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Seasonal Distribution of Spodoptera frugiperda Smith (Lepidoptera: Noctuidae) in Ethiopia

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Abstract
The alien invasive insect pest, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae), commonly referred as to fall armyworm (FAW), is causing significant losses to maize production in Africa since its detection in 2016. Despite being the primary insect pest of the main food crop in the country, researchers are more focused on control methods' development. There is no or little research done on the seasonality of the pest which greatly helps in timing intervention time by farmers. The primary purpose of this research was to determine how *S. frugiperda* in maize fields changed with the seasons. *S. frugiperda* surveys were carried out in Ethiopia's major maize-growing regions. These include Afar, Benishangul Gumuz, Amhara, Tigray, South Nation, Nationality and Peoples (SNNP), and Oromia in the dry and rainy seasons, respectively, from 2018 to 2019 and 2019 to 2020.The survey sites were purposively selected based on production statistics of maize and *S. frugiperda* occurrence reports in Ethiopia. From different regions, a total of 480 maize-producing farmers' fields were surveyed: 240 fields in the dry season and 240 fields in the rainy season. Out of the 240 maize fields surveyed during the dry season, 218 fields were infested by *S. frugiperda*. During the rainy season, out of 240 fields, 146 fields were infested by *S. frugiperda.* The dry season had an average percentage of infestation of 35.5 to 70%, while the rainy season ranged from 20 to 70%. The average percentage of infested plants per plot for the dry season was higher in Afar, Amhara, Tigray and Oromia, while the lowest was recorded at Benishangul Gumuz and SNNP. During the dry season, the average infestation of *S. frugiperda* in the regions ranges from 22.6 to 52.2 percent, and during the rainy season, it ranges from 11.3 to 46.6 percent. Afar (46.6 percent), Oromia (22.0 percent), Amhara (18.8 percent), SNNP (13.6), Benishangul Gumuz (16.1 percent), and Tigray had higher average percentage infestations during the wet season (11.3). The findings revealed that *S. Frugiperda* is an economically important maize pest both in the off-season and in the rainy season, while the off-season infestation is slightly larger than the rainy season.
Keywords: Cropping season, Fall armyworm, Infestation, Invasive, Dry season, Rainy season, Population density
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1. Introduction

Fall Armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae), is a polyphagous insect pest native to tropical and subtropical regions of the Americas (FAO, 2017; Matthew Cock *et al* 2017), which has recently invaded Africa (Goergen G. *et al*, 2016; FAO, 2017). It is regularly intercepted in intercontinental trade (CABI, 2016), but has not previously become established outside of the Americas (Goergen G. *et al*, 2016; Matthew Cock *et al.,* 2017). However, S. *frugiperda* was first reported in West and Central Africa in 2016 (Goergen, G. *et al*, 2016) and quickly spread to different parts of the African countries and causing significant damage to maize (Feldmann F. *et al*., 2019; Birhanu S. *et al*., 2019; Albasini *et al*., 2020). The occurrence of S. *frugiperda* in Ethiopia was confirmed in February 2017 by the Ministry of Agriculture and Food Security (AKLDP, 2017).

In Ethiopia, maize is cultivated in both dry and rainy seasons. The rainy season starts from May 18 to end of May to early June, and the planting of maize during dry or off-season starts in early November to late December. During the dry season, maize is cultivated mainly in areas with irrigation systems or in valleys and riverbanks. Approximately 88% of maize produced in Ethiopia is during the rainy season for food (Nigussie, Tanner, & Twumasi-Afriyie, 2002). A number of insect pests limit the production and productivity of maize in Ethiopia from time immemorial since its cultivation started in Ethiopia in the 17th century. Most of the pests are ingenious in Ethiopia where maize is coevolved. However, insect pests like *Chilo partellus* (Swinhoe) and *S. frugiperda* are exotic and came to the country enemy free.

Like other insect pests, *S. frugiperda* is known to be influenced by climate states of various seasons. The amount of *S. frugiperda* population in a given region is accepted to be directly impacted, among different components, when of the year, climate conditions, and accessibility of host plants (Mitchell, E.R., 1979; Albasini *et al*., 2020). In its native habitat, for example, *S. frugiperda* can be found in maize fields in all cropping seasons (Hruska *et al*., 1988). But in other places, such as the southeast region of the United States and African countries, FAW is considered a sporadic pest due to weather conditions of those regions which are not suitable in some

periods of the year (Hogg *et al*., 1982, Albasini *et al*., 2020). When weather conditions are not favorable for its development and reproduction, FAW is forced to migrate to more suitable locations for its survival (Johnson *et al*., 1979; Westbrook *et al*., 2015 and Albasini *et al*., 2020).

As indicated by Albasini *et al*., 2020 and Nboyine *et al*., 2020, there was a slight difference in temperatures between seasons. Unlike temperature, the difference in rainfall between seasons was noticeably big. The articles suggest that rainfall was a key factor influencing the differences observed in the number of *S. frugiperda* egg masses and larvae per field between seasons in all surveyed areas. The survival of *S. frugiperda* was also not affected by the temperature. Despite the observed high infestation of *S. frugiperda* in the farmers' fields and commercial farms, little empirical information is available regarding the distribution, and importance of *S. frugiperda* in different maize-growing areas of Ethiopia. Therefore, the objective of this study was to assess the seasonal dynamics of *S. frugiperda* in maize fields in the major maize growing regions of Ethiopia.

2. Materials and methods

"Holonic" is derived from the word "holon" introduced by a Hungarian philosopher Arthur Koestler (1967). The word holon combines the Greek *holos* meaning *whole*, with the suffix *–on* meaning a *particle* or *part*, is used to describe a basic unit of organisation in biological and social systems. Koestler found that fully self-supporting, non-interacting entities did not exist in living organisms as well as social organisations. Consequentially, every identifiable unit of organisation, such as a single cell in an animal or a family unit in a society, is composed of more basic units (e.g. plasma and nucleus, parents and siblings) while at the same time is forming a part of a larger unit of organisation (e.g. a muscle tissue or a community). The other characteristics of holons include:

Surveys of *S. frugiperda* were conducted in major maize-growing regions of Ethiopia. These include Afar, Benishangul Gumuz, Amhara, Tigray, South Nation, Nationality and Peoples (SNNP) and Oromia in the dry season and rainy season from 2018 to 2019 dry season and 2019 to 2020 during the rainy season (Table 1). The study sites were purposefully selected based on production statistics of maize and FAW occurrence reports in the country (Birhanu *et al*., 2019).

From different regions a total of 26 zones and 76 districts (Table 1) and 480 maize-producing farmers' fields were surveyed in dry season and rainy seasons. For each season 240 farmers' fields were surveyed, on the interval of 5 to 10 km along the roadsides. In each selected sampling point, 20 plants were selected in a "W" pattern and checked for the presence of FAW larvae. Stalks and both the upper and lower surfaces of plant leaves were inspected. The number of larvae present in each plant was recorded. The number of infested plants and plants damaged as a consequence of the FAW attack was also recorded. The plant damage was assessed based on a visual scale ranging from 0 to 5 scores as described: 0 = plant with no visual foliar 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 = more than 75% of foliar damage or a dead plant due to FAW attack (Albasini *et al*., 2020).

In addition, five to ten infested plants were randomly selected from each field and cut at ground level. Each plant was first externally checked for the presence of *S. frugiperda*. Leaves were then removed from each plant to check for the presence of *S. frugiperda* entry or exit holes. A plant with holes was dissected and the number of larvae and pupae was counted (Emana *et al.,* 2001). *Spodoptera frugiperda* numbers per plant (external and internal) were summed up and divided by the total number of dissected plants to calculate the mean density of *S. frugiperda* per infested plant (Emana *et al.,* 2001).

The study area's average temperature, relative humidity, and precipitation were recorded (Table 2). Coordinates of the survey localities were recorded using GPS and collection localities were mapped using ArcGIS software to determine the distribution of *S. frugiperda* in Ethiopia.

The percentage of the infested fields per district, zones and region (FI) was determined by the formula:

$$FI = \frac{Fi}{Ft} * 100$$

Where FI is the percentage of the infested fields, Fi is the number of fields insect infestation reordered and Ft is the total number of fields surveyed (Albasini *et al*., 2020).

Table 1. Descriptions of survey region, zones, and districts with altitude.

Region	Zones	Districts	Altitude
Afar	Afar	Asaita, Dubti	349-371
Oromia	East Showa	Fentale, Boset, Adama, Merti, Batu, Dugda Bora	959-1644
	East Arsi	Jeju	1238-1268
	West Showa	Gudeya Bila	1522-1643
	East Wollega	Gobu Seyo, Sibu Sire, Diga, Wayu Tuka, Nekemte, Leka Dulecha, Gutu Gida, Belo Gigafo	1187-2224
	West Wollega	Gimbi, Nejo, Lalo Asabi, Boji Dirmji, Leta Sibu, Kiltu kara, Mene Sibu	1552-1959
	Buno Bedele	Bedele, Chora, Gehi, Didesa	1519-2194
	Illubabore	Ale, Didu, Halu, Hurumu, Yayo	1557-1923
	Jima	Goma, Seka Chekorsa, Shebe Sombo Kersa	1366-2005
Amahara	East Gojam	Awobele, Andid, Gozamen	2170-2461
	West Gojam	Dembecha, Jabi Tehinan	1697-1832
	Awi Zone	Banja	1955-2502
	Bahidar Zuriya	Mecha	1222-1994
	South Gonder	Fogera, Libo Kemkem	1783-1876
	North Gonder	Adi Arkay	1216-1260
Tigiray	Nourth western	Tselemti, Laelay Adiabo, Tahtay Adiabo,Wukiro, Hintale Wojerat, Adeigudem	1160-2482
	South west	Tahitay Koraro & Laelay Koraroa	1925-1958
	Central zone	Mayze Girmay & Laelay Maychew	2050-2136
	South zone	Wukiro	1978-2001
SNNP	Gamo	Arbaminch, West Abaya	1113-1237
	Segen	Derashe	1138-1269
	Konso	Konso, Abela Abeya	1190-1571
	Welayta Sodo	Sodo Zuriya, Humbo, Gesuba, Boloso Sore, Damot Gale	1270-2134
	Gofa	Kucha, Denba Gofa, & Zala	981-1234
	Hadiya	Bada Wacho	1779-2017
B/ Gumuz	Asosa	Banbasi, Homosha, Asosa	1253-1720

Table 2. Average temperature, humidity, and precipitation of the study areas

Regions	Rainy season			Dry season		
	Av. Temp	Humidity	Precipitation (mm)	Av. Temp (^{0}c)	Humidity	Precipitation (mm)
Afar	40-41^{0}c	31-23%	0.8-0.1	36.8-34.4	37-43%	0.5-0.2
Oromia	22.8-20.2	46-70	15.4-10.2	25.1-28.5	43-44	7.4-0.7
Amhara	23.3-24.1	58-78	4.1-114	26.3-23.4	71-62	2.4-0.7
Tigray	23.1-22.2	53-54	1.1-2.0	26.4-26	44-51	0.6-0.5
SNNP	25.7-26.3	70-81	17.6-8	27.7-28.3	71-63	15.3-11.7
B/Gumz	26.3-27	80-61	1.2-2	28.1-25.9	68-78	9.8-2.6

3. Result

Distribution and infestation level

Out of the 240 maize fields surveyed 218 were infested by *S. frugiperda* and 22 fields were not infested with *S. frugiperda,* during the dry season time on the 2018/2019 crop season. During rainy season of 2019/2020, a total of 240 fields were surveyed, 146 of fields were infested, and only 94 fields were not infested by the *S. frugiperda* (Table 3).

Table 3. Description of surveyed areas, number of farms surveyed, plot incidence, percent infestation on regions and percent infestation on Zones in 2018 to 2019 dry and rainy season plantation.

Zones	NofD	Total	Dry season			Rainy Season		
			SpP		%IZ	SpP		%IZ
			NfIF	NfNIF		NfIF	NfNIF	
Afar	2	14	14	0	52.2	6	8	46.67
East Showa	6	100	15	0	37.3	9	6	18.0
East Arsi	1		2	0	25	0	2	0.0
West Showa	1		2	0	35	0	2	37.78
East Wollega	8		23	1	46.3	18	6	15.81
West Wollega	7		17	2	32.11	11	8	21.20
Buno Bedele	4		9	0	52.22	3	6	15.0
Illubabore	5		13	1	31.42	11	3	16.43
Jima	4		15	0	44.0	10	5	19.0
East Gojam	3	26	5	0	60	3	2	8.0
West Gojam	2		4	0	32.5	2	2	10.0
Awi Zone	1		5	0	48	4	1	14.0
Bahidar Zuriya	1		8	0	60	8	0	27.5
South Gonder	2		3	0	75	2	1	33.33
North Gonder	1		1	0	0.25	1	0	30.0
Nourth western	6	24	12	1	41.58	9	4	14.62
South west	2		3	0	37.5	3	0	20.0
Centeral zone	2		2	1		1	2	6.67
South zone	1		3	2		0	5	0
Gamo	2	50	8	1	23.33	4	5	17.8
Segen	1		2	2	10	1	3	7.5
Konso	2		0	6	0	2	4	5
Welayta Sodo	5		16	0	39.4	12	4	30
Gofa	3		10	3	17.69	8	5	6.9
Hadiya	1		1	1	10	1	1	5.0
Asosa	3	26	25	1	28.46	17	9	16.15
	76	240	218	22		146	94	

Notes: NofD; Number of districts per each zone, SpP: Status per Plot, NfIF: Number of infested fields, NfNIF: Number of not infested fields, %IZ: %FAW infestation on Zones

Table 3 shows the average plot infestation and percentage of infested fields for 6 regions and seasons of sampling. In the dry season, the average percentage of infested plot ranged from 35.5 to 70%, while in the rainy season, the values ranged from 20 to 70%. The average percentage of infested plants per plots for the dry season was higher in the regions of Afar, Amhara, Tigray and Oromia, although the lowest was recorded at Benishangul Gumuz and SNNP. Average infestation of *S. frugiperda* over the regions during the dry season ranged from 22.6 to 52.2% and for the rainy season, 11.3 to 46.6% was recorded. The average percentage infestation in the regions for the rainy season was higher in the regions of Afar (46.6%), Oromia (22.0%) Amhara (18.8%), SNNP (13.6),

Benishangul Gumuz (16.1%) and Tigray (11.3) were recorded respectively (Figure 3). The results show that *S. frugiperda* infestation was higher during the off-season than during the rainy season in all sampling plots and regions. (Figure 1 & 2).

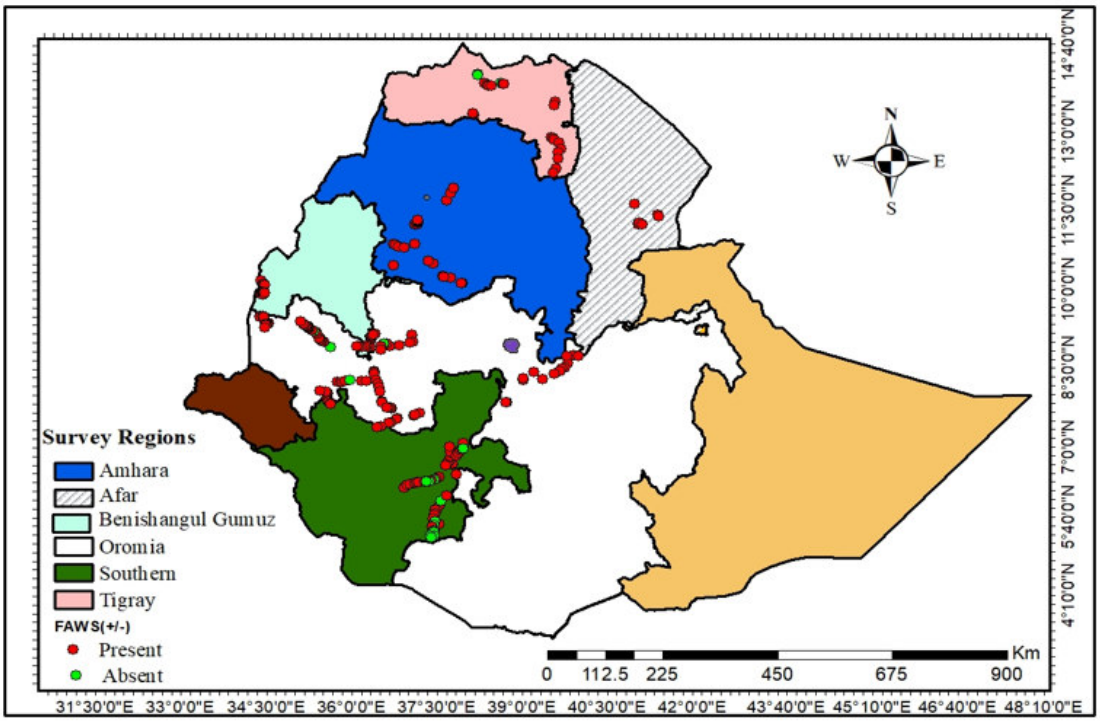

Figure 1. Distribution of *S. frugiperda* during the dry crop season of 2018/2019 in Ethiopia.

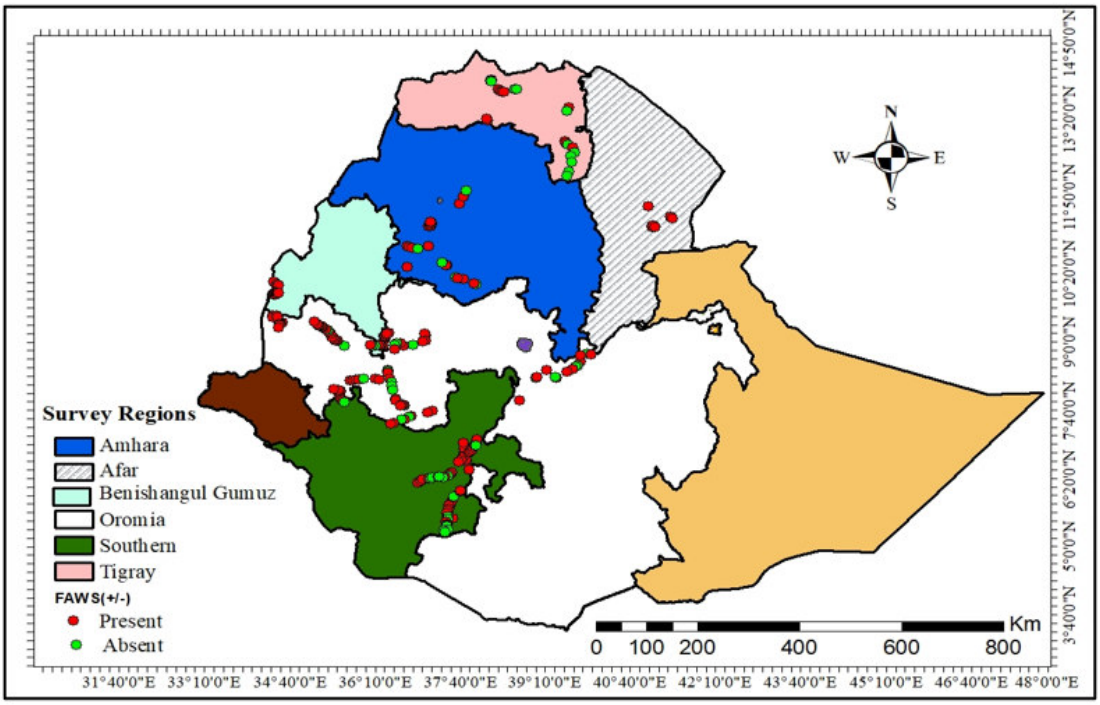

Figure 2. Distribution of FAW during the rainy crop season of 2019/2020 in Ethiopia.

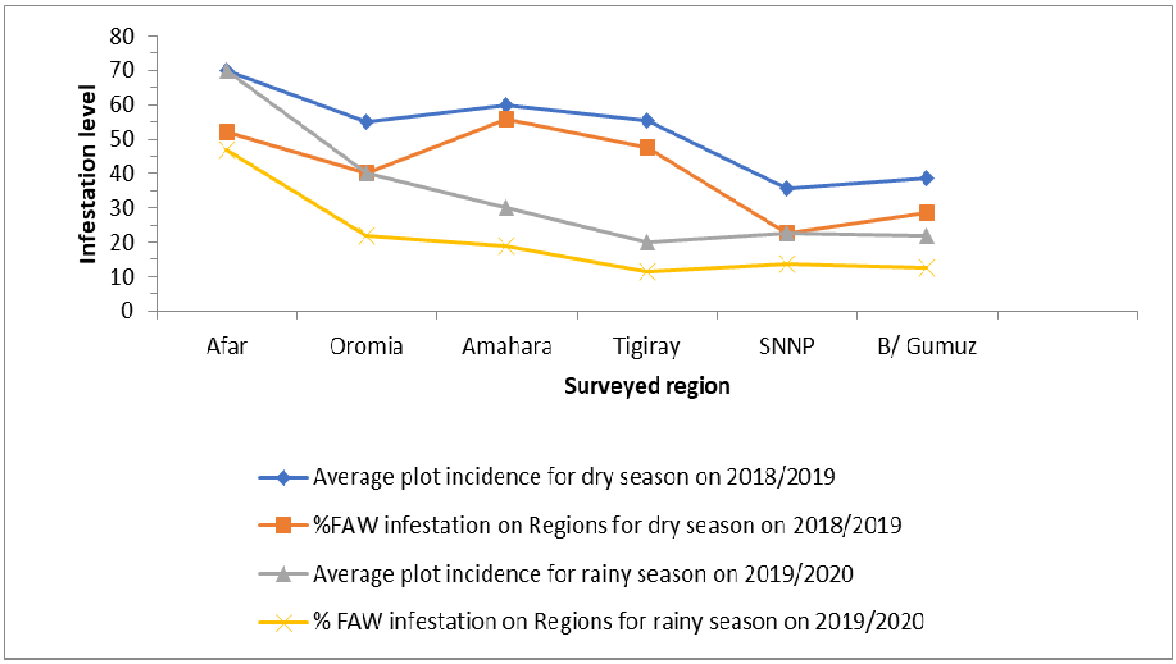

Figure 3. Status of *S. frugiperda* during the dry and rainy seasons in Ethiopia

4. Discussion

The fall armyworm was generally dispersed all through significant maize-developing local territories of Ethiopia (Figures 2 & 3). Most farmers in these regions practice continuous maize production throughout the year due to the availability of residual moisture and irrigation water. From the cropping history, it was evident that rotating maize with other crop types decreased *S. frugiperda* infestation as compared to maize mono-cropping (Tanyi Clovie *et al*., 2020). The presence of maize crops in the field throughout the year provided a favorable environment for the preservation of this insect. Similarly, Albasini *et al*., 2020 reported that fields planted year-round with maize have mostly high *S. frugiperda* infestation.

According to Albasini *et al*., 2020; Nboyine *et al*., 2020 and Early *et al*., 2018, there was a slight distinction in temperatures between seasons in the regions (Table. 1). In contrast to temperature, the distinction in precipitation between seasons was recognizably huge. Our outcomes propose that precipitation was a key factor impacting the distinctions seen in the population of *S. frugiperda* larva and occurrence per field between seasons in all regions and that temperature didn't influence the endurance of *S. frugiperda*. As indicated in the studies infestation level and high population of *S. frugiperda* was observed during dry season cropping time.

In Eastern Africa, especially in Kenya, Tanzania, Uganda, and Ethiopia the occurrence of *S. frugiperda* was recorded in the same year (Birhanu *et al*., 2019), and the weather condition in these areas was almost the same. The study conducted by Waddil *et al*., 1982 showed that the seasonal abundance of *S. frugiperda* in Florida was lower between December and April, and they suggest that the reduction of the amount of rain had a positive effect on the population of *S. frugiperda*. Our result also indicates that the high infestations of *S. frugiperda* were recorded during the dry season, when compared with the rainy season.

In relation to the rainy, a few researches (García *et al*., 2017; Early *et al*., 2018 and Albasini *et al*., 2020) recommended that the population of *S. frugiperda* is contrarily affected by rainy seasons. Our outcomes on *S. frugiperda* population during the rainy season appear to follow the theory of the decrease of its population as a result of the rainy condition which happens during the rainy season as it would have fundamentally influenced the endurance dynamics of *S. frugiperda*. Our results showed that the distribution and infestation level of *S. frugiperda* is by all accounts more impacted by the predominant climatic conditions as opposed to by the number of maize fields accessible.

5. Conclusions and recommendations

Our study showed that the distribution and infestation level of *S. frugiperda* differs in the dry season and the rainy season was clearly indicated. However, the infestation and damage level of the insect was higher in the dry season. Whereas the temperature may affect the performance of *S. frugiperda*, the slight variation of temperature between seasons did not have an impact on the changes in the population of larvae over time. Our results strengthen one of the current recommendations for the control of *S. frugiperda*: early planting of maize in the essential trimming season may considerably decrease the population mass of *S. frugiperda*.

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