Literature Review on the Natural Enemies of Spodoptera Frugiperda J. E. Smith (Lepidoptera: Noctuidae) and the Effectiveness of Their Use in the Management of This Pest in Corn (Zea Mays L.)

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ABSTRACT: The fall armyworm Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) is an important maize pests that threaten food security in sub-Saharan Africa. In order to evaluate the diversity of natural enemies and especially their effectiveness for a sustainable management of this pest in Africa, a literature review was carried out. It consisted in exploiting 35 scientific publications from the most highly rated journals, over the period 2015-2020 relating to the inventory of the natural enemies of S. frugiperda and their effectiveness in the world in general and more particularly in Africa. It emerges from this study that there is a large diversity of natural enemies of S. frugiperda in the world. In total, 66 species of natural enemies belonging to 21 families in 10 orders have been recorded. Parasitoids have been the most studied 43 (64.18%) and the most used in the control of S. frugiperda, followed by predators 13 (19.40%) and entomopathogens (13.42%). In Africa, 24 of the 67 species have been recorded in 9 countries. Parasitoids were also created with a rate of 26.86% or 75.00% at the African level. The main most effective parasitoids were Telenomus remus (Hymenoptera: Scelionidae), Chelonus insularis Cresson (Hymenoptera: Braconidae) and Cotesia marginiventris Cresson (Hymenoptera: Braconidae) with parasitism rates varying between 0.85 and 9.90% depending on the environments. In view of the results, since these species have been listed in Africa, they seem to be real candidates for future programs for the sustainable management of this caterpillar. Research is underway in Togo and probably in the rest of the countries of the continent for a better knowledge and development of these natural enemies.

KEYWORDS: Corn, S. frugiperda, natural enemies, efficacy.

I. INTRODUCTION

The harmful consequences of chemical pesticides on human health and on the balance of the various ecosystems are no longer in doubt [1]. The issues of pollution, loss of biodiversity and diseases linked to the use of plant protection products are becoming increasingly alarming [2]. Since the dawn of time with the industrial revolution, the use of chemicals to control crop pests has always been controversial. Cereals, and in particular corn, are the staple food of sub-Saharan populations [3]. Since 2016, an exotic caterpillar Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) has emerged, reducing maize production by 15-73% and thus posing a serious threat to global food security [4]. In order to achieve the Sustainable development goals, which call for the preservation of biodiversity [5], environmentally friendly control methods are increasingly being promoted in various biodiversity management programmes. Much research has been done and more is underway to sustainably manage pests with bio-pesticides. Genetic improvement for pest control is controversial in terms of ethics under the 1992 Rio Convention on Biological Diversity, but also in terms of the loss of intrinsic values of wild varieties. A study by [6] on two corn varieties showed that the new varieties were less resistant to S. frugiperda due to the loss of resistance genes during the crossing process. There is a range of techniques to manage this caterpillar but the sustainable management strategy is one that includes the use of natural enemies [7]. Natural enemies are therefore alternatives to chemicals against S. frugiperda but also a technique to support environmental protection and the sustainability of agroecosystems [8]. Several investigations have been carried out on this topic.
in the USA, where the insect originates [9, 10], in Mexico and Central America [11] and in Latin America [12, 13]. Although recognised as effective, pest management using natural enemies remains a vast area of instigation in sub-Saharan Africa. There is very little knowledge that can constitute a reliable database on the use of natural enemies in pest management over the last five years worldwide and more particularly in Africa. This study aims to summarise the work done on the main natural enemies of *S. frugiperda* and especially on their effectiveness in the management of this pest in the world in order to lay the foundations for sustainable biological control in Africa.

II. MATERIALS AND METHODS

A. Source of Information

The need to develop sustainable management methods for *S. frugiperda*, has led to recent bibliographic syntheses on the inventory of natural enemies of this pest and especially on tests to evaluate their effectiveness in influential journals. The research focused on the collection of relevant information from 35 published scientific articles, from bibliographic references on the inventories of natural enemies of *S. frugiperda* and their efficacy on the pest, and also from articles and abstracts of scientific papers. The synthesis was inspired by the methodology used by [11] in the USA to make a synthesis on parasitoids and parasites of *S. frugiperda*. They identified and analysed the literature related to the inventory of natural enemies of *S. frugiperda* and tests to evaluate their level of parasitism. Based on the work of [11], the methodological approach of the present paper, which focuses on the period 2015-2020, pays attention to the careful choice of the keywords to be inserted in the search engines so as not to lead to works significantly far from the main meaning of the subject. The approach was adopted by using mainly the following words and phrases: "natural enemies", "*S. frugiperda*", "parasitism rate", "efficiency". Publications mainly from journals such as "Florida entomologist", "Biological control", "Journal of insect science", "Elsevier", "PLOS ONE" and "Economic Entomology" were used for this synthesis.

B. Information's Organisation

Various information was obtained on the natural enemies of *S. frugiperda* in the world in general and in Africa in particular and is presented in Table 1. The information is presented in Table 1. It covers, in order, parasites and parasitoids of *S. frugiperda*, predators, entomopathogenic fungi, bacteria and viruses. For each of the natural enemies, information such as: classification, country in which it was reported and the reference of the article are reported. Then the results on the effectiveness of the main natural enemies were presented. These results were also discussed, according to the study environments.

The approach was therefore to make a comparative study of the diversity of natural enemies in Africa and in the world. The efficiencies of the main natural enemies were then assessed in order to give some guidance on the possible potential of natural enemies at the African level.

III. RESULTS

A. Management of *S. Frugiperda* in Togo

In Togo as in most African countries, several investigations in recent years have focused on the management of *S. frugiperda*. [14], found molecular similarity between *S. frugiperda* genes from Togo and those from the Americas and the West Indies. In the perspective of sustainable management, efficiency tests of different pheromone traps were carried out in Togo [15]. The latter evaluated both the effectiveness of three different types of pheromone traps in terms of sensitivity, specificity and cost. Nowadays, contrary to the countries where the insect originates, no more information about natural enemies and even less about their effectiveness in the African context and more particularly in Togo. [16], showed that although *S. frugiperda* infestations seem to be gradually decreasing from 2016 to 2018, they remain high in Togo compared to Ghana. Hence the need to shed light on all the work done on the inventory of *S. frugiperda* natural enemies and especially their efficacy during the period 2015-2020.

B. Summary of the Main Natural Enemies Recorded

The inventory of the main natural enemies of *S. frugiperda* during our synthesis period resulted in the identification of numerous natural enemies of *S. frugiperda* (Table 1). All the natural enemies recorded were divided by order of representation into 10 main orders: Hymenoptera, Diptera, Coleoptera, Dermaptera, Heteroptera, Hypocreales, Nematoda. The different results are presented in the following order: parasites and parasitoids, predators and entomopathogens.
Table 1. SUMMARY of NATURAL ENEMIES of S. FRUGIPERDA RECORDED WORLDWIDE DURING the PERIOD 2015-2020

| TYPE of NATURAL ENEMY | ORDER and FAMILY | COUNTRY of COLLECTION | CULTURE | REFERENCE |
|-----------------------|------------------|-----------------------|---------|-----------|
| 1-Parasits and Parasitoids |                  |                       |         |           |
| *Chelonus bifoveolatus* Szpligeti | Hymenoptera: Braconidae | Ghana, Senegal, Benin | Corn | [17]; [18]; [16] |
| *Ch. insularis* Cresson | Hymenoptera: Braconidae | Mexico, Florida, Tanzania, India | Corn, Sorghum | [19]; [10]; [20]; [21]; [22]; [23]; [24] |
| *Ch. curvimaculatus* Cameron | Hymenoptera: Braconidae | Kenya | Corn | [25] |
| *Ch. formosanus* Sonan | Hymenoptera, Braconidae | India | Corn | [24] |
| *Meteorus arizonensis* Muesebeck | Hymenoptera: Braconidae | Mexico, Florida | Corn | [19]; [10] |
| *M. laphygmae* Viereck | Hymenoptera: Braconidae | Mexico | Corn | [20] |
| *Microplitis manilae* Ashmead | Hymenoptera: Braconidae | India | Corn | [24] |
| *Coccygidium luteum* Brullé | Hymenoptera: Braconidae | Benin, Mozambique | Corn | [17]; [26]; [16] |
| *Bracon* sp. | Hymenoptera: Braconidae | Ghana | Corn | [16] |
| *Cotesia icipe* Fernandez, | Hymenoptera: Braconidae | Benin, Ghana, Ethiopia | Corn | [17]; [25]; [16] |
| *C. ruficrus* Haliday | Hymenoptera: Braconidae | India | Corn | [27] |
| *C. marginiventris* Cresson | Hymenoptera: Braconidae | Florida, Tanzania, India | Corn | [10]; [20]; [23]; [24] |
| *Meteoridea testacea* Granger | Hymenoptera: Braconidae | Ghana, Benin | Corn | [17]; [16] |
| *Glyptapanteles creatonoti* Viereck | Hymenoptera: Braconidae | India | Corn | [28] |
| *Aleioles laphygmae* Viereck | Hymenoptera: Braconidae | Florida | Corn | [10] |
| *Coccygidium melleum* Roman | Hymenoptera: Braconidae | India, Tanzanie | Corn | [29]; [23] |
| *Campoletis sonorensis* Cameron | Hymenoptera: Ichneumonidae | Mexico, Senegal | Corn | [19]; [18] |
| *C. flavicincta* Ashmead | Hymenoptera: Ichneumonidae | Mexico | Corn | [19] |
| *Charops* sp. | Hymenoptera: Ichneumonidae | Benin, Ghana | Corn | [17] |
| *Pristomerus sp* | Hymenoptera: Ichneumonidae | Mexico | Corn | [19] |
| *Ophion flavidus* | Hymenoptera: Ichneumonidae | Florida | Corn | [10] |
| *Metopius discolor* Tosquinet | Hymenoptera: Ichneumonidae | Ghana | Corn | [17] |
| *M. rufus* Ashmead | Hymenoptera: Ichneumonidae | India | Corn | [24] |
| *Netelia* sp. | Hymenoptera: Ichneumonidae | India | Corn | [24] |
| *Ichneumon promissorius* Ericson | Hymenoptera: Ichneumonidae | India | Corn | [24] |
| *Pristomerus pallidus* Kriechbaumer | Hymenoptera: Ichneumonidae | Benin | Corn | [17] |
| *Euplectrus platyhypenae* Howard | Hymenoptera: Eulophidae | Mexico, Florida | Corn | [19] |
| Species                          | Family          | Country       | Pest          | Notes                                  |
|---------------------------------|-----------------|---------------|---------------|----------------------------------------|
| *Anatrichus erinaceus* Loew     | Diptera: Chloropidae | Ghana         | Corn          | [16]                                   |
| *Eucelatoxia bryani*            | Diptera: Chloropidae | Mexico        | Corn, Sorghum | [21]                                   |
| *Exorista sorbillans* Wiedemann | Diptera: Tachinidae | India         | Corn          | [29]                                   |
| *Drino quadrizonula* Thomson    | Diptera: Tachinidae | Benin, Mozambique | Corn | [17]; [26] |
| *Archytas marmoratus* Townsend  | Diptera: Tachinidae | Mexico        | Corn          | [19]                                   |
| *Lespesia sp.*                  | Diptera: Tachinidae | Mexico        | Corn          | [19]                                   |
| *Une brachycère non identifiée* | Diptera: Tachinidae | Ghana         | Corn          | [16]                                   |
| *Eriborus sp.*                  | Hymenoptera: Ichneumonidae | India       | Corn          | [10]; [29]                             |
| *Campoletis sp.*                | Hymenoptera: Ichneumonidae | Senegal     | Corn          | [18]                                   |
| *C. chlorideae* Uchida          | Hymenoptera: Ichneumonidae | India       | Corn          | [28], [29]                             |
| *Metopius rufus* Ashmead        | Hymenoptera: Ichneumonidae | India       | Corn          | [24]                                   |
| *Odontepyris sp.*               | Hymenoptera: Bethylidae | India       | Corn          | [29]                                   |
| *Telenomus remus*               | Hymenoptera: Scolionidae | South Africa, Benin, Ivory Coast, Niger, Kenya, Mexico, China | Corn, Sorghum | [21]; [30]; [31]; [25] |
| *Telenomus sp.*                 | Hymenoptera: Platygastridae | India       | Corn          | [28]                                   |
| *Trichogramma sp.*              | Hymenoptera: Trichogrammatidae | India       | Corn          | [28]                                   |
| *Trichogramma atopovirilia* Oatman and Platner | Hymenoptera: Trichogrammatidae | Mexico | Corn, Sorghum | [22]                                   |
| *Hexamermis cf. albicans* Siebold | Mermithida: Mermithidae | India       | Corn          | [24]                                   |

**2-Prédateurs**

| Species                          | Family          | Country       | Pest          | Notes                                  |
|---------------------------------|-----------------|---------------|---------------|----------------------------------------|
| *Pheidole megacephala*          | Hymenoptera: Formicidae | Ghana       | Corn          | [16]                                   |
| *Haematochares obscuripennis* Stål | Heteroptera: Reduviidae | Ghana       | Corn          | [16]                                   |
| *Peprius nodulipes* Signoret    | Heteroptera: Reduviidae | Ghana       | Corn          | [16]                                   |
| *Cosmolestes sp.*               | Heteroptera: Reduviidae | India       | Corn          | [24]                                   |
| *Forficula sp.*                 | Dermaptera: Forficulidae | India       | Corn          | [28]; [29]                             |
| *Harmonia octomaculata* Fabricius | Coleoptera: Coccinellidae | India       | Corn          | [29]                                   |
| *Coccinella transversalis* Fabricius | Coleoptera: Coccinellidae | India       | Corn          | [29]                                   |
| *Doru sp.*                      | Dermaptera : Forficulidae | Mexico       | Corn, Sorghum | [22]                                   |
| *Eocanthecona furcellata* Wolff  | Hemiptera: Pentatomidae | India       | Corn          | [24]                                   |
| *Andrallus spinidens* Fabricius  | Hemiptera: Pentatomidae | India       | Corn          | [24]                                   |
| *Podisus maculiventris*         | Hemiptera: Pentatomidae | India       | Corn          | [24]                                   |
1) PARASITS and PARASITOIDS of S. FRUGIPERDA: Parasits and parasitoids represent the most important natural enemy of S. frugiperda among all other groups both in number and in species. Forty-three (43) parasitoids have been reported worldwide. [19], in their work in Mexico reported the presence of Chelonus insularis Cresson and Meteorus arizonensis Muesebeck (Hymenoptera: Braconidae); Camporelis sonorensis Cameron, Pristomerus sp. and C. flavicincta Ashmead (Hymenoptera: Ichneumonidae); Euplectrus platyhypenae Howard (Hymenoptera: Eulophidae); Archytas marmoratus Townsend and Lespesia sp. (Diptera: Tachinidae) on Corn. [10] reported in their work during the period of 2010-2015 in three countries of South Florida, two main parasitoids of S. frugiperda eggs on Corn crop which are Cotesia marginiventris Cresson (Hymenoptera: Braconidae) and C. insularis. The work of [20] in northern Sinaloa focused on Meteorus lophygmae Viereck (Hymenoptera: Braconidae), C. insularis and C. marginiventris as the most abundant parasitoids. The work of [21] and [22] has confirmed the presence of C. insularis in some areas of Mexico. These investigations also identified Telenomus remus (Hymenoptera: Scelionidae) Trichogramma atopovirilia (Hymenoptera: Trichogrammatidae) and a Diptera Eucletoria bryani (Diptera: Chloropidae) on corn and sorghum. In Asia, research by [28] identified parasitoids such as Glyptapanteles creatonotii Viereck (Hymenoptera: Braconidae), Telenomus sp. (Hymenoptera: Platygastriidae), Trichogramma sp. (Hymenoptera: Trichogrammatidae) and C. chlorideae (Hymenoptera: Ichneumonidae) on Corn in India. A year later, [27] and [29] identified four new parasitoids in the same country which are Odontepyris sp. (Hymenoptera: Bethylidae); Erirbus sp. (Hymenoptera: Ichneumonidae); Exarista sordillans Wiedemann (Diptera: Tachinidae); Coccygdiun melleum Roman (Hymenoptera: Braconidae) and C. ruficrus Haliday (Hymenoptera: Braconidae). The latest research by [24] has identified 5 new parasitoids and one parasite in India. These parasitoids are : Metopius rufus Ashmead, Ichneumon promissorius Ericson ; Netelia sp. (Hymenoptera: Ichneumonidae); C. formosanus Sonan; Microplitis manilae Ashmead (Hymenoptera: Braconidae). The species Hexamermis cf. albicans Siebold (Mermithida: Mermithidae) remains the only parasite identified during this work in India on Corn. In China, T. remus was the first natural enemy to be identified on Corn in the south of the country [30].

In Africa, although research on possible natural enemies of S. frugiperda is recent, to date there are numerous natural enemies, mainly parasitoids, recorded across Africa. The first report on the parasitoid of S. frugiperda was done by [25] and later supplemented by [31] and later by the same author [25]. The work of [17], [18] and [16] completes the very limited list of work done on the natural enemies of this insect in Africa. Indeed, [25] identified for the first time in Africa and more particularly in Tanzania, Ethiopia, Kenya and Mozambique 5 species of eggs and larvae parasitoids of S. frugiperda during their work on Corn. They identified for the first time in three localities in Ethiopia Cotesia icie Fernandez, Coccydiunu luteum Brunell (Hymenoptera: Braconidae) and Polexorista zonata (Diptera: Tachinidae). In Kenya, Charops ater (Hymenoptera: Ichneumonidae), P. zonata, C.
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Luteum, C. icipe and C. curvimaculatus were identified in five localities. In Tanzania, however, C. ater and C. luteum were observed for the first time in four localities. In the Mozambique Republic it was only in 2020 that C. luteum and D. quadrijronula were reported for the first time on Corn in the central province of Monica. Work on the natural enemies of S. frugiperda in West Africa highlighted the presence of C. bifoveolatus for the first time in Benin [17], Senegal [18] and Ghana [16]. C. luteum, Charops sp. and Meteoridea testacea, were identified in Benin and Ghana by [16, 17]. T. remus has been an important egg parasitoid, identified in South Africa, Benin, Ivory coast, Niger and Kenya by [31] and [25]. Recent studies in Tanzania have identified C. insularis as an egg parasitoid of S. frugiperda [23].

2) PREDATORS OF S. FRUGIPERDA: Predators are the second most abundant group after parasitoids and parasites. They represent 19.70% of the species listed in all the articles consulted for this synthesis. These predators belong to five main orders, which are Hymenoptera, Hemiptera, Heteroptera, Coleoptera and Dermaptera.

In the Americas and more specifically in Mexico, [22] reported in their work a single predator species on Corn and Sorghum, a Forficulidae called Doru sp. (Dermaptera: Forficulidae). Research in Asia, particularly in India and China, has identified several species of predators. [28], reported the presence of Forficula sp (Dermaptera: Forficulidae) in their work. A year later, this species was confirmed in the same country by [29]. The latter were able to record two other species Harmonia octomaculata Fabricius and Coccinella transversalis Fabricius (Coleoptera: Coccinellidae). The most recent research on the natural enemies of S. frugiperda in India was carried out by [24] on Corn. Six (6) species of predator were recorded belonging to three (3) families from three different orders. Hemipterans represented by three (3) species of the Pentatomidae family, two (2) species of Hymenoptera of the family Vespidae and one Heteroptera of the family Reduviidae. These species are Eocanthecona furcellata Wolff, Androllus spinidens Fabricius and Podisus macculiventris (Hemiptera: Pentatomidae); Ropalidia brevita and Polistes cf. olivaceus (Hymenoptera: Vespidae) and Cosmolestes sp. (Heteroptera: Reduviidae).

3) ENTOMOPATHOGENS OF S. FRUGIPERDA : The entomopathogens listed in this inventory are mainly nematodes, fungi, bacteria and viruses. Two (2) species of nematodes were reported in this review. These include Hexamermis sp. (Nematoda: Meremithidae), recorded in Senegal on corn (Tendeng et al., 2019) and Ovomermis sinensis (Nematoda: Meremithidae) also on corn in China [32]. Concerning entomopathogenic fungi, Beauveria bassiana (Hypocreales: Cordycipitaceae), Metarhizium anisopliae (Hypocreales: Clavicipitaceae), M. rileyi and Nomuraea rileyi (Hypocreales: Clavicipitaceae) were recorded in the different works. B. bassiana and M. anisopliae were identified in India [19] before being confirmed 3 years later by [33]. In Mexico, the research conducted by [24] reported this species. N. rileyi was the third fungal species reported from India by [28,29]. In Africa, only one species of fungus has been reported in Kenya: M. rileyi [34]. Two (2) viruses have been observed in Argentina in Mexico and India and a bacterium in Kenya on Corn as natural enemies of Corn. SfMNPV (Spodoptera frugiperda nucleopolyhedrovirus) was observed in Mexico [37] and India [24; 35] on Corn. On the other hand, SGV ARG is a virus that has only been observed in Argentina [36]. The bacterium that has been identified in Kenya is Bacterial 16S rRNA gene according to research conducted by [34].

C. SUMMARY OF THE EFFECTIVENESS OF S. FRUGIPERDA NATURAL ENEMIES WORLDWIDE

The management of S. frugiperda by means of its natural enemies has been the subject of much research around the world. As well as the inventory of these natural enemies, the implications of parasitoids in the management of this pest are enormous. This section summarises the main work on sustainable management of S. frugiperda during the period 2015-2020.

The majority of publications consulted on the use of natural enemies in the management of S. frugiperda have been carried out in the Americas, where the pest originates. In general, parasitoids and parasites have been the most used. [21] reported a parasitism rate between 5; 6.3 and 9.9% for three main parasitoids on Corn in Mexico which are C. insularis, N. rileyi and Trichogramma spp. In Brazil, [38] reported that the use of T. pretiosum in the control of S. frugiperda reduced larval density and promoted a production gain of 0.7t/ha equivalent to a financial gain of US$96.5 per hectare. [39] showed that the entomopathogenic virus SfMNPV controlled the population dynamics of S. frugiperda by breaking the insect's resistance. A significant increase in larval mortality of S. frugiperda was obtained in Brazil by [40] using M. anisopliae strains. The influence of the migration capacity of T. remus on the efficiency of this parasitoid, evaluated in Brazil has been demonstrated [41]. [37] also pointed out that the application of the entomopathogenic virus SfMNPV at a frequency of 7 days controlled the larval density of the caterpillar by 84% and reduced the incidence of parasitoids in Mexico. In the same country, [22] showed the efficiency of T. atopovirilia with parasitism rates of 70, 14 and 8% respectively in laboratory and field conditions. Competition relationships were highlighted by [42] in their work in Brazil on three egg parasitoids T. remus, Trichogramma spp. and T. pretiosum of S. frigiperda. [43] showed the effectiveness of the predator-parasitoid symbiosis in controlling the caterpillar in Brazil under laboratory conditions. In Florida, [44] showed the effectiveness of the association of P. maculiventris, E. floridanus and C. marginiventris in...
the integrated management of *S. frugiperda* and the conditions for a better use of these natural enemies. In their study, [45] showed that the association of the fungus *Trichoderma atroviride* with the Corn root system improved the parasitism rate of *Campoletis sonorensis* (Hymenoptera: Ichneumonidae) on *S. frugiperda* in Mexico. [46] showed the efficacy of *M. anisopliae* in reducing the incidence and level of leaf damage associated with the pest on Corn. Recent investigations in Mexico showed the synergistic effect of combinations of *B. bassiana*, *M. anisopliae* and small doses of spinosad in controlling the dynamics of the L3 stage larvae of *S. frugiperda* in the laboratory [33]. [47] showed the efficiency of *T. remus* in controlling *S. frugiperda* according to the larval density of the parasitoid and the phenological stage of the plant and the influence of temperature in the mass rearing of this parasitoid in Brazil.

In Asia, control trials against *S. frugiperda* using *N. rileyi* reduced infestation rates by 58.91-62.87% and leaf damage levels and larval density by 62.50-66.46% and 66.84-73.05% on Corn depending on the locality [48] in India. A parasitism rate between 10 and 15% of this fungus was also reported on Corn one year later in the same country [29]. In their investigations, [49] showed predation of both adults and larvae of *Chrysopa pallens* (Neuroptera: Chrysopidae) on *S. frugiperda*. The entomopathogenic fungus *M. rileyi* and the bacterulovirus, SpfrNPV were reported to be the most dominant entomopathogens in controlling the caterpillar with a larval mortality rate of more than 50% in India [24].

In Africa, [50] carried out the first work on the efficacy of natural enemies, especially entomopathogenic fungi. They used 20 different concentrations of two strains of fungi, which are *B. bassiana* and *M. anisopliae* in the laboratory on L2 stage larvae and neonates in their trials. The lowest efficacy was 30% with *B. bassiana* on second instar larvae. Most concentrations gave efficacy ranging from 83-97.5% on both second instar larvae and neonates but the best efficiencies were obtained with *M. anisopliae*. The concentrations that provided the best mortality rates were proposed for experiments under field conditions for further evaluation. [23] showed the efficacy of *C. margiventris* in combination cropping in controlling *S. frugiperda*. In Kenya, *T. remus* was reported to be the most effective egg parasitoid to be promoted in the control of the caterpillar with a parasitism rate of 69.3% against only 42% for the larval parasitoid *C. icipe* [25]. [26] pointed out that with a parasitism rate of 23.68% and 8.86% and relative abundance values of 100 and 96.3 for *C. luteum* and *D. quadrizonula*, respectively, these are important to promote.

### III. DISCUSSION

The inventory of the natural enemies of the armyworm through 35 recent articles and publications covering the period 2015-2020, made it possible to identify 67 species belonging to 21 families divided into 10 orders. In general, the work published has focused on three continents: America, Africa and Asia.

Very little work has been done on the inventory of the natural enemies of this caterpillar in America during this period. These results can be explained by the fact that the caterpillar is native to the Americas, and much research has already been carried out in this area with a view to highlighting the biodiversity of the natural enemies of this pest and testing their effectiveness. [51] had already reported for the first time in North and South America, 53 species of parasitoids of *S. frugiperda* belonging to 43 genera and 10 families, of which the families Braconidae, Ichneumonidae and Tachinidae represented respectively 16, 19 and 47% of the genera and 15, 17 and 53% of the species. Secondly, [11] identified 150 species of parasitoids and parasites of *S. frugiperda* in the Americas and the Caribbean Basin, belonging to 14 families from 3 main orders: Hymenoptera, Diptera and nematodes. In Africa, as in Asia, many inventories have been made because the caterpillar is a current threat and, as in the country of origin, better control requires a better knowledge of the insect’s bioecology. In such a short period of time, the work already done on these continents shows an important biodiversity of natural enemies, including most of those already reported on the American continent. These continents would have many alternative host plants and favourable climatic conditions for the development of the insect and of these natural enemies. These results confirm those of [52] who reported that the insect would be an endemic and multi-generational pest in Africa because the continent offers diverse host plant sources and favourable climatic conditions for constant reproduction.

With regard to the effectiveness of natural enemies, parasitoids were the most effective against the caterpillar. Predators were the second most effective group of natural enemies. These results are in agreement with those of [10] and [20] but disagree with those of [53] who showed that parasitoids, notably *T. remus*, did not have a significant effect on the reduction of *S. frugiperda* larval density and that this reduction was rather linked to natural mortality but also to the action of predators. The natural enemies of *S. frugiperda* would also be those of the main stem and ear borers of Corn, thus explaining the interest in this pest. Indeed, our results confirm those obtained by [54], who showed that *Telenomus busseolae* Gahan and *T. isis* Polaszek were the main ovolarvarian parasitoids of *B. fusca* and *S. calamistis* on Corn, Sorghum and millet. They also confirm those of [55] who reported that *Trichogramma sp.* was the main ovularvarial parasitoid of *Chilo partellus* on Corn and Sorghum. Our results also support those of [56] who mentioned Bracon sesamiae as the main larval parasitoid of *E. saccharina* on Corn. Entomopathogenes have been less
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recommended because they are slow acting and therefore, in relation to the biology of the insect, would not be effective in controlling it. Our investigations support the work of [33] who recommended a combination of entomopathogenic fungi B. bassiana and M. anisopliae with small doses of spinosad insecticides to control L3 stage larvae in the laboratory. They also support those of [57] with the use of the entomopathogenic nematode Steinernema carpocapsae (Rhabditida: Steinernematidae) in combination with low doses of chemical pesticides in the management of S. frugiperda in the USA. In Africa, [25; 58] were able to promote the first natural enemies to be valued. T. remus was proposed by [17] in Ghana and Benin and [16] in Ghana to control the caterpillar.

According to [59], the production of a parasitoid such as T. remus on S. frugiperda eggs would require 0.0004 US$ (on average 3 CFA francs). Given the whole process to be followed before their release, the production cost of natural enemies would remain one of the major constraints to biological control based on the use of natural enemies in Africa.

IV. CONCLUSION
At the end of this study, it is noted that there is a significant diversity of natural enemies of S. frugiperda around the world. Very little research has been done on natural enemy inventories in the USA, unlike in other countries. This is because much work has already been done to identify natural enemies, and perspectives on their efficacy are sought. In contrast, in African and Asian countries, research on potential natural enemies is just beginning. In only five years after its official report on the African continent and only two years on the Asian continent, the majority of the natural enemies listed on the American continent have already been found on these continents. This study lays the groundwork for the start of research into the use of the most effective natural enemies in our countries. The research is ongoing and will allow a better assessment of natural enemies and their efficacy in Africa.

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