ESJ Natural/Life/Medical Sciences

Effectiveness of Neem Oil and Jatropha Oil in Controlling *Spodoptera frugiperda* (J.E Smith) on Maize in the Republic of Chad

Mbaidiro Taambaijim'd Josue
Institut Tchadien de Recherche Agronomique pour le Développement, ITRAD, N'Djamena, Tchad. Université de Parakou, École Doctorale des Sciences Agronomiques et de l'Eau, Parakou, République du Bénin. Faculté d'Agronomie. Laboratoire de Phytotechnie, d'Amélioration et de Protection des Plantes (LaPAPP) ; Université de Parakou, République du Bénin
Onzo Alexis
Université de Parakou, École Doctorale des Sciences Agronomiques et de l'Eau, Parakou, République du Bénin. Faculté d'Agronomie. Laboratoire de Phytotechnie, d'Amélioration et de Protection des Plantes (LaPAPP) ; Université de Parakou, République du Bénin

Doi:10.19044/esj.2022.v18n30p223

Submitted: 10 March 2022
Accepted: 07 September 2022
Published: 30 September 2022

Cite As:
Mbaidiro T.J. & Onzo A. (2022). *Effectiveness of Neem Oil and Jatropha Oil in Controlling Spodoptera frugiperda (J.E Smith) on Maize in the Republic of Chad*. European Scientific Journal, ESJ, 18 (30), 223. https://doi.org/10.19044/esj.2022.v18n30p223

Abstract

Upon the evidence of its invasion in Chad in 2018, *Spodoptera frugiperda* has become a serious threat to maize production, thereby prompting farmers to a massive use of chemical pesticides to reduce its damage. However, given the adverse negative effects of chemical pesticides on human health and the environment, alternatives to chemical control are highly sought. In that respect, the effectiveness of Neem oil and Jatropha oil, two bio pesticides widely acknowledged for their insecticidal properties, was evaluated in the field in comparison with the chemical insecticide, Emamectin benzoate, in a Fisher Blocks design with 4 treatments and 4 replicates. The mean larval density per 25 plants was significantly the lowest ($P < 0.0001$) on Emamectin benzoate-treated plants(1.13 ± 0.70), followed by Jatropha oil (6.13 ± 0.87) and Neem oil treatments (7.13 ± 0.80) while the highest density

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

was recorded on the untreated plants (12.31 ± 0.87). Similarly, the infestation rates were significantly lower on plots that received the chemical insecticide or the bio pesticides compared to the control plots (P < 0.0001). Foliar and ear damage scores were also significantly lower on the treated than on the control plots (P < 0.0001); and the number of ears attacked was significantly higher on the untreated control than on the other treatments. Maize grain yields were significantly higher in the treated plots compared to the control plots (P < 0.001). Yield gains over the control were 132.57%, 90.91% and 72.73% respectively for Emamectin benzoate, Jatropha oil and Neem oil treatments. It appears, therefore, that the use of Jatropha oil or Neem oil could significantly contribute to an effective and sustainable management of *S. frugiperda* on maize in Chad, thereby calling for the need for further investigations in that area in the frame of integrated pest management of this pest..

Keywords: Fall armyworm, *Zea mays*, *Azadirachta indica*, *Jatropha curcas*, biopesticides, sustainable pest management

Introduction

The Fall Armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), is a polyphagous pest native to tropical and subtropical regions of the Americas that attacks more than 80 plant species including maize, sorghum, sugar cane and some vegetable crops (Rwomushana *et al*., 2018). Its presence has been confirmed in 44 African countries, with maize as its main host-plant in Sub-Saharan Africa (Prasanna *et al*., 2018). In the Republic of Chad (Central Africa), its presence was confirmed in 2018 following its devastating impact, mainly on maize, throughout the majority of the provinces (FAO, 2018). This field infestation by *S. frugiperda* threatens food security in Chad, as it does in many other African countries, given its high potential for dispersal (Kansiime *et al*., 2019). As it generally happens at the discovery of an invasive agricultural pest, the first control strategy used by farmers was massive applications of chemical insecticides (Cook *et al*., 2004; Agboyi *et al*., 2019). However, the indiscriminate use of these chemical insecticides often leads to negative effects such as induction of pest resistance, elimination of natural enemies and the presence of toxic substances (residues) in food, water, air and soil; which can affect human health and pollute the environment (Kishi, 2005; Williamson *et al*., 2008). It, therefore, urges to find alternatives to chemical control, at least as a key component of an integrated control strategy against FAW (FAO, 2018).

To this end, botanical extracts have long been proposed as alternatives to synthetic pesticides in pest management because of their low cost that make them economically affordable; they are ecofriendly since they are biodegradable and generally target-specific (Sisay *et al*., 2019). Moreover, botanical extracts are essentially nontoxic and non-pathogenic to animals and humans (Miresmailli and Isman, 2014; Stevenson *et al*., 2017). Therefore, the use of plant-based pesticides has become a major asset in plant protection that has shown its effectiveness in the management of diverse crop pests (Bateman *et al*., 2018; Sisay *et al*., 2019). In that respect, many plant species have shown insecticidal properties against FAW in several parts of the world. Such plant species include, among others, *Azadirachta indica* (Silva *et al*., 2015; Stevenson *et al*., 2017; Sisay *et al*., 2019), *Jatropha curcas* L (Sisay *et al*., 2019), *Melia azedarach* L (Santos *et al*., 2008; Bullangpoti *et al*., 2012). More specifically in the Republic of Chad, there is a wide range of opportunities linked to plant diversity that would be worth testing and promoting within the framework of alternative methods for controlling crop pests. As example, Neem (*A. indica*) and Jatropha (*J. curcas*) are plant species available in Chad; however, no studies have been conducted to evaluate their potentials against FAW. The objective of the present study was, therefore, to evaluate the effectiveness of Neem oil and Jatropha oil in controlling *S. frugiperda*, in comparison with Emamectin of benzoate, a chemical insecticide widely acknowledged as effective against the pest (Deshmukh *et al*., 2020), and commonly used by maize growers.

1. Materials and methods

1.1. Study site

The study was carried out at the Agronomic Research Station of Bébédjia (8° 40' 34’ N; 16° 33’58’E; 397 m of altitude). This station is located in the Southern part of Chad, at c.a. 524 km south of N’Djamena the capital city. It prevails in this area a Sudanian tropical climate characterized by the alternation of a rainy season (4 to 5 months) which extends from April to October and a dry season (7 to 8 months) which runs from November to March. The average annual rainfall ranged between 600 mm and 1200 mm. During the study period, the average monthly rainfall collected was 81.78 mm and the average temperature varied between 23.62°C and 35.07°C with the minimum in August and the maximum in October. Relative humidity during the study period varied between 79 % and 86% with an average of 82 ± 1.64 %.

1.2. Study materials

Spodoptera frugiperda was the study insect, whereas the maize variety 'TZEEW' known as susceptible to FAW in Chad (Mbaidiro *et al*., 2021) constituted the plant material.

The pesticides tested included:

- Neem oil, a bio-pesticide applied at the dose of 1.4L/ha (Kammo *et al*., 2019);
- Jatropha oil, a bio-pesticide applied at the dose of 1.25 L/ha (Abdoul Habou *et al*., 2013); and
- Emacot 19 EC (Emamectin benzoate 19 g/L), a chemical insecticide, applied at the dose of 0.6 L/ha (manufacturer's recommendation).

1.3. Experimental setup

The experimental plots were tilled to a 15-20 cm-depth, and harrowed to prepare the seedbed. Maize was sown on July 12, 2021 at the rate of 3 seeds per seed hole with a spacing of 0.60 m x 0.40 m, after a rainy day of at least 20 mm rainfall. A first weeding was carried out 14 days after plant emergence and a second occurred 21 days after the first. The chemical fertilizer N, P, K (20-10-10) for cereals was applied as the basal dressing fertilizer, at the dose of 150 kg/ha. It was buried in furrows, dug at 10 cm from the seed line. Urea was applied as a cover fertilizer in two sets at the dose of 25 kg/ha, when maize plants have developed the 10^{th} leaf and at tasseling, respectively.

The experiments were set up following a randomized complete block design (RCBD), with 4 treatments and 4 replicates. Each block contained four elementary plots (totaling 16 plots), separated from each other by a 1.5 m-buffer while a 2 m-buffer separated the blocks. Each elementary plot was 7 m long and 5 m wide and had 13 rows of seedlings. The treatments were as follows: T1- Untreated maize plots (control); T2 - Maize plots treated with Neem oil; T3- Maize plots treated with Jatropha oil, and T4 - Maize plots treated with Emacot (Emamectin benzoate). All the pesticides (chemical and plant extracts) were applied four times at 7-day intervals, from Day 33 to Day 54 after sowing, using a knapsack sprayer. After each application, care was taken to properly wash the sprayer before shifting from one product to another to avoid any contamination, thereby preventing bias in the results.

2. Data collection

2.1. Effect of treatments on the population dynamics of *S. frugiperda*

To evaluate infestation rates and population densities of FAW larvae on each elementary plot, 25 maize plants were randomly selected from the five central rows of each plot. A total of 100 plants were, therefore, sampled per treatment. Samplings were made every 7 days from the 33^{rd} day after sowing until the 54^{th} day after sowing, just before spraying the plot with the corresponding insecticide. On each sampling day and per elementary plot, the number of FAW-infested plants (i.e. maize plants showing any symptoms of FAW attack), were determined. In addition, the number of FAW larvae encountered on the selected plants were also counted. Data collected included the mean densities of FAW-larvae as well as the infestation rate of each plot.

The infestation rate was calculated as the ratio between the number of infested plants (i.e., harboring the pest) and the total number of plants sampled.

2.2. Effect of treatments on leaf damage caused by *S. frugiperda*

To evaluate damage caused by the feeding activities of FAW larvae, sampling was carried out on 25 maize plants randomly selected from each elementary plot. To achieve this, 5 plants were observed on each of the 5 central rows of each elementary plot. On each sampling day, the number of maize plants bearing freshly consumed leaves and/or with dead hearts was determined. The extent of the pest damage to maize stalks, and/or leaves was also recorded. Damage level was scored following a scale of 0 to 4, modified from the 0 to 9 scale developed by Davis *et al.* (1992). Damage levels were then ranked as follows: 0 = zero damage; 1 = 1% to 25% damaged; 2 = 25% to 50% damaged; 3 = 50% to 75% damaged; and 4 = dead hearts (75% to 100%); This scale is the one generally used for research purposes by researchers, including for testing the efficacy of phytosanitary treatments (Toepfer *et al.*, 2021).

2.3. Effect of treatments on cob damage by *S. frugiperda*

The extent of cob damage was assessed using the 0-9 scale from CYMMIT (2020), unpublished protocol (Table 1; Figure 1). Sampling was carried out on 25 plants randomly selected from the five central rows of each elementary plot. The number of cobs attacked and the overall cobs damage index were determined and recorded per elementary plot. It has indeed been shown from recent studies that the invasive *S. frugiperda* exhibited a clear competitive advantage over other resident stemborers within maize cropping systems, thereby quickly excluding the latter through several mechanisms including intraguild predation (Mutua *et al*., 2022). Therefore, where *S. frugiperda* is present, damages can almost exclusively be attributed to hat invasive pest

Table 1. Scale of damage of *S. frugiperda* to maize cobs
(Source: CYMMIT 2020, unpublished protocol)

Score	Damage symptoms / description
1	No damage caused to the cob
2	Damage on a few grains (<5), or less than 5% damage on a cob
3	Damage on a few grains (6 to 15), or less than 10% damage on a cob
4	Damage on 16 to 30 grains, or less than 15% damage on a cob
5	Damage on 31 to 50 grains, or less than 25% damage on a cob
6	Damage on 51 to 75 grains, or more than 35% but less than 50% damage on a cob
7	Damage on 76 to 100 grains, or more than 50% but less than 60% damage on a cob
8	Damage on> 100 grains, or more than 60% but less than 100% damage on a cob
9	Almost 100% damage to a cob

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

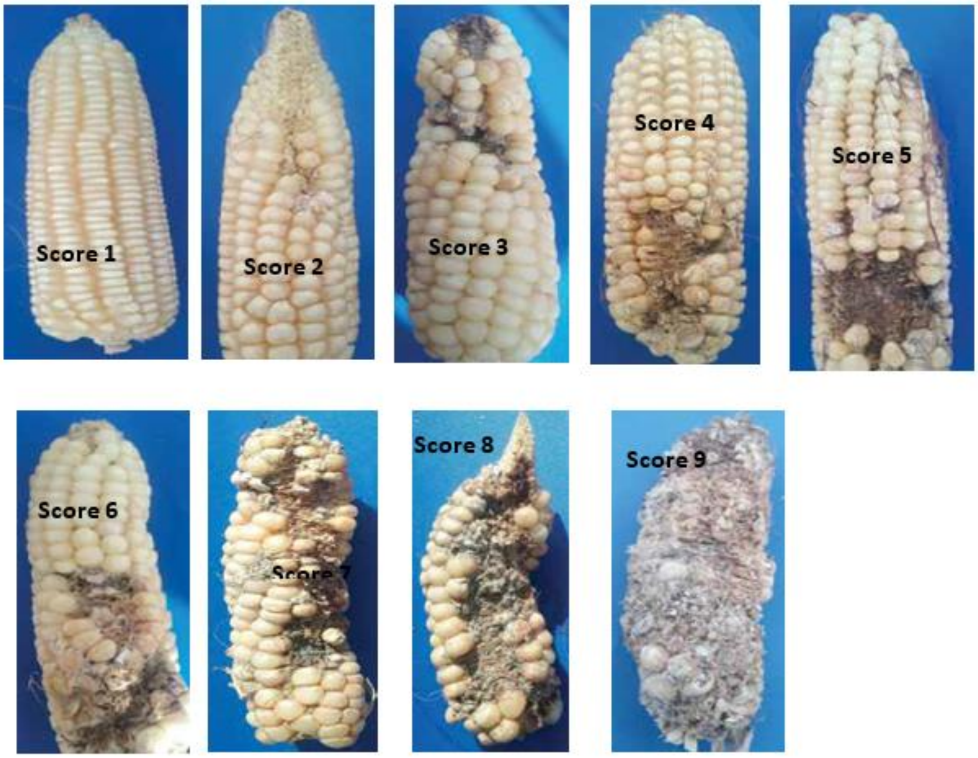

Figure 1. Scale of maize cob damage by *S. frugiperda*

2.4. Effect of treatments on maize yield

At maturity, the grain yield was determined per elementary plot. For that, all maize ears from the five central rows of each elementary plot were harvested, and dried after removing the husk. Cobs were then manually shelled and maize grains dried and weighed using a Steinberg brand electronic balance (300 kg; int. Precision 50 g). The yield obtained from this 21 m^2 area (i.e. the harvested plot size), was thereafter converted per hectare for clarity and to ease comparisons. The rate of yield increase accrued from each pesticide treatment as compared to the untreated control was calculated as follows:

$$YR\ (\%) = (YT-YC) \times 100/YC;$$

where:

- YT: grain yield obtained with a specific pesticide treatment;
- YC: grain yield obtained in the untreated control plot;
- YR: the rate of yield increase.

3. Statistical analyses

Data were compared among treatments to determine the effect of each one on the population size of FAW, and their damage on maize plants and

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

yield. Comparisons were made using a one-way analysis of variance (ANOVA). For that, all the data were subjected to the Shapiro - Wilk test for normality (Shapiro and Wilk, 1965), and the Levene test for homogeneity of variances before being used in the statistical analysis. To correct for homogeneity of the variances, data on FAW counts were transformed using log10(x+1), whereas data on proportions were transformed using Arcsine√ (X / 100), before their use in the statistical analyses. When ANOVA revealed significant differences among treatments, means were separated using the Student-Newman-Keuls (SNK) multiple range test. All data analyses were performed using XLSTAT Software, Version 2016.02.27444.

4. Results

4.1. Effect of treatments on the population dynamics of *S. frugiperda*

The temporal trend of *S. frugiperda* densities per 25 maize plants (Table 2), showed high densities of FAW larvae on the 33rd day after sowing (33rd DAS) in all the four treatments. These densities gradually decreased from the 40th DAS to reach their lowest levels at the 54th DAS corresponding to the last sampling day. Mean population densities of *S. frugiperda* larvae ranged from 1.13 ± 0.28 to 12.31 ± 1.36 caterpillars on 25 plants. The analysis of variance revealed a significant influence of treatments on the population density of *S. frugiperda* larvae (df = 3, F = 27.40, P = 0.0001). The Emamectin benzoate (Emacot) treatment harbored the lowest density of larvae per 25 plants (1.13 ± 0.28), followed by the Jatropha oil and Neem oil treatments, with statistically similar densities (Table 2). The highest larval densities were observed on the untreated control, with 12.31 ± 1.36 caterpillars on 25 plants.

Table 2. Mean densities (± SE) of *S. frugiperda* caterpillars on 25 plants in each in treatment

Treatment	33 DAS	40 DAS	47 DAS	54 DAS	Overall mean
Control	15.75 ± 3.11 a	12.00 ± 3.55 a	11.25 ± 2.29 a	10.25 ± 1.93 a	12.31 ± 1.36 a
Neem oil	9.75 ± 1.54 a	8.50 ± 0.65 ab	6.00 ± 0.40 b	4.25 ± 0.85 b	7.13 ± 0.70 b
Jatropha oil	9.25 ± 1.03 a	6.50 ± 2.06 ab	4.25 ± 1.31 bc	4.50 ± 0.64 b	6.13 ± 0.80 b
Emamectin benzoate	2.00 ± 0.71 b	1.50 ± 0.64 b	0.75 ± 0.25 c	0.25 ± 0.25 c	1.13 ± 0.28 c
df	3	3	3	3	3
F	9.26	4.33	10.65	10.72	27.40
Pr > F	0.002	0.027	0.001	0.0001	0.0001

In a column, the means followed by the same letter are not statistically different (SNK test).

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

4.2. Effect of treatments on the infestation of maize plants by *S. frugiperda*

The temporal trend of the infestation of maize plants by FAW on the different treatments (Figure 2) showed that the infestation rate was the highest in all the treatments at the 33rd DAS. It, thereafter, decreased to reach its lowest level over all the treatments on the 54th DAS, corresponding to the last sampling day. On average, the infestation rate varied from 0.50 ± 0.28% to 50.75 ± 4.80%. The ANOVA revealed a significant influence of the treatments on the infestation rate (df = 3, F = 18.63, P < 0.0001). Over the entire experimental period, the untreated control showed the highest average rate of infestation (29.44 ± 4.12%), while the lowest rate was recorded with Emacot (3.25 ± 0.84%). In the plots treated with Jatropha oil (13.00 ± 8.54%) or Neem oil (14.06 ± 10.33%), infestation rates were moderate and statistically similar (Figure 2).

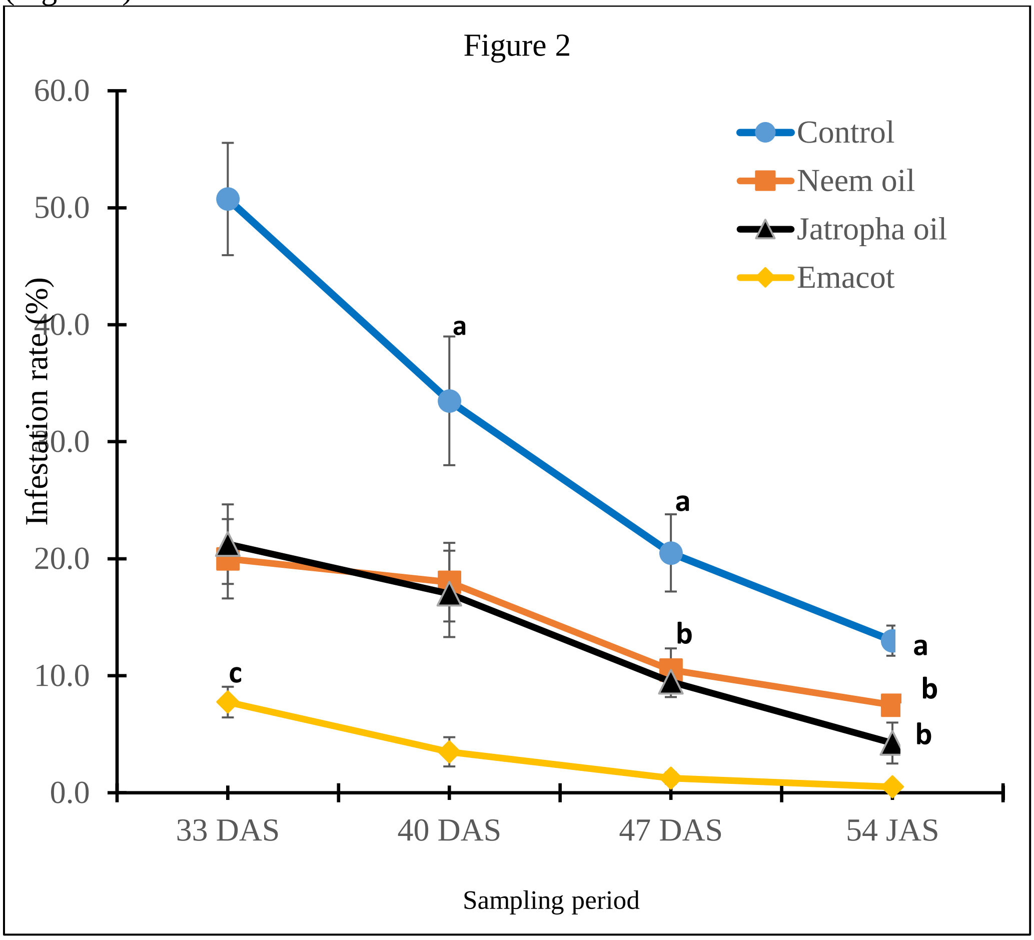

Figure 2. Infestation rate by *S. frugiperda* on the different treatments

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

4.3. Effect of treatments on leaf damage *by S. frugiperda*

In all the treatments, the leaf damage index was high at the 33rd DAS and declined gradually to reach its lowest value at the 54th DAS, corresponding to the last assessment (Figure 3). Mean leaf damage level scores ranged from 0.50 ± 0.28 to 3.25 ± 0.25, corresponding, respectively to the Emacot and control treatments. The analysis of variance revealed a significant among-treatment differences (df = 3, F = 15.27, P < 0.0001) with the highest damage in the control treatment while the lowest damage was observed in the Emacot treatment. However, no significant differences were observed among the two biopesticides and the chemical pesticide treatments (Figure 3).

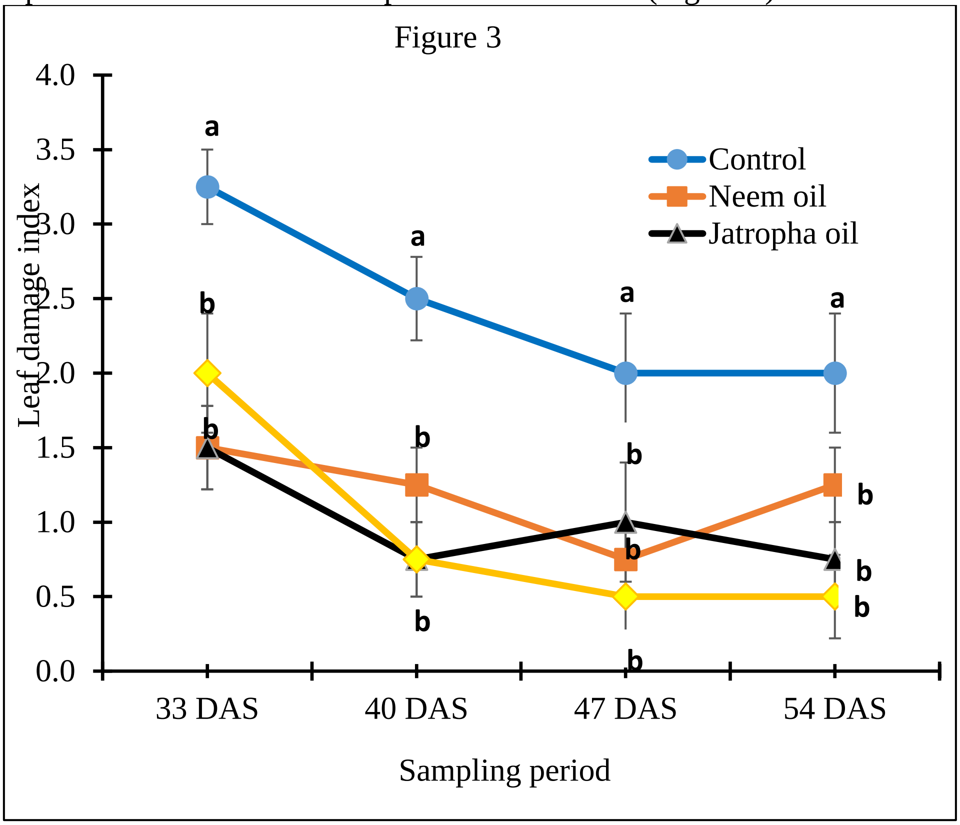

Figure 3. Evolution of leaf damage score caused by *S. frugiperda*

4.4. Effect of treatments on *S. frugiperda* damage to maize cobs

The mean number of cobs attacked over 25 maize plants varied from 2.50 ± 0.28 to 11.75 ± 1.97 per elementary plot (Table 3). The analysis of variance revealed a significant among-treatment differences in the number of cobs damaged by the pest (df = 3, F = 10.50, P < 0.001). The control treatment harbored the highest number of damaged cobs (11.10 ± 1.29), while the lowest number was recorded in the Emamectin benzoate treatment, followed by the Jatropha oil and Neem oil treatments. As for the damage index on the cob, it varied from 1.00 ± 0.00 to 4.25 ± 0.47, with the highest index recorded in the untreated control treatment (df = 3, F = 20.79, P < 0.0001). Emamectin benzoate and Jatropha oil treatments recorded the lowest damage indices, followed by the Neem oil treatment.

Table 3. Effect of treatments on cobs damage by *S. frugiperda*

Treatment	Number of cobs attacked/25 plants	Maize cob's damage score
Control	11.75 ± 1.97 a	4.25 ± 0.47 a
Neem oil	8.00 ± 0.71 b	2.50 ± 0.28 b
Jatropha oil	6.75 ± 1.03 b	1.50 ± 0.28 c
Emamectin benzoate	2.50 ± 0.28 c	1.00 ± 0.00 c
Df	3	3
F	10.50	20.79
Pr > F	0.001	0.0001

In a column, the means followed by the same letter are not statistically different (SNK test).

4.5. Effect of treatments on cob weight, grain yield and yield increase

Over all the treatments, mean cob weight per 25 maize plants ranged from 2.38 ± 0.49 kg to 4.28 ± 0.20 kg (Table 4). The ANOVA revealed a significant among-treatment differences (df = 3, F = 5.91, P < 0.010). The untreated control had the lowest cob weight per 25 plants. The estimated maize grain yield varied from 785.71 ± 30.73 Kg/ha to 1827.38 ± 235.57 Kg/ha. The ANOVA revealed a significant impact of the treatments on grain yield (df = 3, F = 10.47, P < 0.001). The lowest yield was recorded on the untreated control while the highest yields were obtained, respectively, with Emamectin benzoate, Jatropha oil and Neem oil treatments, with no significant differences among these three treatments (Table 4). Maize yield gains accrued from the pesticide treatments in comparison to the untreated control treatment were 132.57%, 90.91% and 72.73%, respectively for Emamectin benzoate, Jatropha oil and Neem oil (Table 4).

Table 4. Impact of treatments on cobs weight, the grain yield and the gain in grain yield of maize

Treatment	Cobs weight (Kg/25plants)	Grain yield (Kg/ha)	Grain yield increase (% control treatment)
Emamectin Benzoate	4.28 ± 0.20 a	1827.38 ± 235.57 a	132.57
Jatropha oil	3.63 ± 0.20 a	1500.00 ± 68.73 a	90.91
Neem oil	3.95 ± 0.37 a	1357.14 ± 105.58 a	72.73
Control	2.38 ± 0.49 b	785.71 ± 30.73 b	-
Df	3	3	-
F	5.91	10.47	-
Pr > F	0.010	0.001	-

In a column, the means followed by the same letter are not statistically different (SNK test).

5. Discussion

The present study is a prerequisite for the development of alternative methods to the chemical control of *S. frugiperda* in the Republic of Chad, and hopefully in many other maize growing countries. It appears from the results of this study that the application of Neem oil or Jatropha oil against this key maize pest could well replace Emamectin Benzoate, a chemical insecticide commonly acknowledged as effective against the pest (Deshmukh *et al*., 2020). Indeed, densities of *S. frugiperda* larvae, infestation rates of maize plots as well as damages caused to maize leaves and cobs by *S. frugiperda* were significantly lower in the Emamectin benzoate, Neem oil and Jatropha oil treatments than in the control treatment. Moreover, Emamectin Benzoate outcompeted the biological pesticides in only few of the maize growth parameters evaluated.

Indeed, it results from this study that Neem oil and Jatropha oil significantly reduced the density of the pest's larvae, its infestation rate, leaf damage and damage to the ears, thereby generating a considerable yield increase although slightly lower than that obtained with Emamectin benzoate. The effectiveness of neem extracts has already been reported by several authors in the management of more than 400 pest species on which they act mainly as insecticide, or have deterrent, anti-ovipositional, antifeedant, growth-disrupting (growth-regulating), fecundity- and fitness-reducing properties on insect pests (Schmutterer, 1990; Isman, 1999; Erler *et al*., 2010). More specifically, Sisay *et al*. (2019), showed in both laboratory and field trials, the efficacy of wettable powder of neem seed (applied in 5% water) against *S. frugiperda*. Likewise, Neem oil has also been reported by several other authors as effective in controlling *S. frugiperda* (Adeye *et al*., 2018; Duarte *et al*., 2019; Phambala *et al*., 2020; Aniwanou *et al*., 2021). The efficacy of Neem extracts on *S. frugiperda* and other insect pest species is linked to its biochemical composition that includes substances toxic to the targeted pests (Medina *et al*., 2003; Rakshit *et al*., 2008; Li *et al*., 2010; Insanu *et al*., 2013; Dono *et al*., 2020). These substances generally, have deterrent and antifeedant properties on *S. frugiperda* larvae (Nesseim *et al*., 2012; Okumu *et al*., 2007). Likewise, several authors reported that incorporating Neem oil into the diet of *S. frugiperda* larvae affects the survival as well as the development of all juvenile stages, even including adult moths (Correia *et al*., 2013; Duarte *et al*., 2019). They argued that ingestion of Neem oil affects the immune defense of *S. frugiperda* larvae thereby increasing their mortality.

As for Jatropha oil, its toxicity and insecticidal effects have been reported by several authors on several insect pests such as the diamondback moth *Plutella xylostella* (Lepidoptera: Plutellidae) (Diabate *et al*., 2014b), the whitefly *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrididae) and the cotton bollworm *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) on

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

tomato plants in Côte d'Ivoire (Diabate *et al*., 2014 a). Moreover, several studies have demonstrated the insecticidal and deterrent potentials of Jatropha oil or of pure compounds isolated from parts of *J. curcas* plants on insect pests of cowpea stocks (Adebowale and Adedire, 2006), as well as on various other stored grain pests (Silva *et al*., 2012; Ukpai *et al*., 2017). In this register, Devappa *et al*. (2012), showed the effectiveness of phorbol esters, extracted from Jatropha oil, in significantly reducing the consumption of maize leaves by third-instar *S. frugiperda* caterpillars. Meanwhile, Adebowale and Adedire (2006), reported anti-ovipositional as well as ovicidal effects of Jatropha oil on the cowpea storage bruchid pest, *Callosobruchus maculatus* F. (Coleoptera: Bruchidae). Indeed, they found that Jatropha oil contains sterols and triterpene alcohols that are responsible for its insecticidal properties, and suggested, therefore, its incorporation into grain legume protection programs.

Emamectin benzoate (Emacot 19 EC) used in this study as a positive control is a chemical insecticide acknowledged by several authors as effective against *S. frugiperda* (Deshmukh *et al*., 2020). This product is authorized for usage in Chad and is frequently used by farmers to control lepidopteran crop pests (CSP, 2018). It is a semi-synthetic insecticide of the Avermectins family, resulting from the natural fermentation of abamectin produced by *Streptomyces avermitilis* which belongs to the most profuse group of microorganisms in soil: the *Actinomycetes.* They are aerobic and Gram-positive bacteria, with anthelmintic and insecticidal potentials (Kuster, 1968; Kim and Goodfellow, 2002).

Emamectin benzoate is used worldwide for its insecticidal and acaricidal properties (Jansson and Dybas, 1998). Deng *et al* (2020), reported that it could quickly dissipate in the environment when released; it is less toxic to beneficial insects and harmless to human health at the concentration recommended by the manufacturer. Therefore, Emamectin benzoate is considered as an alternative to highly toxic synthetic broad-spectrum pesticides. Several authors have demonstrated its efficacy against *S. frugiperda* worldwide including on the African continent (Bonni *et al*., 2020; Deshmukh *et al*., 2020; Ahissou *et al*., 2021; Aniwanou *et al*., 2021; Dileep Kumar and Murali Mohan, 2021).

Our results also suggest that Emacot 19 EC showed supremacy over the biological pesticides tested, notably, in reducing pest densities and damage to maize plants. However, a careless use of emamectin benzoate could cause environmental pollution and serious harm to other non-target organisms (Deng *et al*., 2020). Thus, this product is still regarded as at least, moderately toxic or even dangerous compound by the World Health Organization (Wang *et al*., 2012). It urges therefore, that farmers are sufficiently trained on the ideal way of using this product, or instead, they should safely shift to alternatives such as one of the two biopesticides tested in this study. Indeed, although the maize yield increase is relatively higher with Emacot 19 EC than in the biopesticide treatments, this gain may not significantly differ from those obtained with Neem oil and Jatropha oil. Similarly, several authors have also reported yield increase of many crops treated with Neem or Jatropha oil to control insect pests (Diabaté *et al*., 2014a; Kammo *et al*., 2019; Aniwanou *et al*., 2021).

Based on our findings, it appears that those two biological products could well be an alternative to Emacot 19 EC in the management of *S. frugiperda* in maize fields in the Republic of Chad. Beside their availability, other advantages accrued from using those biopesticides emerged from their low toxicity to the environment, their biodegradability as well as their compatibility with biological control strategies since they better preserve the natural enemy guild of diverse crop pests, thereby mitigating side effects (Deravel *et al*., 2014). By virtue of all those positive protective effects, the two biopesticides tested in the present study can safely be incorporated in Integrated Pest Management (IPM) strategies against FAW in Chad and certainly many other countries on the continent.

Conclusion

This study evaluated the effectiveness of Neem and Jatropha oil in the management of *S. frugiperda* in maize fields. The application of these two biopesticides resulted in a significant reduction in the larval density, incidence of attack, leaf damage and ear damages to caused by the fall armyworm. As a result, a notable increase in maize yield was recorded compared to plots that received no pesticide application. Both biopesticides outperformed the untreated control and provided almost as effective control as the chemical insecticide Emacot 19 EC. Although further trials are still needed, the present results clearly indicate that both biopesticides (Neem oil and Jatropha oil) can well be included in the control strategies against *S. frugiperda* as an alternative to harmful chemical control.

Acknowledgment

This work was founded by the Strengthening Agricultural Productivity and Climate Resilience Project (ProPAD). The authors thank the technicians at the research station of Bébédjia for their support in the implementation of the activities related to this study.

References:

1. Abdoul Habou, Z., Toudou, A., Haubruge, E., Verheggen, F., 2013. Insectes ravageurs et propriétés biocides de *Jatropha curcas* L.(Euphorbiaceae) : synthèse bibliographique. Biotechnologie, Agronomie, Société et Environnement 17, 604–612.

2. Adebowale, K.O., Adedire, C.O., 2006. Chemical composition and insecticidal properties of the underutilized *Jatropha curcas* seed oil. African Journal of Biotechnology 5, 901–906.
3. Adeye, A.T., Sikirou, R., Boukari, S., Aboudou, M., Amagnide, G., Idrissou, B.S., Drissou-Toure, M., Zocli, B., 2018. Protection de la culture de maïs contre *Spodoptera frugiperda* avec les insecticides Plantneem, Lambdace 25 EC et Viper 46 EC et réduction de pertes de rendement au Bénin. Journal de la Recherche Scientifique de l'Université de Lomé 20, 53–65.
4. Agboyi, L.K., Mensah, S.A., Clottey, V.A., Beseh, P., Glikpo, R., Rwomushana, I., Day, R., Kenis, M., 2019. Evidence of leaf consumption rate decrease in fall armyworm, *Spodoptera frugiperda*, larvae parasitized by *Coccygidium luteum*. Insects 10, 410.
5. Ahissou, B.R., Sawadogo, W.M., Bokonon-Ganta, A.H., Somda, I., Kestemont, M.P., Verheggen, F.J., 2021. Baseline toxicity data of different insecticides against the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) and control failure likelihood estimation in Burkina Faso. African Entomology 29, 435–444.
6. Aniwanou, C.T., Sinzogan, A.A., Deguenon, J.M., Sikirou, R., Stewart, D.A., Ahanchede, A., 2021. Bio-Efficacy of Diatomaceous Earth, Household Soaps, and Neem Oil against *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Larvae in Benin. Insects 12, 18.
7. Bateman, M.L., Day, R.K., Luke, B., Edgington, S., Kuhlmann, U., Cock, M.J., 2018. Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. Journal of applied entomology 142, 805–819.
8. Bonni, G., Houndete, T.A., Sekloka, E., Balle, R.A., Kpindou, O.D., 2020. Field and laboratory testing of new insecticides molecules against *Spodoptera frugiperda* (JE Smith, 1797) infesting maize in Benin. Issues in Biological Sciences and Pharmaceutical Research.
9. Bullangpoti, V., Wajnberg, E., Audant, P., Feyereisen, R., 2012. Antifeedant activity of *Jatropha gossypifolia* and *Melia azedarach* senescent leaf extracts on *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and their potential use as synergists. Pest Management Science 68, 1255–1264.
10. Cook, D.R., Leonard, B.R., Gore, J., 2004. Field and laboratory performance of novel insecticides against armyworms (Lepidoptera: Noctuidae). Florida Entomologist 87, 433–439.
11. CSP, 2018. Liste globale des pesticides autorisés par le Comité Sahélien de pesticides.

12. Deng, L., Chen, L., Guan, S., Liu, J., Liang, J., Li, X., Li, Z., 2020. Dissipation of emamectin benzoate residues in rice and rice-growing environments. Molecules 25, 483.
13. Deshmukh, S., Pavithra, H.B., Kalleshwaraswamy, C.M., Shivanna, B.K., Maruthi, M.S., Mota-Sanchez, D., 2020. Field efficacy of insecticides for management of invasive fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on maize in India. Florida Entomologist 103, 221–227.
14. Devappa, R.K., Angulo-Escalante, M.A., Makkar, H.P., Becker, K., 2012. Potential of using phorbol esters as an insecticide against *Spodoptera frugiperda*. Industrial Crops and Products 38, 50–53.
15. Diabaté, D., Gnago, J.A., Tano, Y., 2014. Toxicity, antifeedant and repellent effect of *Azadirachta indica* (A. Juss) and *Jatropha carcus* L. aqueous extracts against *Plutella xylostella* (Lepidoptera: Plutellidae). Journal of Basic and Applied Scientific Research 4, 51–60.
16. Dileep Kumar, N.T., Murali Mohan, K., 2021. Variations in the susceptibility of Indian populations of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) to selected insecticides. International Journal of Tropical Insect Science 1–6.
17. Dono, D., Hidayat, Y., Suganda, T., Hidayat, S., Widayani, N.S., 2020. The toxicity of neem (*Azadirachta indica*), citronella (*Cymbopogon nardus*), castor (*Ricinus communis*), and clove (*Syzygium aromaticum*) oil against *Spodoptera frugiperda*. CROPSAVER-Journal of Plant Protection 3, 22–30.
18. Erler, F., Cetin, H., Saribasak, H., Serttas, A., 2010. Laboratory and field evaluations of some botanical pesticides against the cedar leaf moth, *Acleris undulana*. Journal of Pest Science 83, 265–272.
19. FAO, 2018. Présence de la chenille légionnaire d'automne au Tchad : la FAO appuie une initiative d'urgence de clarification [WWW Document]. URL http://www.fao.org/africa/news/detail-news/fr/c/1105351/ (accessed 12.20.21).
20. Insanu, M., Dimaki, C., Wilkins, R., Brooker, J., van der Linde, P., Kayser, O., 2013. Rational use of *Jatropha curcas* L. in food and medicine: from toxicity problems to safe applications. Phytochemistry reviews 12, 107–119.
21. Isman, M.B., 1999. Neem and related natural products, in: Biopesticides: Use and Delivery. Springer, pp. 139–153.
22. Jansson, R.K., Dybas, R.A., 1998. Avermectins: biochemical mode of action, biological activity and agricultural importance, in: Insecticides with Novel Modes of Action. Springer, pp. 152–170.
23. Kammo, E.Q., Suh, C., Mbong, G.A., Djomo, S.H., Chimi, N.L.L., Mbeungang, D.L., Mafouasson, H., Meseka, S., Menkir, A., 2019.

Biological versus chemical control of fall armyworm and Lepidoptera stem borers of maize (*Zea mays*). Agronomie Africaine 31, 187–198.
24. Kishi, M., 2005. The health impacts of pesticides: what do we now know? The pesticide detox: towards a more sustainable agriculture 23–38.
25. Li, C.-Y., Devappa, R.K., Liu, J.-X., Lv, J.-M., Makkar, H.P.S., Becker, K., 2010. Toxicity of *Jatropha curcas* phorbol esters in mice. Food and Chemical Toxicology 48, 620–625.
26. Mbaidiro, T.J., Alexis, O., Doyam Nodjasse, A., 2021. Effet de la durée du cycle de développement de quelques variétés de maïs sur leur susceptibilité à Spodoptera frugiperda (J.E. Smith) en zone soudanienne du Tchad. Journal of Animal & Plant Science 49, 8856–8865. https://doi.org/10.35759.
27. Medina, P., Smagghe, G., Budia, F., Tirry, L., Vinuela, E., 2003. Toxicity and absorption of azadirachtin, diflubenzuron, pyriproxyfen, and tebufenozide after topical application in predatory larvae of *Chrysoperla carnea* (Neuroptera: Chrysopidae). Environmental Entomology 32, 196–203.Miresmailli, S., Isman, M.B., 2014. Botanical insecticides inspired by plant–herbivore chemical interactions. Trends in Plant Science 19, 29–35.
28. Mutua, J.M., Mutyambai, D.M., Asudi, G.O., Khamis, F., Niassy, S., Jalloh, A.A., Salifu, D., Magara, H.J.O., Calatayud, P.-A., Subramanian, S., 2022. Competitive plant-mediated and intraguild predation interactions of the invasive *Spodoptera frugiperda* and resident stemborers *Busseola fusca* and *Chilo partellus* in maize cropping systems in Kenya. Insects, 13, 790. https://doi.org/10.3390/insects13090790.Nesseim, T.D.T., Fillet, M., Mergeai, G., Dieng, A., Hornick, J.-L., 2012. Principes toxiques, toxicité et technologie de détoxification de la graine de *Jatropha curcas* L. (synthèse bibliographique). Biotechnologie, Agronomie, Société et Environnement 16, 531–540.
29. Okumu, F.O., Knols, B.G., Fillinger, U., 2007. Larvicidal effects of a neem (*Azadirachta indica*) oil formulation on the malaria vector *Anopheles gambiae*. Malaria journal 6, 1–8.
30. Phambala, K., Tembo, Y., Kabambe, V.H., Stevenson, P.C., Belmain, S.R., 2020. Bioactivity of common pesticidal plants on fall armyworm larvae (*Spodoptera frugiperda*). Plants 9, 112.
31. Prasanna, B.M., Huesing, J.E., Eddy, R., Peschke, V.M., 2018. Fall armyworm in Africa: a guide for integrated pest management.
32. Rakshit, K.D., Darukeshwara, J., Raj, K.R., Narasimhamurthy, K., Saibaba, P., Bhagya, S., 2008. Toxicity studies of detoxified Jatropha

meal (*Jatropha curcas*) in rats. Food and Chemical Toxicology 46, 3621–3625.

33. Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., Clottey, V., Davis, T., Day, R., Early, R., 2018. Fall armyworm: impacts and implications for Africa. Fall armyworm: impacts and implications for Africa.
34. Santos, W.L. dos, Freire, M. das G.M., Bogorni, P.C., Vendramim, J.D., Macedo, M.L.R., 2008. Effect of the aqueous extracts of the seeds of *Talisia esculenta* and *Sapindus saponaria* on fall armyworm. Brazilian Archives of Biology and Technology 51, 373–383.
35. Shapiro, S.S., Wilk, M.B., 1965. An analysis of variance test for normality (complete samples). Biometrika 52, 591–611.
36. Silva, G.N., Faroni, L.R.A., Sousa, A.H., Freitas, R.S., 2012. Bioactivity of *Jatropha curcas* L. to insect pests of stored products. Journal of Stored Products Research 48, 111–113.
37. Silva, M.S., Broglio, S.M.F., Trindade, R.C.P., Ferrreira, E.S., Gomes, I.B., Micheletti, L.B., 2015. Toxicity and application of neem in fall armyworm. Comunicata Scientiae 6, 359–364.
38. Sisay, B., Tefera, T., Wakgari, M., Ayalew, G., Mendesil, E., 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. Insects 10, 45.
39. Stevenson, P.C., Isman, M.B., Belmain, S.R., 2017. Pesticidal plants in Africa: a global vision of new biological control products from local uses. Industrial Crops and Products 110, 2–9.
40. Toepfer, S., Fallet, P., Kajuga, J., Bazagwira, D., Mukundwa, I.P., Szalai, M., Turlings, T.C., 2021. Streamlining leaf damage rating scales for the fall armyworm on maize. Journal of Pest Science 94, 1075–1089.
41. Ukpai, O.M., Ibediungha, B.N., Ehisianya, C.N., 2017. Potential of seed dusts of *Jatropha curcas* L., *Thevetia peruviana* (Pers.), and *Piper guineense* Schumach. against the maize weevil, *Sitophilus zeamais* (Motschulsky, 1855) (Coleoptera: Curculionidae) in storage of corn grain. Polish Journal of Entomology 86, 237.
42. Wang, L., Zhao, P., Zhang, F., Li, Y., Du, F., Pan, C., 2012. Dissipation and residue behavior of emamectin benzoate on apple and cabbage field application. Ecotoxicology and environmental safety 78, 260–264.
43. Williamson, S., Ball, A., Pretty, J., 2008. Trends in pesticide use and drivers for safer pest management in four African countries. Crop Protection 27, 1327–1334. https://doi.org/10.1016/j.cropro.2008.04.006