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The fall armyworm *Spodoptera frugiperda* (J.E. Smith), a new pest of maize in Africa: monitoring, damage evaluation and identification of natural enemies on production areas of Senegal

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ABSTRACT

The fall armyworm (FAW) *Spodoptera frugiperda* (J.E. Smith), an invasive pest of cereal crops in Africa, poses a real threat to food security in sub-Saharan African countries where cereals are the staple food. Since its appearance in Africa in 2016, the FAW has invaded almost all African countries due to its great dispersal capacity. Because of its resistance to a number of chemical pesticides but also the risks associated with the use of these, the search for an alternative method becomes essential. In order to report on the incidence of this pest and explore its associations with native natural enemies, a monitoring study of *S. frugiperda* populations, its damage as well as its natural enemies was carried out during the period of August to September 2020 in corn fields of two agro-ecological zones of Senegal and in the laboratory. Monitoring results show a heavy infestation with rates of up to nearly 75% of defoliated plants and more than 60% of attacked ears. The damage recorded remains low overall (score below 3/9). A wide range of auxiliary insects (17 families) made up of parasitoids and predators were identified in the field and in the laboratory as well as an endoparasitic nematode with a parasitism rate of 38.46% and a fungus in one of the sites. These results pave the way for the development of an approach to control CLA with these biological agents.

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Keywords : invasive pest, cereal crops, food security, incidence, Senegal.

INTRODUCTION

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith, 1797), is a polyphagous insect native to tropical and subtropical

America (Ayala et al., 2013; Sharanabasappa et al., 2018). The invasive FAW was first reported in West Africa in late 2016 (Goergen et al., 2016); in early 2017, the pest invaded

sub-Saharan Africa including Senegal (Brevault et al., 2017) and it quickly spread to different parts of the continent. Currently, its presence has been officially reported in 44 African countries (Rwomushana et al., 2018; Prasanna et al., 2018). *Spodoptera frugiperda* is one of the most destructive crop pests, known to attack more than 353 plants worldwide (Montezano et al., 2018; CABI, 2020), including maize, sorghum, rice, soybeans, cotton, wheat and sugar cane.

Due to its ability to spread rapidly and inflict widespread damage on several crops, the fall armyworm seriously threatens the food and nutrition security and livelihoods of millions of farm households in sub-Saharan Africa (Abrahams et al., 2017; Goergen et al., 2016; Rwomushana et al., 2018; Prasanna et al., 2018). In Africa, crop losses caused by FAW each year are approximately \$ 16 billion (Harrison et al., 2019). Faced with this numerous damage, control strategies have been developed against this pest, in particular the intensive application of chemical pesticides in several countries leading to the acquisition of resistance by FAW (Yu et al., 2003; Zhao et al., 2019). In general, the excessive use of insecticides and the associated risks have raised issues of farmer income management, sustainability, health and food security. This highlights the need to develop integrated pest management (IPM) strategies that meet the needs of African smallholder farmers. And this in particular through the use of biological control agents.

Therefore, the general objective of this study is to contribute to the integrated management of the fall armyworm *Spodoptera frugiperda* for sustainable food security. More specifically, it involved making the inventory of the infestation, assessing the damage caused and determining the association with native natural enemies of this pest.

MATERIALS AND METHODS

Study area

The study locations (zones) are represented according to their geographical coordinates, annual precipitation and temperature (Table 1).

Niayes zone

The Niayes, between the 200 to 500 mm isohyets, stretches from Dakar to Saint-Louis over a length of nearly 180 km and over 30-35 km in width and is located along the north-western coast in the regions of Dakar, Thiès, Louga and Saint-Louis and covers an area of 3090 km². It is characterized by closed interdune depressions with flush or sub-flush water table in the Ogolian dune system (red dunes). The microclimate is described as sub-Canarian: the relatively cool air, the higher humidity and a later rainfall season, are its characteristics unlike other parts of the country. Temperatures are on average 20 to 30 °C and the average annual rainfall is around 400 mm (Ndao, 2012; Camara et al., 2013, 2014b; the SONED-AFRIQUE Study Office, 2013).

Central zone

Two regions are chosen in the central zone: the Kaolack region and the Kaffrine region. In the Kaolack region, three sites were all chosen in the Department of Niour du Rip (Keur Aly Guèye, Keur Abibou Niass and Mbitayène) and in the Kaffrine region two sites including Ndjigui (3 fields) and Boulel (3 fields). The location of the different sites is shown in Figure 1.

Methodology

This study was carried out in two stages. First, it is a field investigation during which monitoring (presence, damage intensity and natural enemies of FAW) was carried out. Insect samples were taken for further morphological and molecular characterization. Then, the Center for the Development of Horticulture (CDH), ISRA, Dakar, Senegal, formed the second, in the laboratory where the identification of collected insects and their natural enemies was made. The caterpillars brought back from the field are reared in the laboratory to identify the parasitoids that have previously infested them.

Monitoring

* Installation of traps

Delta type pheromone traps, three-component pheromone (Z) -tetradec-9-enyl acetate, (Z) -hexadec-11-enyl acetate, Z-7-

dodecyl acetate, Alpha Scents, Portland, OR, USA) were used to capture males of *Spodoptera frugiperda*.

In each of the sites (field), a trap was set up and these traps were monitored every week in order to count and identify the insects captured.

After morphological identification using the binocular magnifying glass and the identification key proposed by EPPO (2015), the captured adults of *S. frugiperda* were placed in vials containing 70% denatured ethanol.

* **Damage evaluation**

In the 10 fields of the two agroecological zones, the damage assessment is done every two weeks during the period from August to September 2020.

In each field, 5 rows were selected according to a W diagram. Observation covered 12 successive plants at each row. At the vegetative stage, the observation is made on the three upper leaves and the damage was evaluated according to the scale proposed by Davis et al. (1992).

The percentage of infested fields was calculated as follows:

- % of fields infested with FAW = (Number of fields infested with FAW) / (Total number of fields studied) x 100

The percentage of infested plants per quadrant was calculated using the formula:

- % FAW infestation = (Number of plants infested with FAW) / (Total number of plants observed) x 100

* **Parameters observed in the field**

- The observations focused on:
- The impact of the pest on crops: determined according to the number of plants attacked out of the total number of plants sampled;
- The number of *Spodoptera frugiperda* by locality

- The degree of attack or severity was determined on the basis of a rating scale proposed by Davis et al. (1992).
- The number of natural enemies: determined by captures in the field and during monitoring of parasitized larvae.

The Maize Leaf Damage Rating Scale for *S. frugiperda* is presented in the appendix. This rating or classification scale for damage to maize leaves has been subdivided into three classes. The score of 0 to 4 is considered low, 5 to 7 is considered medium, and 8 to 9 is considered high.

Larval sampling

At each site a number of *S. frugiperda* larvae were collected for laboratory monitoring to observe the potential emergence of parasitoids. The emerged parasitoid species were identified using a binocular magnifying glass and a version 2.0 dinocapture.

Inventory and sampling of predators and parasitoids of *Spodoptera frugiperda*

Predators as well as *S. frugiperda* parasitoids seen in the fields were photographed using a smartphone.

Insects that were difficult to capture were photographed while those that were easy to capture were placed in 50 ml polystyrene bottles containing 70% ethanol.

Data analysis

All of the data collected was recorded and arranged on an Excel spreadsheet and subsequently served as a database for statistical analyses. Normality tests (Shapiro-Wilk), comparison of means (Kruskall Wallis) were subsequently carried out with R software version 3.6.1 to see in particular the differences in the level of infestation depending on the areas but also depending on the vegetative stage.

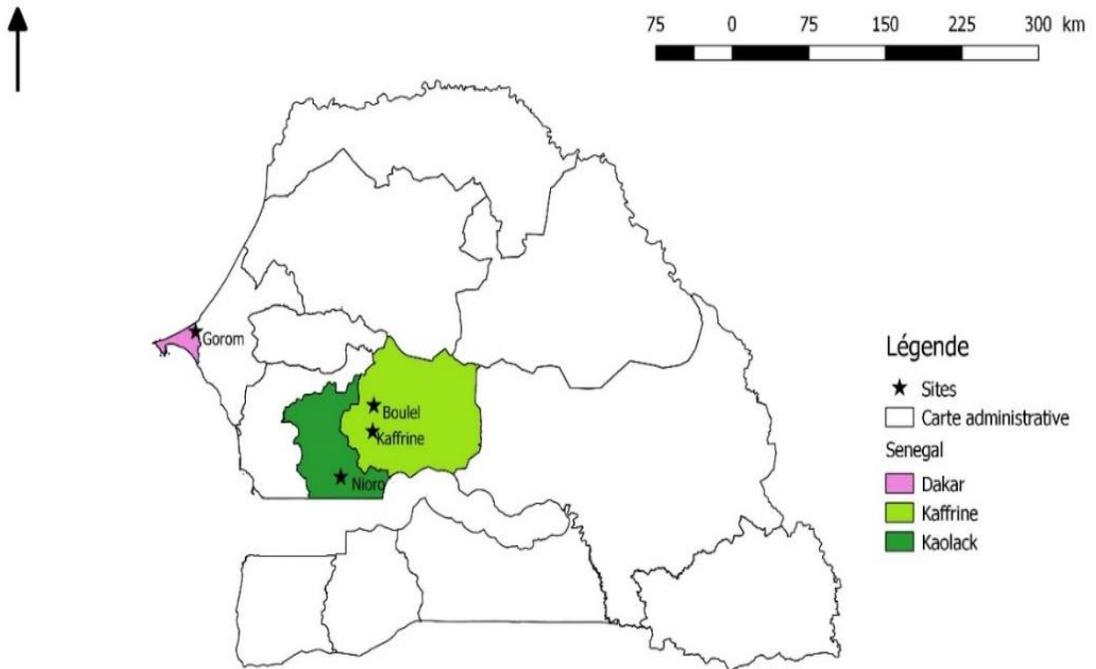


Figure 1: Location map of the study localities.

RESULTS

The impact of the pest on crops

- **Percentage of plants attacked by site and by stage**

The 10 fields monitored during this study in the 3 regions all recorded damage linked to attacks by *S. frugiperda*, ie a percentage of infested fields of 100%. The percentages of attacks by site and according to the stage of development are presented in the following Figure 2.

Statistically significant differences are observed between sites at the vegetative stage with the Wilcoxon test which shows percentages ranging from more than 40% (Boulel sd 0,4987) to around 75% (Gorom sd 0,4434) for all of the two zones (center and niayes) during the period. At the mature stage, Kaffrine records a higher percentage of plants attacked compared to the rest of the sites. The lowest percentages at both the vegetative and mature stages are noted at Boulel.

- **The damage level**

Assessment of the degree of defoliation and damage to the ear on the basis of the rating scale of Davis et al. (1992), Figure 3.

Statistically significant differences are observed between localities with the kruskal wallis test (chi-squared = 202.87, p-value <2.2e-16), sd=0.8537. Damage scores assessed on the Davis scale are relatively low across all sites (mean score between 1 and 3) with the exception of one site, Gorom, where strong defoliation is noted during the vegetative stage. At the mature stage, Kaffrine records the greatest damage compared to the rest of the sites. The lowest damage, both at the vegetative and mature stages, is noted at Boulel.

- **The average number of larvae by locality and adults of *Spodoptera frugiperda* caught by locality as a function of time** (Figure 4)

Statistical analyses showed that the average number of larvae is globally low,

however it is higher at the vegetative stage in Gorom. The Kruskal Wallis test divided the results into four groups at the vegetative stage (a, b, c and bc) where the differences are all significant (p-value < 2.2e-16 and an sd equal to 0,2516) except for group bc (Kaffrine Boulel and Kaffrine Nioro).

At the mature stage, the average number of larvae is much higher in Kaffrine and the significance test (Kruskal Wallis) allowed to divide the results into three groups (A, B and C) where the differences are all significant with a p-value = 6.023e-13 and an sd equal to 0,4261 (Figure 4).

• **The average number of adults of *Spodoptera frugiperda* caught per trap as a function of time**

Monitoring *S. frugiperda* populations using pheromone traps yielded the following results (Figure 5). The number of adults captured on the traps is relatively low

throughout the study period, with an average maximum of around 2 individuals towards the end of culture at Nioro. In all 27 adults of *S. frugiperda* were captured on the 10 traps, the maximum number of individuals that were captured on a trap is 3. It should also be noted that there was no trap capture in Gorom.

Identifications of natural enemies of *Spodoptera frugiperda*

• **Predators and parasitoids of *Spodoptera frugiperda***

A total of 341 individuals (246 in the Central zone and 95 in the Niayes zone) were listed as potential natural enemies of *Spodoptera frugiperda* (Photo 1) on the host plant maize and belonging to 6 orders and 18 families including 4 unidentified families and some species of the order Araneae also belonging to 3 unidentified families in these two agroecological zones (Table 2).

Table 1: Location of study sites.

| Locality | Site | Coordinates | Annual precipitation | Annual average temperatures |
|-----------------|-------------------|-------------------------------------|----------------------|-----------------------------|
| Boulel | Boulel 1 | 15° 32' 39.52" W ; 14° 17' 18.49" N | 766,3 | 29,8 |
| | Boulel 2 | 15° 33' 7.16" W ; 14° 16' 48.58" N | | |
| | Boulel 3 | 15° 33' 55.39" W ; 14° 16' 39.04" N | | |
| Kaffrine | Ndjigui 1 | 15° 33' 36.64" W ; 14° 5' 0.19" N | 766,3 | 29,8 |
| | Ndjigui 2 | 15° 33' 45.21" W ; 14° 5' 15.44" N | | |
| | Ndjigui 3 | 15° 33' 48.24" W ; 14° 5' 15.03" N | | |
| Nioro | Mbityèné | 15° 56' 28.62" W ; 13° 44' 6.53" N | 766,3 | 29,8 |
| | Keur Abibou Niass | 15° 50' 59.13" W ; 13° 44' 56.35" N | | |
| | Keur Aly Gueye | 15° 50' 40.9" W ; 13° 46' 7.59" N | | |
| | | | | |
| Dakar | Gorom | 17° 9' 21.82" W ; 14° 49' 38.06" N | 455,1 | 28,1 |

Climate data source: Infoclimat.fr Version 5.4

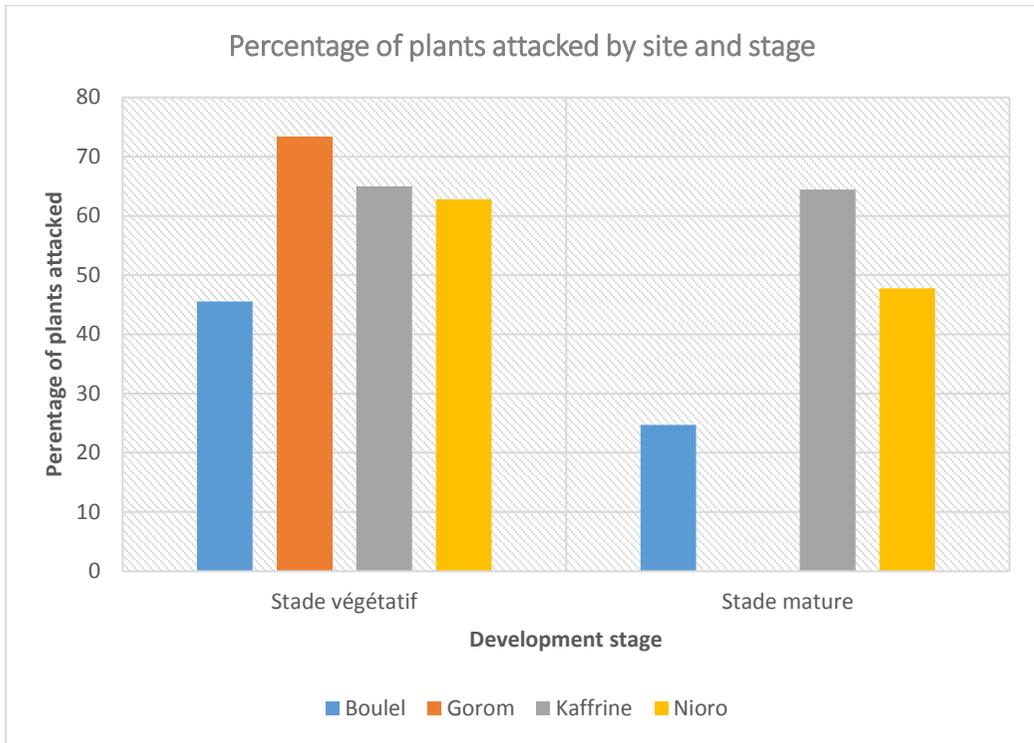


Figure 2: Percentage of plants attacked by site and stage.

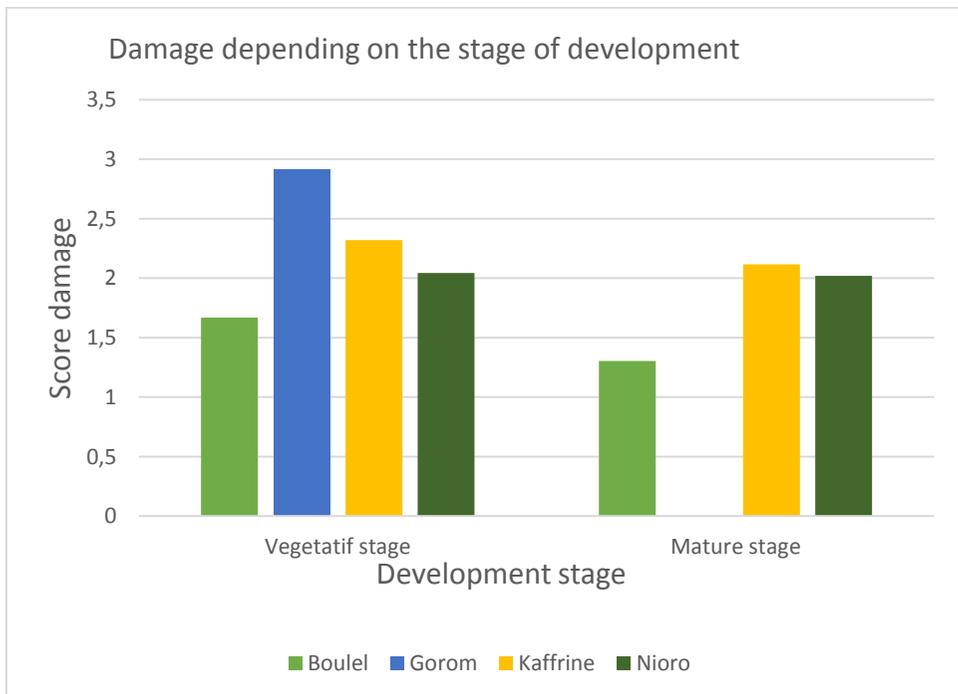


Figure 3: Damage depending on the stage of development.

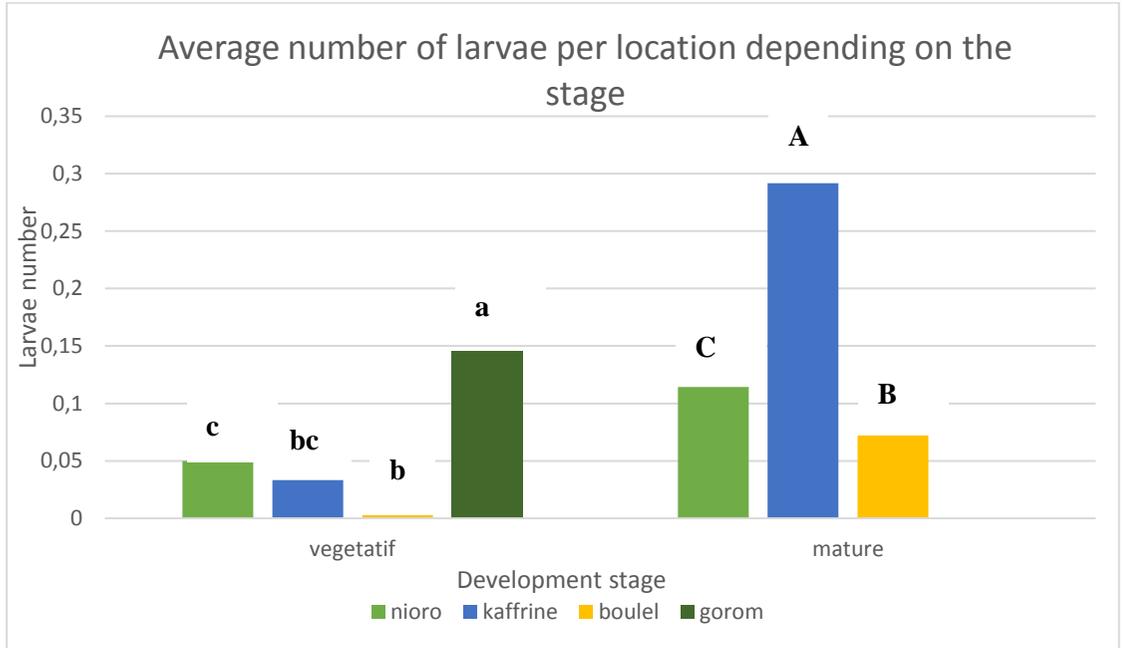


Figure 4: Average number of larvae per location depending on the stage.

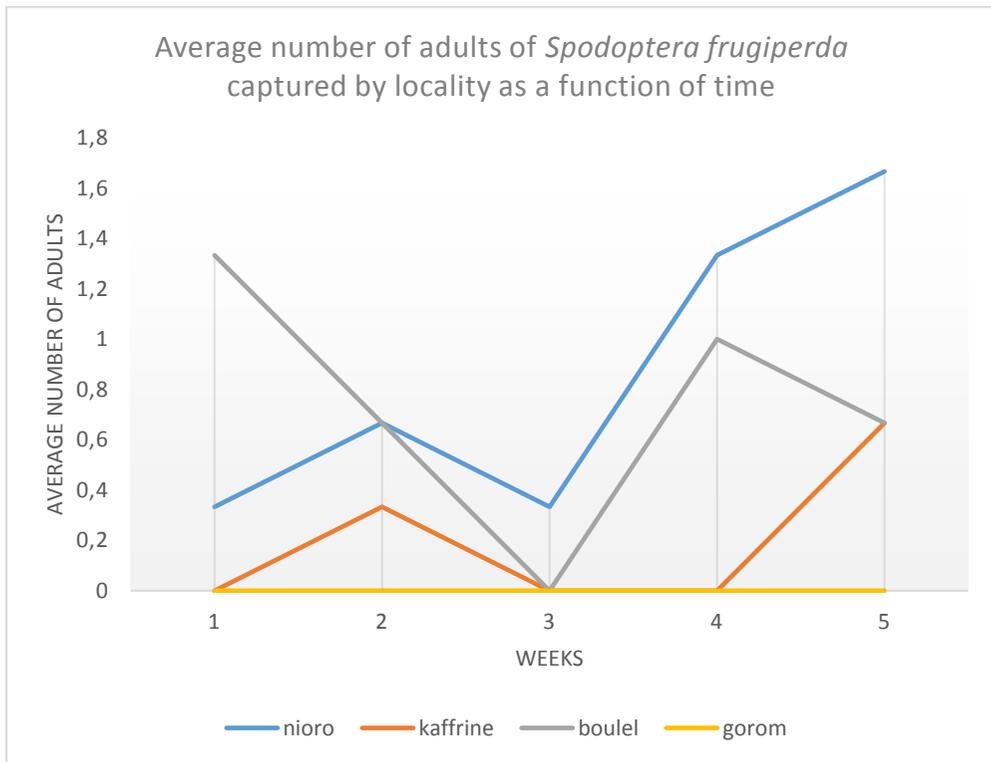


Figure 5: Average number of adults of *Spodoptera frugiperda* captured by locality as a function of time.

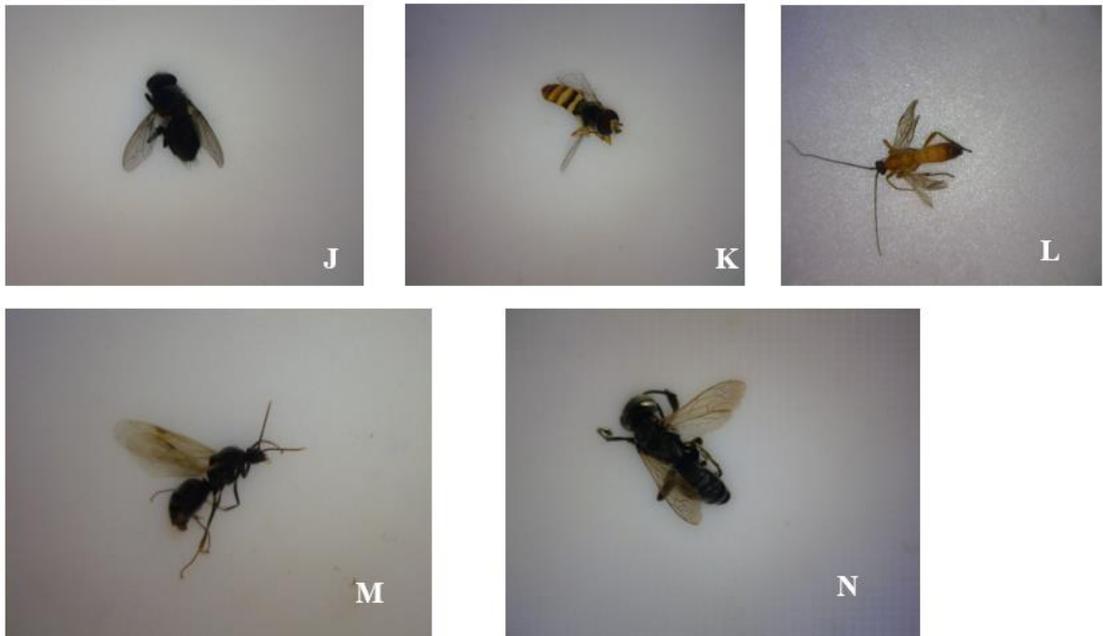


A= Coleoptera Carabidae, B= Coleoptera Coccinellidae, C= Coleoptera Curculionidae, D= Carcinophoridae, E= Dermaptera Forficulidae, F= Coléoptère Chrysomelidae, G= Hymenoptera Formicidae, H= Hemiptera Pentatomidae, NI*= Unidentified family.

Photo 1: Natural enemies found.



Figure 6: Predators captured.



I= Diptera Stratiomyidae J= Diptera Tachinidae, K= Diptera Syrphidae, L= Hymenoptera Braconidae, M= Hymenoptera Scoilidae, N= Hymenoptera Sphecidae, NI*= Unidentified family

Figure 7: Emerged parasitoids in laboratory.

Table 2: Natural enemies of *Spodoptera frugiperda* identified at family level.

| Natural enemies recorded and captured by locality | | | | |
|--|-----------------|-------------------|----------------------|---|
| Order | Family | Host Plant | Status | Number of individuals |
| | | | | 109 (41 recorded et 68 recorded) |
| Nioro | | | | |
| Coleoptera | Curculionidae | Maize | Predator | 6 |
| | Chrysomelidae | Maize | Predator | 1 |
| | Carabidae | Maize | Predator | 5 |
| | NI* | Maize | Potential Predator | 6 |
| Diptera | Tachinidae | Maize | Parasitoids | 40 |
| Dermaptera | Forficulidae | Maize | Predator | 6 |
| | | | | 82 (45 recorded et 37 captured) |
| Kaffrine | | | | |
| Coleoptera | Coccinellidae | Maize | Predator | 1 |
| | Chrysomelidae | Maize | Predator | 15 |
| | Carabidae | Maize | Predator | 3 |
| | NI* | Maize | Potential Predator | 2 |
| Diptera | Tachinidae | Maize | Parasitoid | 9 |
| | Syrphidae | Maize | Parasitoid | 3 |
| Dermaptera | Carcinophoridae | Maize | Predator | 2 |
| Hymenoptera | Scoilidae | Maize | Parasitoid | 2 |
| | | | | 55 (37 recorded et 18 captured) |
| Boulel | | | | |
| Coleoptera | Carabidae | Maize | Predator | 4 |
| Diptera | Syrphidae | Maize | Predator | 1 |
| Dermaptera | Forficulidae | Maize | Predator | 3 |
| | Carcinophoridae | Maize | Predator | 2 |
| Hemiptera | Pentatomidae | Maize | Predator | 1 |
| | NI* | Maize | Potential Predator | 1 |
| Hymenoptera | Braconidae | Maize | Parasitoid | 2 |
| | Sphecidae | Maize | Parasitoid | 1 |
| | Scoilidae | Maize | Parasitoid | 1 |
| | NI* | Maize | Potential Parasitoid | 1 |
| Araneae | NI* | Maize | Predator | 1 |
| | | | | 95 (55 recorded et 40 captured) |
| Gorom | | | | |
| Diptera | Stratiomyidae | Maize | Potential Parasitoid | 1 |
| Coleoptera | Carabidae | Maize | Predator | 4 |
| | Coccinellidae | Maize | Predator | 7 |
| Hymenoptera | Formicidae | Maize | Predator | 3 |
| | NI* | Maize | Potential Predator | 1 |
| Hemiptera | Pentatomidae | Maize | Predator | 20 |
| | NI* | Maize | Predator | 1 |
| Araneae | NI* | Maize | Predator | 1 |
| | NI* | Maize | Predator | 1 |
| | NI* | Maize | Predator | 3 |

DISCUSSION

The percentages of plants attacked are important for both stages even if the damage scores evaluated according to the scale of Davis et al. (1992) remain low. This low damage could be explained by the abundance of rains between August and September. In fact, according to observations made in the field, heavy precipitation affects the populations of *S. frugiperda*. During the rains, the whorled leaves where the caterpillars shelter are filled with water causing mortalities on the one hand and on the other hand the larvae that have fallen to the ground come into contact with entomopathogenic microorganisms such as nematodes as described by Early et al. (2018).

The average number of larvae is greater in Gorom in the vegetative stage and in Kaffrine in the mature stage. This result could be explained by the lack of auxiliaries, in particular entomopathogenic nematodes, noted at nioro.

The average number of adults of *Spodoptera frugiperda* captured per trap is relatively low throughout the study period in the central zone as shown by the studies of Cokola (2019) and Kouanda (2020). The absence of capture noted in Gorom could be due to the different climatic conditions between the two study areas but also the presence of other cultivated hosts, the cultivation method and the small size of the plot.

In this study, the natural enemies of *S. frugiperda* identified on maize are mainly predators, parasitoids and entomopathogenic nematodes, and predators are the most represented (see table).

The Carabidae, Coccinellidae, Carcinophoridae, Forficulidae, Formicidae families have been found in the Center zone as in the Niayes zone. On the other hand, the families of Chrysomelidae, Curculionidae, Tachinidae, Braconidae, Syrphidae, Scolidae

and Sphecidae were found only in the central zone.

Coccinellidae and Forficulidae are known to be egg predators (Hoballah et al., 2004), Carabidae and Formicidae attack the larval stage (Lundgren et al., 2010) while the status of Curculionidae and Chrysomelidae are described as predators eggs and young larvae (Cokola, 2019). The species of the Tachinidae, Syrphidae, Scolidae, Braconidae, Sphecidae and Stratiomyidae family are formidable parasitoids found in the two agro-ecological zones.

Endoparasitic nematodes emerged from *S. frugiperda* larvae collected at Nioro. Of a total of 132 *S. frugiperda* larvae collected, 50 larvae died from infestation by these nematodes. This gives an estimated parasitism rate of 38.46%. The parasitism rate was equal to the mortality rate because all parasitized larvae were dead. The emergence of an average of 4 individuals per host was observed. A maximum of 17 individuals per larva was found. The fall armyworm *S. frugiperda* has a high susceptibility to parasitism from these nematodes. In addition, powdery white spores of a fungus were noted on a corpse of *S. frugiperda*.

Conclusion

This work, approached within the framework of the integrated management of the fall armyworm *Spodoptera frugiperda* for sustainable food security in two agro-ecological zones (center and niayes) in Senegal (KAFACI FAW), aimed to assess the level of pest damage on corn and to determine its association with native natural enemies. The results of the monitoring made it possible to measure the incidence of pests and diseases through the percentages of plants attacked, important for the two stages of development and for the two agro-ecological zones, to assess the low severity of attack through the Davis scale. The observations also allowed to know

the average number of larvae, important at the vegetative stage in Gorom and Kaffrine at the mature stage and the pheromone traps installed captured a low average number of adults of *S. frugiperda* throughout the study period. Several natural enemies (predators and parasitoids) have been identified down to the family, and entomopathogenic organisms (nematodes) have emerged from *S. frugiperda* larvae from Niore during rearing in the laboratory. The noted parasitism rate estimated at 38.46% justifies the low larval population of Niore compared to other sites, and therefore promising endoparasites in the biological management of FAW. In addition, there is the development of an unidentified strain of entomopathogenic fungus which opens up other avenues for research on biological control agents.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

AN contributed to the coordination of activities, definition of experimental protocols, statistical data analysis and article writing. MF contributed to the definition of experimental protocols, field data collection, statistical analysis of data and the writing of the article. IB contributed to definition of experimental protocols, the field data collection, statistical analysis of data and the writing of the article. ID contributed to the definition of experimental protocols, field data collection statistical analysis of data and the writing of the article. PMS contributed to the manuscript correction.

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