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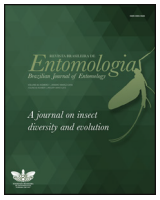

First report of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on Onion (*Allium cepa* L.) in South Kivu, Eastern DR Congo

Marcellin Cuma Cokola [1,2*], Serge Shakanye Ndjadi[1,3], Espoir Basengere Bisimwa[1], Leonard E. Ahoton[3], Frédéric Francis[2]

[1]*Université Evangélique en Afrique, Faculty of Agriculture and Environmental Sciences, Department of Crop sciences, Bukavu, South Kivu, DR Congo.*
[2]*Liege University, Gembloux Agro-Bio Tech, Functional and Evolutionary Entomology, Gembloux, Belgium.*
[3]*University of Abomey-Calavi, Faculty of Agronomic Sciences, School of Plant Production Sciences and Techniques, Plant Biology Laboratory, Cotonou, Benin.*

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ABSTRACT

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith, 1797), has become one of the most devastating pests in the world with diverse host range. To develop effective integrated management strategies against *S. frugiperda*, it is crucial to know its alternative host plants. In this study, we provide the first information on the occurrence of *S. frugiperda* in onion crops in Africa. Monitoring was carried out during the 2019 and 2020 growing seasons in onion monoculture and in intercropping with groundnut to detect the presence and assess the incidence of *S. frugiperda*. The highest average incidence (2.88%) and larval density (0.79 per 9 m^2) were observed in onion monoculture. The classification of the onion leaf damage rating scale indicated low *S. frugiperda* infestation. This suggests that future studies will need to assess this aspect which we consider to be a survival strategy to maintain its population throughout the year, which contributes to sustain the insect in the study area during times when its preferred hosts are not present. Furthermore, genetic studies are needed to provide a better explanation of the ecology of this pest and to find out which of the two existing strain infests onions or whether it is an unknown hybrid population of *S. frugiperda*.

Introduction

The fall armyworm (*Spodoptera frugiperda* J.E. Smith, 1797), is a larva known to be a devastating pest of maize crops in America (Luginbill, 1928; Labatte, 1994). This species, originating from tropical and subtropical America, specifically in the USA, Argentina, the Caribbean, including Puerto Rico (Capinera, 2000), has become an invasive species in Africa since 2016 (Goergen et al., 2016) and later in Asia (Shylesha et al., 2018; Sharanabasappa et al., 2018a). *S. frugiperda* is a long-distance, sporadic migratory pest, whose adult moths can travel several miles from one region to another (Johnson, 1987; Westbrook et al., 2016; Early et al., 2018).

The existence of two strains allows differentiating two particular categories of crops damaged by *S. frugiperda*, all belonging to Poaceae, primarily maize and secondly rice and fodder grasses (Pashley, 1988; Cano-Calle et al., 2015; Dumas et al., 2015). Additionally sugar cane (Srikanth et al., 2018) as well as cotton (Hardke et al., 2015) were found to be infested in India and United States respectively. Damages are frequently observed on maize at the foliar level, but also within the ears in case of severe infestations (Davis et al., 1992). According to Casmuz et al. (2010), *S. frugiperda* can also infest other crops than those previously mentioned. Recent literature revue updated the species infested by *S. frugiperda* with a total of 353 host plants (Montezano et al., 2018).

Nevertheless, a comprehensive survey of *S. frugiperda* host plants is essential to better apprehend its ecology, to conduct future studies and to develop efficient integrated pest management programs (Montezano et al., 2018). In tropical areas with several cropping seasons, it is significant to know the host plants of *S. frugiperda* to predict infestations in future seasons and years. For example in Brazil, it has been recorded that *S. frugiperda* feeds on millet (*Pennisetum glaucum* L.) throughout the dry season, resulting in high populations during the off-season and the following primary cropping season (Favetti et al., 2017). In India, *S. frugiperda* also occurs in ginger (*Zingiber officinale* Roscoe) (Shankar and Adachi, 2019). Studies on alternative hosts for *S. frugiperda* remain poorly documented in Africa.

* Corresponding author.
E-mail: marcellin92cokolacuma@gmail.com (M.C. Cokola).

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According to Luginbill (1928), the primary alternate hosts of *S. frugiperda* are grasses. Onion has been included in the host list of *S. frugiperda* in a compilation of literature from around the world (Luginbill, 1928; Andrews, 1988; Casmuz et al., 2010; Fernandes et al., 2012; Montezano et al., 2018). However, the level of *S. frugiperda* infestation in onion crops and how the damage occurs are unknown. Because of the diversity of cultivated and wild plants in DR Congo, it is possible that *S. frugiperda* attacks other crops apart from maize and sorghum, during both the rainy and dry seasons. This study provides the first information on the occurrence of *S. frugiperda* in onion monoculture and in intercropping with groundnut in Africa.

Materials and methods

Study site

A monitoring was conducted in Kashusha district, at the experimental site of the Université Evangélique en Afrique (UEA/Bukavu). Kashusha is located at 02°18'56" South latitude, 28°47'45.9" East longitude, in the eastern part of the DR Congo, in South Kivu province, Kabare territory and whose altitude is between 1600 and 1750 m.

Identification of *Spodoptera frugiperda* in Onion

From the extant literature (Visser, 2017; Sharanabasappa et al., 2018b; Huesing et al., 2018), larvae with morphological characteristics similar to *S. frugiperda* were collected in onion crops in the study area. Most individuals were likely in the fifth and sixth instar. Marks used for identification include the upside Y mark on the head region and the four larger spots on the second last segment (Visser, 2017; Sharanabasappa et al., 2018b).

Although characteristic marks on the larvae were distinct to the naked eye, a portable magnifying glass (PMS-054 of 6-fold increase) was used for better visualization and confirmation. *S. frugiperda* larvae were compared to larvae of other *Spodoptera* species and other noctuids associated with onion crops to prevent possible confusion in terms of damage assessment. For this purpose, a morphological identification key proposed by EPPO (2015) was used to ascertain whether the damage and larvae observed were indeed those of *S. frugiperda*. To determine the instar larvae, the collected larvae were kept in plastic jars containing onion leaves and taken to the plant protection laboratory (Université Evangélique en Afrique, UEA/Bukavu) for identification. The larval characteristics described by Capinera (2000) allowed us to know the instar larvae by considering the Head capsule widths, the weight and length of the larvae.

Natural survey of *Spodoptera frugiperda* in onion permaculture

The first monitoring was carried out during the 2019 growing season (November 2019) in an onion permaculture. The second one was carried out in the same permaculture during the 2020 growing season (April 2020). The monitoring system was developed in an onion trial sown in intercropping. A total of 48 plots of 9 m^2 each distributed over three blocks and divided into 24 plots of the onion sown in monoculture and 24 plots of the onion intercropped with the groundnut (*Arachis hypogaea* L.) were investigated. The aggregate area of the trial was 1243 m^2. Two varieties of onion namely Red Bombay and Red Creole; and two other groundnut varieties (JL24 and A65) were cultivated. The onion plots in monoculture had 225 plants against 75 plants in intercropping. Monitoring in both seasons was carried out when onion plants were in the first-leaf fall to bulb maturity stage.

Determination of *Spodoptera frugiperda* incidence and pest abundance

Each plant in the sample plot was thoroughly examined. The number of larvae as well as the degree of damage was recorded only on onion plants. The degree of damage was determined solely on the attacked plants in each experimental plot, based on the lesions observed on onion leaves. A rating scale developed on maize by Davis et al. (1992) was adapted to the onion crop. According to Davis et al. (1992), the visual ratings of *S. frugiperda* damage can be done based on the number and size of lesions on the leaves.

One rating scale with six categories from zero to five was considered. 0: no visible leaf damage; 1: small lesions on leaf epidermis; 2: Small elongated (rectangular shaped) lesions (5) of up to 1.3 cm in length on leaf epidermis; 3: Several small to mid-sized 1.3 to 2.5 cm in length elongated lesions (5-10) on several leaves; 4: Several large elongated lesions (>10), greater than 2.5 cm in length present on several leaves; 5: leaves almost completely destroyed. For instance, a score of 1 and 2 is considered to be low, 3 and 4 moderate and 5 higher. The incidence was calculated in each experimental unit according to O'Neil et al. (1989).

Data analysis

The incidence and number of counted larvae in the onion crop were recorded and the T-Student test was applied at significance level of 5% to compare the means of two cropping systems (onion in monoculture and in intercropping with groundnut) when the data followed a normal distribution. Otherwise, the numbers of counted larvae were log-transformed and reanalyzed with T-Student test. The calculated incidence was arcsine square root transformed prior to T-Student test. Frequencies were determined for the severity of attack. These analyses were performed using the XLSTAT 2015 statistical software.

Results

Damage types of *Spodoptera frugiperda* in onion crops

Spodoptera frugiperda larvae were observed in onion in November 2019. The alternate hosts of *S. frugiperda* are not known in Africa and *S. frugiperda* in crops other than maize and sorghum was never previously reported since its invasion in 2016. Here is a basis for an initial study on the occurrence of *S. frugiperda* on onion crops. Illustrations of *S. frugiperda* damage and its presence on onion leaves are provided in Figure 1. Most infestations of *S. frugiperda* were detected at growing stages from the vegetative cycle to bulb maturity in the two seasons. Larvae identified were at the fifth and sixth instar (Fig.1B and 1D).

Spodoptera frugiperda larvae penetrated the tubular leaf and cut the onion leaf tissue in the apical-basal direction (Fig. 1C). The lesions which are observed (Fig. 1A) resulted in weakening of the leaf which eventually broke under the wind effect. Lesions were visible like those observed on maize leaves. Larval attacks in the onion fields were commenced after sufficient rainfall in the region throughout the 2019 cropping season (average monthly rainfall of 215 mm).

Incidence of Spodoptera frugiperda in onion crops

The trend of the results on the incidence of *S. frugiperda* in the onion crop indicated a low incidence either seasonally or by cropping system. The highest average incidence was 2.88%. The variation in incidence indicated that onion sown in monoculture was more infested than in intercropping in 2019 cropping season ($P = 0.013$; df = 46)

(Fig. 2). The 2020 cropping season highlighted the similar trend as for 2019 season ($P < 0.01$; df = 46). On the other hand, larval density did not vary significantly between the two cropping systems in the two seasons ($P > 0.05$; df = 46). The highest average remained 0.79 larvae per 9m² in the onion monoculture experimental plot during 2019 season (Fig. 3).

In both seasons, 50% of onion plots were damaged by *S. frugiperda*. In 2019, score 3 dominated in monoculture against score 1 in intercropping. While in 2020, score 1 dominated in monoculture and score 3 in intercropping. The score 4 was only reached on second year in monoculture for one plot. In general, scores 1 and 2 dominated in all onion plots infested by *S. frugiperda* (Fig. 4). The classification of the

Figure 1 *Spodoptera frugiperda* larvae occurring in the onion crop at the experimental site. A: lesions induced on onion leaf epidermis; B: sixth instar larvae found inside onion leaves; C: severity of damage and faecal pellets in whorl of the onion plant; D: fifth instar larva found on the onion plant.

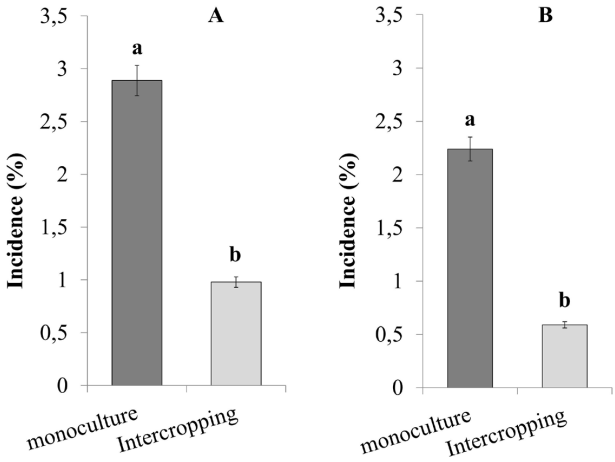

Figure 2 Mean (±S.E) incidence of *Spodoptera frugiperda* in onion as a function of season and cropping system. 24 plots were considered in each cropping system. A and B represents the incidence in 2019 and 2020 respectively.

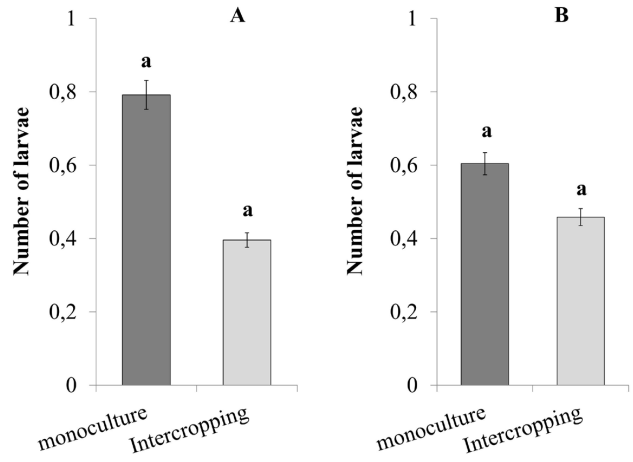

Figure 3 Mean (±S.E) larval density per plot of *Spodoptera frugiperda* as a function of season and cropping system. 24 plots were considered in each cropping system. A and B represents the larval density in 2019 and 2020 respectively.

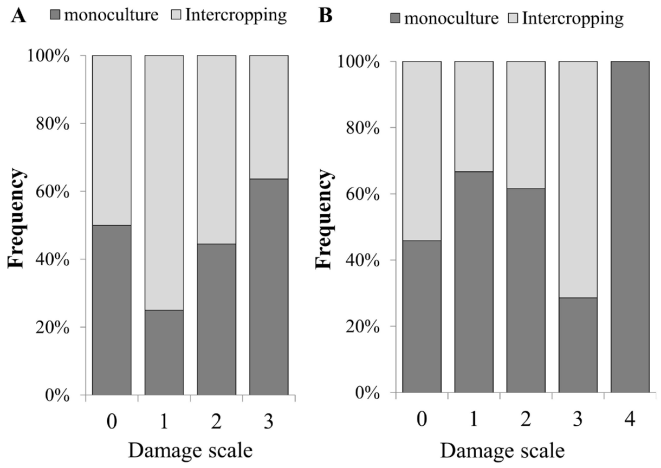

Figure 4 Rates of attack severity of *Spodoptera frugiperda* according the kind of onion crops. A and B: severity in 2019 and in 2020 respectively. 0: no visible leaf damage; 1: small lesions on leaf epidermis; 2: Small elongated (rectangular shaped) lesions (5) of up to 1.3 cm in length on leaf epidermis; 3: Several small to mid-sized 1.3 to 2.5 cm in length elongated lesions (5-10) on several leaves; 4: Several large elongated lesions (>10), greater than 2.5 cm in length present on several leaves; 5: leaves almost completely destroyed.

onion leaf damage rating scale indicated low *S. frugiperda* incidence in the study area.

Discussion

Spodoptera frugiperda is a polyphagous and voracious insect in its native range but also in invaded countries (Navasero et al., 2019). Since its invasion of the African continent, it was expected to be present in crops other than maize, as reported in America (Andrews, 1988; Casmuz et al., 2010; Montezano et al., 2018) and Asia (Srikanth et al., 2018; Shankar and Adachi, 2019). Its presence in the onion crop as demonstrated here represented low incidence (2.8%). In comparison with the literature, Fernandes et al. (2012) had determined an incidence of 5.8% also considered to be low. This was hypothesized to be due to the time of assessment that was performed at the initial stage of the crop. However, in this study, investigations carried out during the advanced stages of onion cultivation highlighted the similar trend.

One of the insect adaptive strategies is to be able to maintain their population year-round. Adults are responsible for selecting the host plant that will convey their forthcoming offspring (Mayhew, 1997; McGraw and Koppenhöfer, 2010). Polyphagous feeding behavior allows *S. frugiperda* to build up or maintain its population outside the primary growing season or outside growing areas, such as wild and cultivated grasses (Luginbill, 1928; Favetti et al., 2017). This is the same finding in the present study where the presence of *S. frugiperda* in the onion crop was observed when growing conditions in its preferred host became unsuitable, especially when rainfall was abundant (average monthly rainfall of 215 mm).

Recent studies on the distribution of *S. frugiperda* in South Kivu have demonstrated rainfall as a key factor in the abundance and occurrence of this pest (Cokola et al., 2020). According to Early et al. (2018) and Cokola (2019), rains cause significant larval mortality within the leaves of maize. To escape, *S. frugiperda* infests onion by first injuring the basal region of the leaves, making small scratches and then piercing and penetrating the tube sheet to hide (Fernandes et al., 2012). This behavior represents a coping strategy for *S. frugiperda*. Nevertheless, the fundamental question which would require much further investigation is related to which of *S. frugiperda* strains is able to infest onion. In the corresponding region, the existence of two strains has been reported from studies by Cokola (2019).

In this study, onions growing in a monoculture were more attacked by *S. frugiperda* than in intercropping with groundnut. Intercropping studies indicate that, compared to monoculture, insect pests in intercropping systems were less abundant than in monoculture (Risch, 1983; Andow, 1991; Sulvai et al., 2016). The cropping system, and more specifically intercropping, is discussed as an alternative for the control of arthropod pests of crops (Smith and McSorley, 2000). Some crops may have a repellent effect on herbivores. It is indicated that pests will be less able to find their hosts due to visual and olfactory interference with the plants used (Pitan and Filani, 2014). Others could create a favorable microclimate for the development of predators and parasitoids of the pest species (Liu et al., 2017; Amala and Shivalingaswamy, 2018). However, the extent of the benefits of intercropping depends on the choice of an appropriate companion crop (Harrison et al., 2019). Legumes are used in crop associations and particularly Desmodium because of its repellent effect against *S. frugiperda* in a push-pull technology (Midega et al., 2018; Hailu et al., 2018). The benefits associated with groundnut in reducing the incidence of *S. frugiperda* in onion crops should be investigated.

Conclusion

In conclusion, this study provides the first information on the occurrence of *S. frugiperda* in onion crops in Africa. Its presence in onion crops represents a significant piece of information in the development of an integrated management strategy for this pest in the future. Knowing onion as reservoirs of *S. frugiperda* individuals will allow setting up a trapping system in the vegetable crops of the region during the dry season, in order to limit infestations in the corn crop at the beginning of the growing season. Effective control practices against *S. frugiperda* will have to consider the presence of host plants in and around maize fields throughout the year. In perspective, genetic and genomic studies are required to further explain the biology of the insect and to know which of the two existing strains is infecting the onion or a new hybrid population of *S. frugiperda*.

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Conflicts of interest

The authors declare no conflicts of interest.

Author contribution statement

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by MCC and SSN. The first draft of the manuscript was written by MCC, SSN, EBB, LEA and FF, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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