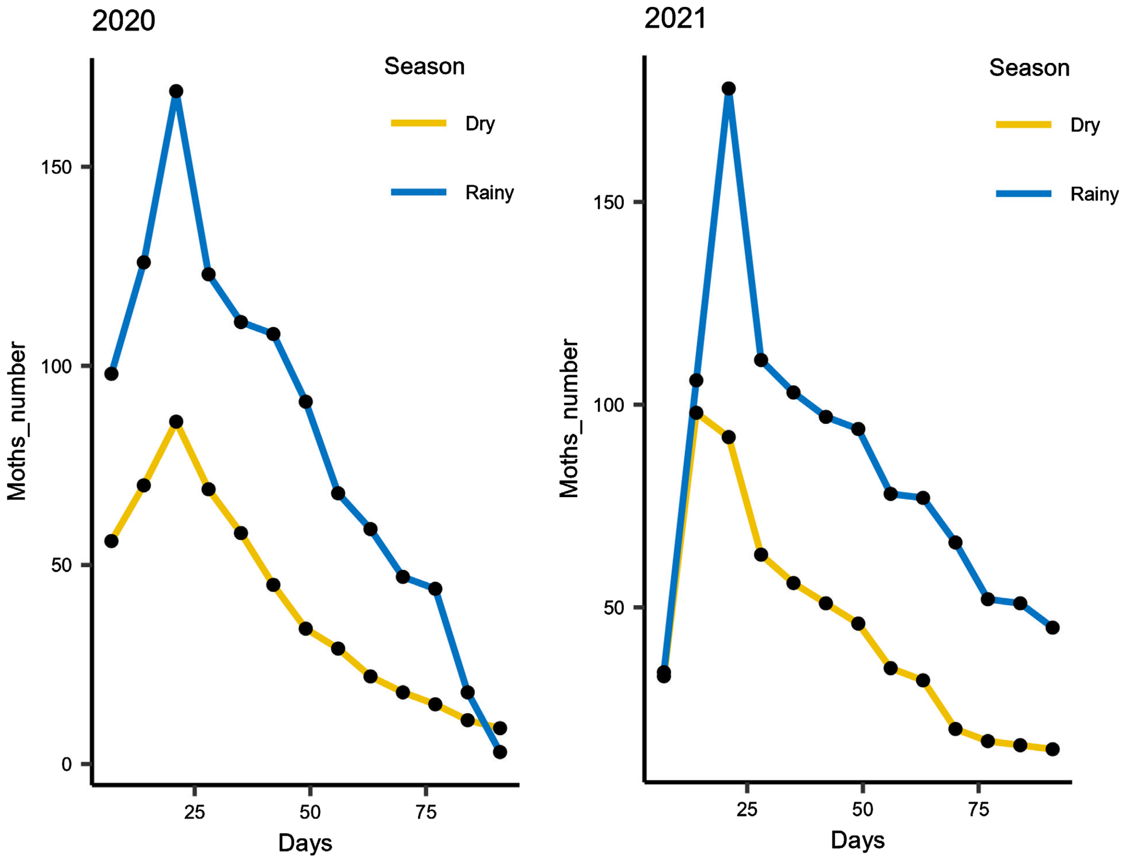

Figure 2. Evolution of moths according to days after sowing during season.

surface was higher than 50%. Statistical analysis revealed significant differences between mean percentages (F = 9.51; ddl = 8; P < 0.001) and between damage indices (F = 6.34; ddl = 8; P < 0.001). In 2021, the highest average percentage of damaged leaves was recorded also at 21st days after sowing. This percentages 98.96% ± 0.60%, with a damage indice higher than 4 (4.28 ± 0.11). Statistical analysis showed significant differences between the mean percentages (F = 3.04; ddl = 8; P = 0.007) and no significant difference between the leaf damage indices (F = 0.53; ddl = 8; P = 0.83) (**Table 1**).

During dry season**,** in 2020, the highest average percentage of damaged leaves damage was observed at 21st day after sowing (late whorl stage) with 45.94% ± 1.01% and the lowest average percentage was 1.36% ± 0.48%, recorded during maturation stage. The highest index was also recorded at the 21sh day after sowing with 2.60 ± 0.08. Statistical analysis revealed significant differences between mean percentages (F = 7.27; ddl = 8; P < 0.001) and between damage indices (F = 4.71; ddl = 8; P < 0.001). In 2021, the highest average percentage of damaged leaves (49.94% ± 1.01%) was recorded at 21st after sowing (late whorl stage). From 49th day after sowing (tasseling stage) to 91st day after sowing (pod maturation), the percentages ranged from 26.91% ± 3.57% to 3.75% ± 0.09%. Leaf damage indices at different days after sowing ranged from 2.03 ± 2.28 to 0.36 ± 1.02. Statistical analysis revealed significant difference between the mean percentages (F = 3.58; ddl = 8; P < 0.05) and no significant difference between

Table 1. Damage according to growth stages during rainy season.

Growth stages	Days after sowing	Rainy season			
		2020		2021	
		Percentage of damage	Indices of damages	Percentage of damage	Indices of damages
	14	93.31 ± 0.76^{c}	4.12 ± 0.05^{c}	97.39 ± 0.80^{b}	4.36 ± 0.19^{a}
	21	94.65 ± 1.48^{bc}	4.04 ± 0.04^{bc}	98.96 ± 0.60^{ab}	4.28 ± 0.11^{a}
Whorl stage	35	71.87 ± 2.96^{ab}	3.78 ± 0.25^{ab}	98.47 ± 0.93^{ab}	4.39 ± 0.10^{a}
	42	52.22 ± 8.61^{a}	2.23 ± 0.19^{a}	66.32 ± 0.41^{a}	2.88 ± 0.15^{a}
	49	49.94 ± 1.20^{a}	2.11 ± 0.13^{a}	45.98 ± 2.30^{a}	1.94 ± 0.1^{a}
Tasselling	63	15.64 ± 4.10^{a}	1.63 ± 0.26^{a}	22.51 ± 0.62^{a}	1.72 ± 0.25^{a}
	70	12 ± 0.89^{a}	1.32 ± 0.18^{a}	7.98 ± 0.13^{a}	0.91 ± 0.16^{a}
Maturation	77	5.38 ± 0.47^{a}	0.54 ± 0.82^{a}	3.42 ± 0.10^{a}	0.79 ± 0.12^{a}
	91	2.64 ± 0.51^{a}	0.35 ± 0.15^{a}	3.75 ± 0.09^{a}	0.22 ± 0.07^{a}
	F	9.51	6.34 a	3.04.	0.53
	Ddl	8	8	8	8
	P	0.00002	0.002	0.007	0.89

Numbers followed by the same letters in the same column are not significantly different at 5% threshold.

the damage indices (F = 1.72; ddl = 8; P = 0.68) (**Table 2**).

3.4. Relationship between Moth Numbers and Some Climatic Factors

A thorough analysis of the relationship between moth numerical abundance and some meteorological factors provided strong results. The research found a negative association (r = −0.684) between moth counts and relative humidity, implying a minor impact on moth population dynamics. Furthermore, the study found a substantial negative association between moth counts and rainfall (r = −0.44). In contrast, there were positive relationships with temperature (r = 0.16), highlighting the significant impact of temperature changes on moth population dynamics. This significant discovery emphasizes the importance of temperature as a crucial driver in regulating moth population dynamics (**Figure 3**).

4. Discussion

The current study marks a significant milestone in Côte d'Ivoire because it is the first to extensively investigate the seasonal dynamics of *Spodoptera frugiperda* within the primary maize production zone. Our findings illuminated the complex relationship between *Spodoptera frugiperda* moths' abundance, maize phenological growth stages. Interestingly, the whorl stage appears as a focal point, with consistently higher average numbers of moths gathered during this

Table 2. Damage according to growth stages during dry season.

growth stages	Days after sowing	Dry season			
		2020		2021	
		Percentage of damage	Indices of damages	Percentage of damage	Indices of damages
Whorl stage	14	44.45 ± 0.92^{ab}	1.97 ± 0.08^{b}	45.87 ± 0.89^{b}	2.09 ± 0.09^{a}
	21	45.94 ± 1.01^{ab}	2.60 ± 0.08^{b}	49.94 ± 1.01^{ab}	2.60 ± 0.08^{a}
	35	45.16 ± 2.28^{ab}	2.27 ± 0.13^{b}	45.98 ± 2.30^{ab}	2.17 ± 0.15^{a}
	42	32.64 ± 4.10^{ab}	1.80 ± 0.28^{ab}	37.92 ± 1.54^{a}	1.91 ± 0.17^{a}
	49	17 ± 0.43^{b}	1.46 ± 0.15^{b}	26.91 ± 3.57^{ab}	1.80 ± 0.26^{a}
Tasselling	63	10.32 ± 0^{b}	0.99 ± 0.17^{b}	15.60 ± 1.20^{ab}	1.51 ± 0.13^{a}
Maturation	70	6.78 ± 1.2^{b}	0.75 ± 0.08^{b}	8.69 ± 0.83^{ab}	0.96 ± 0.09^{a}
	77	4.23 ± 0.51^{a}	0.41 ± 0.73^{a}	2.16 ± 3.14^{ab}	0.53 ± 0.28^{a}
	91	1.36 ± 0.48^{b}	0.28 ± 0.06^{b}	2.03 ± 2.28^{ab}	0.36 ± 1.02^{a}
	F	7.27	4.71	3.58	1.72
	Ddl	8	8	8	8
	P	0.0000061	0.01	0.045	0.68

Numbers followed by the same letters in the same column are not significantly different at 5% threshold.

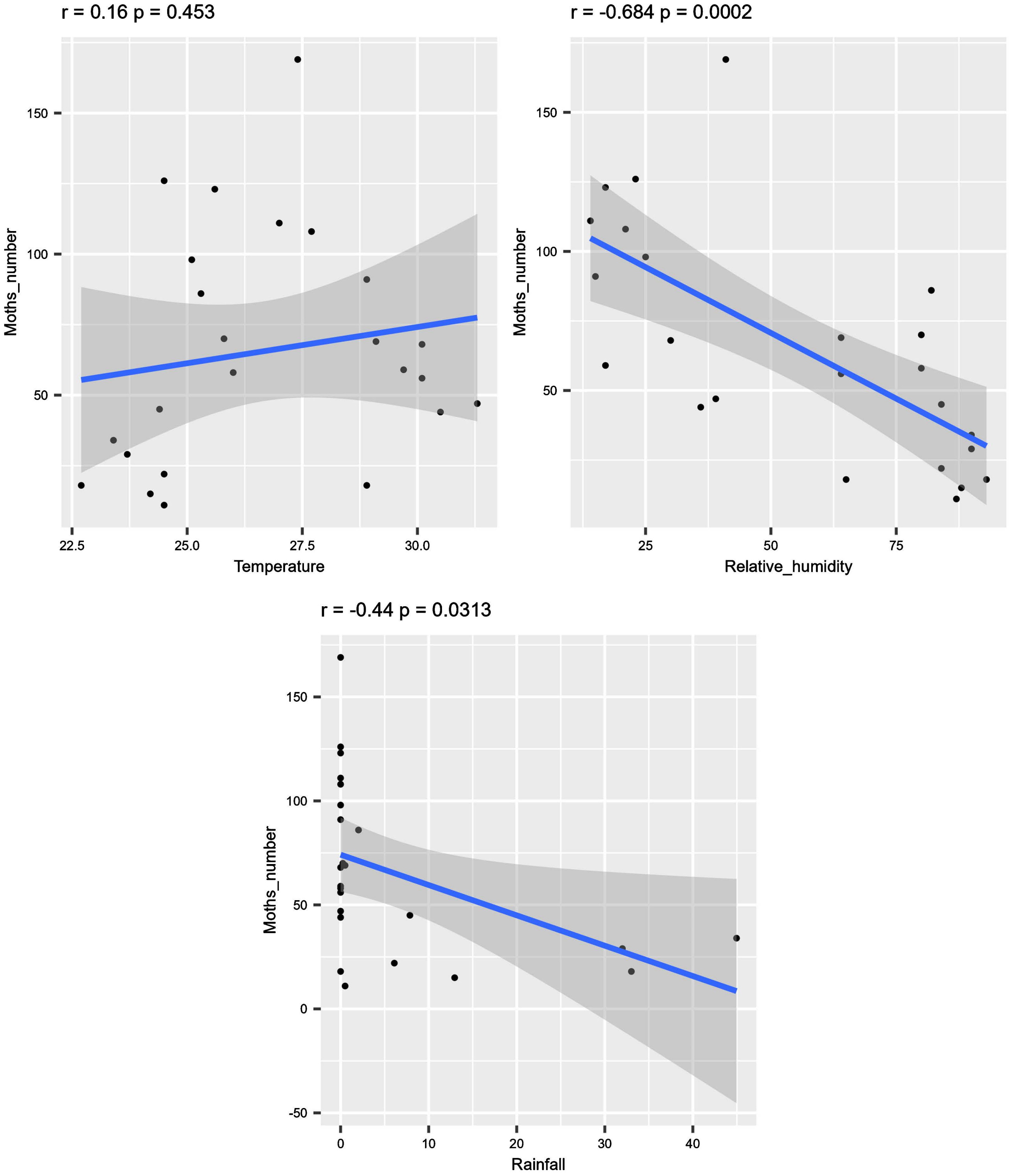

Figure 3. Correlation between number of moths and some climatic factors.

period compared to the tasselling and maturation stages.

Spodoptera frugiperda is thought to be attracted to female moths during the whorl stage, which may be caused by maize producing egg-laying chemicals. The host plant may produce chemicals that encourage females to lay eggs, such that neonates hatching from eggs can eat on tender leaves [22]. *Spodoptera frugiperda* is plant age dependency and the most preferred stages are V2 and V3. For each season, the low numbers recorded on tasselling and maturation stage would be due to the advanced age of the plants, leading to more lignified leaves and therefore be very difficult to consume by larva [23], as younger plants offer more tender leaves for larvae consumption, which would not have been able to maintain the high numbers of *Spodoptera frugiperda*. In agreement with those of [10] who noted a gradual reduction of *Podagrica decolorata* and *Nisotra dilecta* on okra crop due to the advanced age of the plants. These two results are also close to those [23] who reported low number of *Leucinodes orbonalis* larva on aging eggplants. The gradual increase of *Spodoptera frugiperda* moths at the beginning of the maize crop cycle could be explained by the fact that the crop started several weeks after the first rains. They could have left other host plants or weeds to gradually colonize the maize plots [24].

The role of lure could have played an important role in the number of *Spodoptera frugiperda* catches. A study conducted in Argentina, evaluating two experimental formulations of *Spodoptera frugiperda* Pheromone [23]. The manufacturer ChemTica and one commercial formulation (Hercon) to determine which is superior to the one that is presently in use in the country. The results showed that, in wind tunnel experiments, the commercial formulation provoked the maximum attraction. This lure successfully attracted a sizable number of males in field tests. Even with lures that elicited a stronger attraction than the commercial. Because a synthetic lure has not been created for every location and populations from different geographic locations have distinct sex pheromone compositions, the effectiveness of such monitoring has varied in use.

Temperature is correlated with moths abondance. It is the main factor that influences *Spodoptera frugiperda*. In a suitable temperature range, the growth rate of an insect increased with the increase of external temperature, but when the temperature rose to a certain extent, the development rate would decrease [24]. (Valdez-Torres *et al.*, 2012) [25] showed that under laboratory conditions, the highest temperature threshold for the development of *S. frugiperda* is 39.8 C. These results suggested that high temperature can be an important factor to increase the distribution of *Spodoptera frugiperda.* Temperature can impact insect development and physiology through the physiology of the hosts. Depending on the strategy of development of the insect, temperature can have different effects. Some crop pests develop more rapidly during periods of time with suitable temperatures [26]. Insects reproduction is greatly affected by the external temperature [27]. Low temperature tends to decrease the birth rate and increase the death rate of insect species. Within a certain temperature range, the reproductive capacity of the female moth increases with temperatures increase [28].

In contrast, rainfall and relative humidity are negatively correlated with number of moths. [29] reported that, wet season rain was the main factor contributing to the distribution of *S. frugiperda.* Heavy rainfall and precipitation have a direct effect on survival on larva survival as, they cause larva to spill out from the whorl. They also cause collapse of tunnels pupation, that may affect moth emergence and survival [30] [31]. These factors can have a diverse impact on *Spodoptera frugiperda* population. A study conducted by [27], in northern Ghana showed that rainfall and *Spodoptera frugiperda* population are positively correlated. According to them, rainfall provides the luxurious growth of maize and reduces natural enemies. Therefore, excessive rains can reduce *Spodoptera frugiperda* abundance by creating better conditions for rapid growth of its entomopathogens that can maintain low infestation. However, [23] showed that the negative influenced of pluviometric condition is due to the fact, when the whorl of maize is filled up with water, the larva present in whorl are forced to abandon it. Also, the rain washes off the eggs and larva present on the leaves onto the ground. Temperature is one of the key factors of *Spodoptera frugiperda* development and survival [27]. The amount of rain that occur in the zone within the same period can nullify the effect of temperature. Furthermore, [28] has observed in the study conducted in Madagascar that rainfall influences variations in the numbers of male *Spodoptera frugiperda.* According to their results, *Spodoptera frugiperda* exhibit significant fluctuations during rainy periods with high rainfall. However, the lowest levels of male populations are observed during the dry season, and the highest levels occur during periods of maximum rainfall. It appears that precipitation has an impact on the seasonal variation of male populations, leading to an increase when rainfall is on the rise and a decrease during drier periods. It is possible that decreased rainfall during the dry season, through the drying of the surface soil, leads to high mortality among nymphs, either by preventing the penetration of last-stage larvae in the soil or by making it difficult for adults to emerge [29].

Damage to newly formed tender leaves was observed at all growth stages of maize, particularly on whorl stage. Attacks during these three stages would be related to the fact that the leaves were formed during the whole stage. Attacks on pods could be explained by the fact that these organs would contain nutritive resources that could help *Spodoptera frugiperda* adults cope with their huge physiological needs (oviposition). The percentages of damaged leaves and leaf damage indices varied according to the days after sowing and the phenological stages of the different seasons. This would be related to the composition of the volatile substances emitted by the host plant during the different phenological stages [30]. Indeed, these authors, in their studies on plant-insect interactions, reported that the composition of volatiles varies according to the developmental stage and age of the host plants.

There may be other climatic factors (cloudiness, pressure, winds) contributing to the regulation of *Spodoptera frugiperda* population that were not considered during our study. Nevertheless, the consistent availability of host plants throughout the year, together with meteorological conditions, may play a substantial role in the dynamics of *Spodoptera frugiperda*. Seasonal changes in agricultural techniques and cropping patterns are thought to impact insect pest evolution and population dynamics were not also taken into account. Because, traditionally, cropping patterns utilized by smallholder farmers in Sub-sudanese zone may alter significantly, given that, sometime, the same crops are cultivated with the number of fields varying solely by season.

5. Conclusion

This study provides valuable insights into the seasonal dynamic of *Spodoptera frugiperda* in the main maize cultivation zone of Côte d'Ivoire, with a particular focus on its relationship with climatic factors. The results indicate that the average number of *Spodoptera frugiperda* adult moths caught varies according to the phenological growth stages of maize. The highest numbers of moths were observed during the whorl stage, which is when the pest is attracted to the maize plants for egg-laying. The findings underscore the importance of understanding the ecological factors that drive the behavior and abundance of *Spodoptera frugiperda*, particularly in the context of maize cultivation, where this pest poses a significant threat to food security and economic development. The research highlights the need for integrated pest management strategies that consider both biological, climatic factors, phenological growth stages to effectively mitigate the impact of this destructive insect pest on maize production in Côte d'Ivoire.

Data availability

Data will be made available upon request.

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Authors' Contribution

Manuela Klamansoni Akissi Konan participated in the collection and analysis of data as well as writing of the manuscript. Laya Kansaye and Nondenot Roi Louis Aboua guided and supervised the project, reviewed and approval of the final manuscript.

Findings

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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