Innovations

Novel Ecofriendly Management Tactics of the Fall Armyworm Spodoptera Frugiperda (J.E. Smith) (Lepidoptera: Noctuidae) on Maize in Jordan

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Abstract: *Maize, Zea mays L. is one of the most important cereals consumes as grain for human and as forage for animals. Recently, the fall armyworm, Spodoptera frugiperda is becoming a major invasive insect pest causing huge yield losses to maize in much of the world, this study aimed at assaying of five different products against the pest.In 2022, experiments were conducted at the Southern Ghor Agriculture Directorate in Jordan, involving five commercially available products tested on larvae, with three different concentrations for each product, including a controlusing early and late larvae.The results of application of the five products at the three concentrations indicated that with time post application and with increasing concentration from low to high, there was a significant increase in mortality of both early and late larvae, the overall mortality during all days of the experiment and all treatment concentrations indicated that there were significant differences among the treatments, where the most efficacy treatments were rapeseed oil (82.25%), and abamectin (79.83%), followed by deltamethrin (78.92%), B. thuringiensis (71.25%), and pyriproxyfen (67.42%) for the early larvae, while for the late larvae there were abamectin (81.33%), rapeseed oil (80.83%), and deltamethrin (79.75%), followed by pyriproxyfen (71.00%) and B. thuringiensis (69.17%), the mortality percentage of the early larval instars was higher than those of the late larval instarsof S. frugiperda in the six treatments. This indicated that the early larval instars are more susceptible than the late ones to the treatments.*

Keywords*: Spodoptera frugiperda, fall armyworm, invasive pest, ecofriendly management, maize*

1. Introduction

Maize is the second most cultivated cereal crop in the world after wheat. It is one of the most important cereals which consumes as grain for human and as forage for animals (Edmeades, 2013). The total maize production in the world is about 1.16 billion tons, occupying an area of about 202 million hectares in 2020 (FAO, 2020). Recently, the fall armyworm, Spodoptera frugiperda (J.E. Smith, 1797) (Lepidoptera: Noctuidae) is becoming a major invasive insect pest causing huge yield losses to many crops, especially maize nationwide (Deshmukh et al., 2021). In 2016, the pest was detected for the first time in some countries of Africa, and it is distributed to almost whole of Africa (Allen et al., 2021), and hereafter in different parts of Asia in 2018 (Hussain et al., 2021). Recently, S. frugiperda invaded Europe and Australia (Parra et al., 2022). It has now reached above 109 countries globally (Zhao et al., 2022). The pest could damage approximately 353 host plant species (Badhai et al., 2020; Chen et al., 2021). Despite its ability to survive in different host plants, S. frugiperda is known to have a high preference for maize (Ngangambe and Mwatawala, 2020). The larva is the damaging stage and generally feeds on the leaf by scrapping green tissues (Badhai et al., 2020). The fall armyworm is a risky pest to maize due to its polyphagous habit, voracity (Chen et al., 2021), high reproductive capacity (Zhang et al., 2021), long adult dispersal (Deshmukh et al., 2021), and multiple generations/year (Edosa and Dinka, 2021).

The major method of pest control adopted by the majority of farmers is the synthetic insecticides (Al-Zyoud, 2012; Al-Zyoud et al., 2015). Actually, pesticides helped the world meets the increasing food demand by enhancing the agriculture production through controlling pests. However, the misuse of pesticides in agriculture had many negative effects on human health and environment. Due to the rapid global invasion of S. frugiperda, there is a pressing need to understand management options for this serious pest (Overton et al., 2021). Therefore, management approaches need to be utilized in a way that are sustainable and cost-effective, and the risks caused by them to the human and environment are minimum (Naharki et al., 2020).

The use of insecticides is a main component of IPM developed for S. frugiperda control in many countries (Nboyine et al., 2022). Insecticides applied to the growing crops are effective when used at the right time (Sagar et al., 2020). This includes spraying when the larvae are still young (Assefa, 2018). However, the use of chemical insecticides has remained the most widely used approach of S. frugiperda control (Sisay et al., 2019a, b). Various insecticides have been recommended for S. frugiperda control (Sagar et al., 2020). Chlorpyrifos, carbosulfan, emamectin benzoate and beta cypermethrin have been widely used for the control of the pest in Africa (Sagar et al., 2020). In India, diamides, avermectins, spinosyns, and benzylureas are recommended (Sharanabasappa et al., 2020). Spraying of emamectin benzoate, thiodicarb, cypermethrin, spinetoram, lambada-cyhalothrin, acetamiprid, chlorpyriphos, maltodextrin, flubendiamide, indoxacarb, alpha-cypermethrin and malathion were found effective (Sharanabasappa et al., 2020; Niassy et al., 2021; Bortolotto et al., 2022). Multiple sprays of insecticides may lead to the quick development of pest resistance (Paredes-Sanchez et al., 2021). However, due to residues and

resistance problems, new environmentally sound technology is needed to control the pest (Lin et al., 2021).
Biological control is considered a powerful tool and one of the most important alternative control tactic providing environmentally safe, sustainable plant protection, and more economically viable than synthetic insecticides (Al-Zyoud et al., 2007, 2021).S. frugiperda is attacked by bacteria (Assefa and Ayalew, 2019). The entomopathogenic bacterium (EPB),Bacillus thuringiensishas been suggested as the best option for biological control of S. frugiperda (Bateman et al., 2021). In several African countries, a number of bacteria are registered and commercially available, i.e., B. thuringiensis var. kurstaki and B. thuringiensis subsp. aizawai (Bateman et al., 2018).
The drawbacks of synthetic insecticides in agriculture sector led to increase the interest in using plant extracts as an alternative control tactic. Plant extracts are more environmentally accepted management tactics due to their short persistence, and repellent or anti-feeding modes of action (Bhusal and Chapagain, 2020). It is reported that the use of extracts of many plants against S. frugiperda consider effective, less expensive, and safer options for the human and environment (Paredes-Sanchez et al., 2021). Seven plant extracts have shown potential in controlling S. frugiperda, i.e. Azadirachta indica, Melia curcas, Phytolacca dodecandra, Jatropha curcas, Millettia ferruginea and Croton macrostachyus (Sisay et al., 2019a). Ethanolic extracts of Argemone ochroleuca caused S. frugiperda larval mortality due to a reduction in feeding and slowed larval growth (Martinez et al., 2017).The
findings show that respondents are very highly concerned about human health, food safety, and the riskof environmental pollution, and they have a real desire to reduce the use of pesticides. Respondents had amoderate level of knowledge about food safety, pesticides' side effects, pesticides' residues in food orfeed, and usage of pesticides in homes and gardens. According to the respondents, the most commonway that people are exposed to pesticide residues is by consuming pesticide residues in food (Al-Dawood et al., 2023). The main objectives of this study were to investigate the efficacy of synthetic insecticides on S. frugiperda, and to study the effectiveness of ecofriendly management tactics (plant extract, entomopathogenic bacterium, and insect growth regulator (IGRs) against the pest.

2. Materials and methods

2.1. Location and environment

The experiments were conducted in a controlled rearing room at the Southern Ghor Agriculture Directorate, Ghor Al-Safi, Karak, Jordan in 2022. The environmental conditions during the experiments in the rearing room were 27±3°C temperature, 60±10% relative humidity, and a photoperiod of 16: 8 h (L: D).

2.2. Preparations of the commercially available-based products used

All the commercially available-based products used in this study were obtained from private companies, Amman, Jordan. Five products were used: (1) The entomopathogenic bacterium, Bacillus thuringiensis (Biocure®); (2) The IGR, pyriproxyfen (ACIPROX 10®); (3) The rapeseed oil (Fytomax PX®); (4) abamectin (Biotrine 10®); and (5) deltamethrin (Delta®). In addition, a 6th treatment was served as a control using only distilled water.

2.3. Experimental design and procedure

For each product (treatment), three different concentrations of the based-product suspension were evaluated (the lower, medium and higher recommended application concentrations). The used concentrations per 1 L of water of B. thuringiensis, pyriproxyfen, rapeseed oil, abamectin and deltamethrin were shown in Table 1.

Table 1: List of common and trade names, formulation and active ingredient (AI), manufacturer and application rate of commercially available-based products tested.

Common name	Trade name	Formulation and A.I.	Manufacturer	Application rate per 1 L water
Bacillus thuringiensis	Biocure®	WP	Russell IPM	0.5, 0.75 and 1.0 g/l
Pyriproxyfen	ACIPROX 10®	EC, 10% w/v	ACI	0.5, 1.0 and 1.5 ml/l
Rapeseed oil	Fytomax PX®	EC, 77.7% w/w	Russell IPM	15, 20 and 25 ml/l
Abamectin	Biotrine®	EC, 1.8% w/v	Russell IPM	1.0, 1.25 and 1.5 m/l
Deltamethrin	Delta®	EC, 2.5% w/v	Mobedco	0.4, 0.7 and 1.0 ml/l

EC: Emulsifiable Concentrate, WP: Wettable Powder

Thousands of live larvae of S. frugiperda were gathered by the researchers from highly infested maize fields in Ghor Al-Safi, Jordan and taken to the rearing room for further determination of the needed larval instars using a Binocular microscope.

Tenlarvae of early instars (L_1-L_2) or late instars (L_4-L_5) were kept per each Petri-dish (11 cm in diameter and 3 cm in height), and each treatment was replicated four times (4x10=40 larvae for each treatment). The experiment was a Complete Randomized Design (CRD). The effect of all the treatments and their compartment concentrations on S. frugiperdalarvae were determined by exposing the L_1-L_2 and L_4-L_5 instars of S. frugiperda to products' residues on maize leaf discs of the cultivar, Asgrow, as needed for the larval feeding. The maize leaf discs were dipped in already prepared solutions of the five products and their compartment concentrations, and were offered to the larvae in Petri-dishes that were partially filled with 0.5 cm thick layer of wetted cotton pad, and the lid of each Petri-dish had a hole closed with organdie fabric for ventilation. In the control treatment, the maize leaf discs were treated similarly with only distilled water. The effect of residual exposure of the different products on the larval mortality was daily recorded until the death of all larvae.

2.4. Statistical analysis

The statistical analysis was performed using the Proc GLM of the Statistical Package SigmaStat version 16.0 (SPSS, 1997). The data were analyzed by one/two-way ANOVA to detect any differences in the larval mortality among the different treatments (products) (Zar, 1999). When significant differences were detected, differences among several means were separated using the Least Significant Difference (LSD) at $P \leq 0.05$ (Abacus Concepts, 1991). T-Test was used for comparisons between only two means (Anonymous, 1996). Also, the correlations between the mortality and the concentration of the tested productswere calculated by Spearman's method (Zar, 1999). For correlation analysis, the lower, medium and higher concentrations were coded 1, 2 and 3, respectively.

3. Results

3.1. Effect of different products with different concentrations on the early larval instars (L_1-L_2) of Spodoptera frugiperda

Figure 1 shows that the results of all treatments were better than the results of the control. Mortality in early instars larvae increased more clearly in the medium concentration and the higher concentration of the five treatments than in the lower concentration. The results indicated that the 100% mortality of the early larvae was reached on the 9th, 10th, and 8th days post exposure to the low, medium, and high concentrations of B. thuringiensis, respectively. It indicating that the higher concentration killed all larvae in 1 and 2 days earlier than the low and medium concentrations, respectively(Fig. 1-1). Same trend of results was also obtained for pyriproxyfen treatment, but the complete death rate was reached in less number of days than that of the Bt treatment for the higher pyriproxyfen concentration compared with the lower and medium concentrations (Fig. 1-2). Results of Figure (1-3) revealed that the mortality of the early instars larvae reached the full percentage using rapeseed oil (all concentrations) earlier than that of Bt and pyriproxyfen treatments. Nevertheless, the complete mortality (100%) of the early larvae was reached on the 7th, 6th, and 6th days post exposure to the low, medium, and high concentrations of abamectin, respectively, indicating that the higher concentration of abamectin killed all larvae in 1 day earlier than the low concentration (Fig. 1-4). The mortality of young larvae reached the full percentage using the highest concentration of deltamethrin, with a difference of days from the lowest and middle concentrations, and this difference of days is the highest compared to the other four treatments tested (Fig. 1-5). The results of the control treatment indicated that with the progress of time, there was a significant increase ($F=5.278$; 9, 40 df; $P=0.000$)in mortality of the early larval instars (Figure 1-6). The percentage mortality oflarvae increased significantly, where the least mortality of 10.0±2.13% was recorded on the 1st day of the experiment, and increased hereafter until reached 40.0±2.13% on the last day (10th day) of the experiment.

3.2. Effect of different products with different concentrations on the late larval instarsof Spodoptera frugiperda

Results showed that the mortality in all treatments were clearly higher than the mortality of the control (Figure 2). However, the complete mortality (100%) of the late larvae of the pest was reached earlier for abamectin than the other 4 treatments. Moreover, it was found that the highest concentration of abamectin treatment was the fastest to reach 100% larval mortality among all concentrations for all treatments. The results of the control treatment demonstrated that with time, there was a significant increase ($F=8.919$; 9, 40 df; $P=0.000$) in mortality of the late larval instarsof S. frugiperda by feeding maize leaves (Figure 2). The percentage mortality of S. frugiperda larvae increased significantly, where no larval mortality was reported on the 1st day, and then the mortality increased hereafter until reached 32.5±1.31% on the 10th day of the experiment (Figure 2).

3.3. Effect of the three concentrations together of the different products on the early and late larval instars of Spodoptera frugiperda

The mortality results of the early and late larval instarsof S. frugiperda by application the three concentrations together in the five products and the control are shown in Figure 3 (I and II). In all the five treatments, the overall effect of the three concentrations together indicated that with time there was a significant increase ($F=108.507$; 9, 120 df; $P=0.000$)in mortality of the early larval instarsof S. frugiperda by feeding maize leaves (Figure 3-I). Furthermore, further statistical analysis of the mortality results of early and late larval instarsof S. frugiperda was performed among the overall effect of the three concentrations of the five treatments, in addition to the control treatment, within the same experimental day (Figure 3). Overall, from the 3rd day until the 10th day of the experiment all the five treatments caused significantly higher mortality than the control.

The overall average mortality of the early larvae during all days of the experiment and all treatment concentrations indicated that there were significantly differences among the different treatments ($F=4.762$; 4, 600 df; $P=0.001$). The most efficacy treatments significantly were the rapeseed oil (82.25%), and abamectin (79.83%), followed by deltamethrin (78.92%), B. thuringiensis (71.25%), and pyriproxyfen (67.42%) (Figure 4-A). The overall average mortality of the late larvae during all days of the experiment and all treatment concentrations showed that there were significantly differences among different treatments (F=5.204; 4, 600 df; P=0.000). The most efficacy treatments significantly were abamectin (81.33%), rapeseed oil (80.83%), and deltamethrin (79.75%), followed by pyriproxyfen (71.00%) and B. thuringiensis (69.17%) (Figure 4-B).

The mortalities of both early and late larval instarsof S. frugiperda by feeding on maize leaf discs treated with B. thuringiensis, pyriproxyfen, rapeseed oil, abamectin, and deltamethrin of the three different concentrations together, as well as the control treatment in a residual exposure test are shown in Figure 5. As a general trend, the mortality percentage of the early larval instars was higher than that of the late larval instarsof S. frugiperda in the six treatments in most days post application. This indicated that the early larval instars are more susceptible than the late ones to the different products. However, the increase in the larval mortality was significant in some treatments and days (Figure 5).

There was a weak positive significant correlation between the product concentration and the mortality of the early larval instars (r=0.101, P=0.013) at 0.05 probability level, and a weak positive significant correlation between the product concentration and the mortality of the late larval instars (r=0.101, P=0.014) at 0.05 probability level. In addition, there was a weak positive significant correlation between the concentration and mortality of both early and late larval instars together (r=0.102, P=0.000) at 0.01 probability level. Furthermore, there was a significant interaction between larvae type and product type (F=7.220; 5, 1439 df; P=0.000), larvae type and time post application (F=4.640; 9, 1439 df; P=0.000), product type and concentration (F=3.781; 10, 1439 df; P=0.000), product type and time post application (F=15.816; 45, 1439 df; P=0.000), larvae type, product type and product concentration (F=2.465; 10, 1439 df; P=0.006), and larvae type, product type and time post exposure (F=2.579; 45, 1439 df; P=0.000).

4. Discussion

Insect pest control with synthetic chemical insecticides has profound side effects the environment and human health (Naharki et al., 2020). Furthermore, many insecticides have become ineffective due to repeated spraying and the emergence of resistance (Lin et al., 2021; Paredes-Sanchez et al., 2021). Therefore, it was necessary to look for effective and safe alternatives of synthetic chemical insecticides (Bhusal and Chapagain, 2020), where plant extracts, entomopathogenic bacteria and IGRs were used in the present study.

In the current study, it is worth mentioning that all the five products tested namely; B. thuringiensis, pyriproxyfen, rapeseed oil, abamectin, and deltamethrin, were caused a significant and higher mortality to both early and late larval instars of S. frugiperda as compared to the control treatment. The overall mortality results indicated that there were significantly differences among products, where the most efficacy ones significantly were rapeseed oil and abamectin, followed by deltamethrin, then B. thuringiensis, and pyriproxyfen for the early larvae. For the late larvae the most effective products were abamectin, rapeseed oil, and deltamethrin, followed by pyriproxyfen and B. thuringiensis. The plant extract, rapeseed oil, and abamectin gave very promising results superior to the other three products, in which the killing rate was ≥80% in both early and late larval instars.

In addition, the high concentration of all products killed all larvae (100% mortality) in 1-3 days earlier than both low and medium concentrations. Furthermore, the mortality of the early larvae was higher than the late larvae in the five products tested, indicating that the early larval instars are more susceptible than the late ones to the different applications of the products. In the rapeseed oil and abamectin, the killing rates of all larvae reached 100% within 5-7 days, and this time period was 1 to 3 days less than the periods when S. frugiperda larval mortality reached 100% for the other three treatments (B. thuringiensis, pyriproxyfen, and deltamethrin).

Idrees et al. (2022) found the same trend of results; where the abamectin proved to be the most toxic among the eight synthetic insecticides tested having the highest toxicity (78%) against the 2^{nd} instar larvae of S. frugiperda. In addition, the findings of Idrees et al. (2022) suggested that larval mortality of early larval instar significantly increase with increasing concentrations, which is also in a complete agreement with the results of the current study. Huang et al. (2011) revealed that within the concentrations of 5-15 μg/mL, abamectin inhibited the development of S. frugiperda and induced apoptotic cell death in a time- and dose-dependent manner, which is also agreed with the current results since the mortality of S. frugiperda larvae were significantly affected product concentration and time post application. Sileshi et al. (2022) tested six insecticides (deltamethrin, malathion, diazinon, alpha-cypermethrin, lambda-cyhalothrin, and dimethoate) at laboratory, and their result showed that deltamethrin caused 100% mortality 3 days post application. They concluded that the pyrethroid class of insecticides reduced the damage and infestation level of S. frugiperda in the maize field conditions, which is partially agreement with the current findings, where the pyrethroid insecticide, deltamethrin caused ~90% mortality to S. frugiperda larvae on the 5^{th} day post exposure. Furthermore, Vinha et al. (2021) evaluated the efficacy of deltamethrin and they confirmed that deltamethrin is toxic to S. frugiperda larvae through decreasing larval survival rate, reduced larval mobility, low respiration rate and inhibiting food consumption. Using leaves dipped in insecticide dilutions, as what is done in the current study, Zanuncio et al. (2009) reported that among the four selected insecticides, deltamethrin was the most toxic compound. Spraying of emamectin benzoate, cypermethrin, lambada-cyhalothrin, chlorpyriphos, indoxacarb, malathion and alpha-cypermethrin were found effective (Niassy et al., 2021; Bortolotto et al., 2022). Under field conditions, Mallapur et al. (2019) reported that spinetoram, emamectin benzoate and spinosad reduced larval population to 98%, 96% and 96%, respectively.

Furthermore, in addition to its effectiveness against the pest, the plant extract, rapeseed oil is listed among the 15 bio-pesticides permitted for use in organic agriculture, and is listed as such in Annex II of Commission Regulation (EC) 889/2008 on rules for organic production (EU, 2013). Moreover, Viteri et al. (2019) found that larvae of the fall armyworm were susceptible (mortality >80% at 96 h) to Steinernema carpocapsae (Weiser), rapeseed oil and methomyl among the 9 insecticides tested. The rapeseed oil caused 53% of S. frugiperda larval mortality at 5 days post-treatment. Similarly, neem plant extract is found to be larvicidal and the oil extracted from the seeds of long pepper are found to be checking spermatogenesis of the pest; supporting the results in the current study (Bhusal and Chapagain, 2020).Curzio et al. (2009) investigated the bioactivity of Ipomoea murucoides methanolic extracts at a concentration of 2 mg/mL, and found that 7 days post exposure the crude leaf extracts caused up to 46% mortality to the 1st larval instars of the pest.Cespedes et al. (2005) reported that methanol extract of Myrtillocactus geometrizans exhibited IGR and insect killing activities against S. frugiperda. Sisay et al. (2019b) reported high mortality of S. frugiperda with the plant extracts of J. curcas, Militia ferruginea, P. dodecandra, Scinus molle, M. abyssinica, N. tabacum, Lantana camara, Chenopodium ambroides and Jatropha gossypifolia. Seven plant extracts have shown potential in controlling S. frugiperda with mortality greater than 75% after 3 days of exposure, i.e. A. indica, P. dodecandra, S. molle, J. curcas, M. curcas, M. abyssinica, M. ferruginea and C. macrostachyus (Sisay et al., 2019a). Negrini et al. (2019) stated that among many plant essential oils used in controlling S. frugiperda, the efficient essential oils were C. citriodora and Lippia microphylla. Lima et al. (2010) found that S. frugiperda larvae ingesting maize leaves treated with the essential oil of Ageratum conyzoides caused 70% mortality at a concentration of 0.5%. Kamel (2010) reported that moringa oil induced a lower feeding ratio expressed as the ratio of consumed area of treated leaf discs to consumed area of untreated (control) leaf discs, and the highest mortality percentage of S. frugiperda, and he concluded that at 10% concentration, moringa oils can be used as a botanic insecticide in the management of S. frugiperda. In addition, Phambala et al. (2020) stated that the most promising plant species against S. frugiperda were L. javanica, Ocimum basilicum and Cymbopogon citratus which showed various activities including anti-feeding and increased mortality, and these three species have low mammalian toxicity and are safer than synthetics. Almeida et al. (2017) stated that the ethanolic extract of Euphorbia pulcherima leaves was fed to S. frugiperda larvae, and at 0.5 and 1% concentrations, the extracts resulted in greater larval mortality. In the contact toxicity tests, the highest larval mortality was obtained from extracts of N. tabacum (66%) and L. javanica (66%) (Phambala et al., 2020). Ethanolic extracts of A. ochroleuca caused S. frugiperda larval mortality due to a reduction in feeding and slowed larval growth (Martinez et al., 2017). It was found that neem seed oil was as effective as synthetic insecticide, emamectin benzoate in S. frugiperda control (Babendreier et al., 2020). Thus, the use of extracts of many plants against S. frugiperda consider effective, less expensive, and safer options for the environment and humans (Paredes-Sanchez et al., 2021).

Bhusal and Chapagain (2020) stated that B. thuringiensis is effective for controlling the larvae of fall armyworm in maize, which agreed with the finding of the current study, where B. thuringiensis caused mortalities of 71% and 69% for the early and late larvae of the pest. Viteri et al. (2018) found that the highest larval mortality (>90%) of S. frugiperda was noted with high dosages of B. thuringiensis at 3 days post application. Al-Dababseh et al. (2014) reported that B. thuringiensis was effective against the cereal leafminer, Syringopais temperatella under laboratory conditions by feeding larvae on bacteria-contaminated barley leaves. Their results indicated that B. thuringiensis cause concentration and time related mortality, in which the highest mortality was recorded at the highest concentration, and the early larvae were significantly more susceptible to all concentrations of B. thuringiensis than the late larvae. Their findings regarding concentration, time after exposure and larval instars are in complete agreement with the current findings. Nevertheless, B. thuringiensishas been suggested as the best option for controlling S. frugiperda (Bateman et al., 2021). In several African countries, a number of bacteria are registered and commercially available, i.e., B. thuringiensis var. kurstaki and B. thuringiensis subsp. aizawai (Bateman et al., 2018). B. thuringiensis has been produced at low cost in Cuba and Brazil (Hruska, 2019), and it was applied in Tanzania, Uganda and Kenya against the pest (Niassy et al., 2021).

Regarding using the IGR, Calderon et al. (2001) found that acute toxicity against adults of S. frugiperda was found. Gedunin (IGR isolated from Cedrela spp.) and n-hexane extract had the most potent activity with LD_{50} value of 10.8, and 12.8 ppm, respectively. In addition, gedunin caused acetylcholinesterase inhibition with 100% at 50 ppm. The IGR used in this study (pyriproxyfen) gave a moderate percentage of S. frugiperda larval mortality of 67% and 71% for early and late larvae, respectively, but it was not used against adult insects. Resmitha et al. (2016) useddifferent concentrations of the IGR, pyriproxyfen against relative insect species of S. frugiperda such as Spodoptera mauritia, and reported that at high concentrations, pyriproxyfen caused the death of the larvae of S. mauritia after 1 day and with increasing concentration of pyriproxyfen, the larval mortality increased, which is agreement of the current findings. Furthermore, Alizadeha et al. (2012) stated that pyriproxyfen is highly effective against the 3rd larval instars of the diamondback moth, Plutella xylostella in the laboratory both directly (causing mortality) and indirectly (disruption of normal growth and development). It is worth mentioning that the leaf dip method used in this study was effective and in agreement with what it is reported by Mahmoudvand et al. (2015), in which application of pyriproxyfen in leaf dip method has an effective

way of suppressing the population of larvae of the diamondback moth, since in leaf dip method, the product took effect orally and also by contact action.
In conclusions, the fall armyworm, S. frugiperda is a major invasive insect pest causing huge yield losses to maize. This is a very alarming situation for Jordanian farmers. Thus, Jordan has begun to address the S. frugiperda problem. We have the basic information on some IPM tactics to manage the pest in an ecofriendly manner. The five products test in this study caused significantly higher mortality to the pest than the control. There were significant differences among the different products, where the most efficacy ones were the rapeseed oil and abamectin, followed by deltamethrin, then B. thuringiensis and pyriproxyfen. Mortality of S. frugiperda is a time-, dose-, and larval instar-dependent manner.The three ecofriendly management tactics: the plant extract (rapeseed oil), the bacterium (B. thuringiensis) and the IGR (pyriproxyfen) could be used effectively to manage S. frugiperda in Jordan.Furthermore, the two used synthetic insecticides (abamectin and deltamethrin) could be used to manage S. frugiperda since both of them classified as either slightly toxic or relatively nontoxic (toxicity categories III, signal word: caution, LD_{50}: abamectin = >1,800, and deltamethrin = >2,000, and the restricted-entry interval for both are only 12 hours). It is recommended that the fall armyworm control should be done using the five tested products in a short period after the appearance of the pest infestation, since the early larvae are more susceptible to the products than the late larvae.Maize farmers should learn that incorporating several effective control tactics into a management strategy is the most effective way to manage S. frugiperda in a sustainable manner. The outcomes of this study should be transferred to through farmer field schools (FFS) and workshops for the maize farmers in Jordan. Nevertheless, it appears that future studies should focus on survey the whole country to detect the pest whether on maize or other crops and the resistance factors in different cultivars requires analyzing the compounds in the leaves of these cultivars to unravel their role in host-plant resistance. More attention should be paid to investigate predators and parasitoids of the pest in Jordan.

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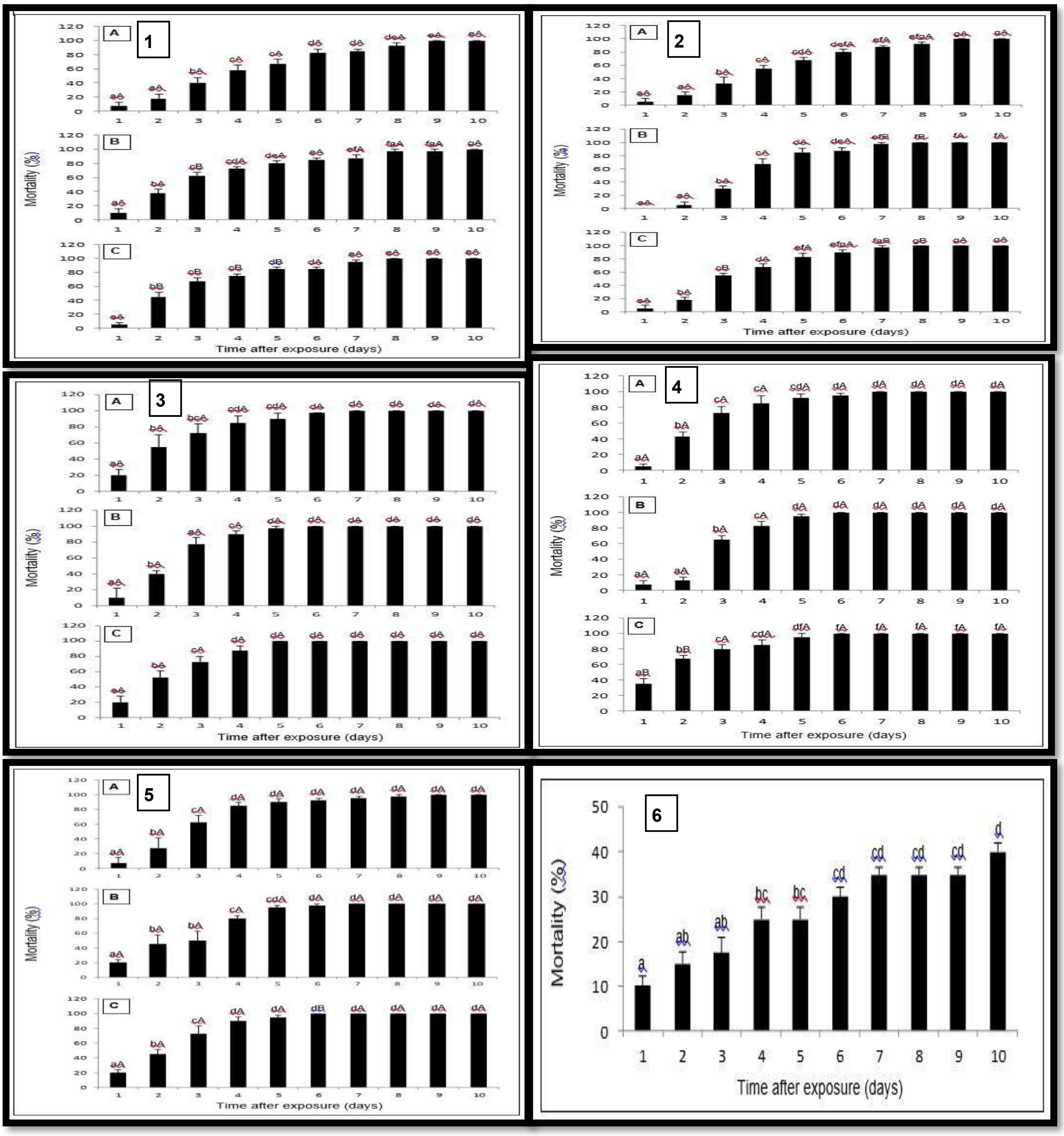

Spodoptera frugiperda by feeding on maize leaf discs treated with three different concentrations (low: A, medium: B, high: C) of Bacillus thuringiensis (1), pyriproxyfen (2), rapeseed oil (3), abamectin (4), deltamethrin (5), and distilled water- control treatment (6)in a residual exposure test. [Different small letters above bars indicate significant differences among the different days within the same product and concentration, while capital letters above bars indicate significant differences among the different concentrations within the same product and day at P≤0.05(two-factor analysis of variance)].

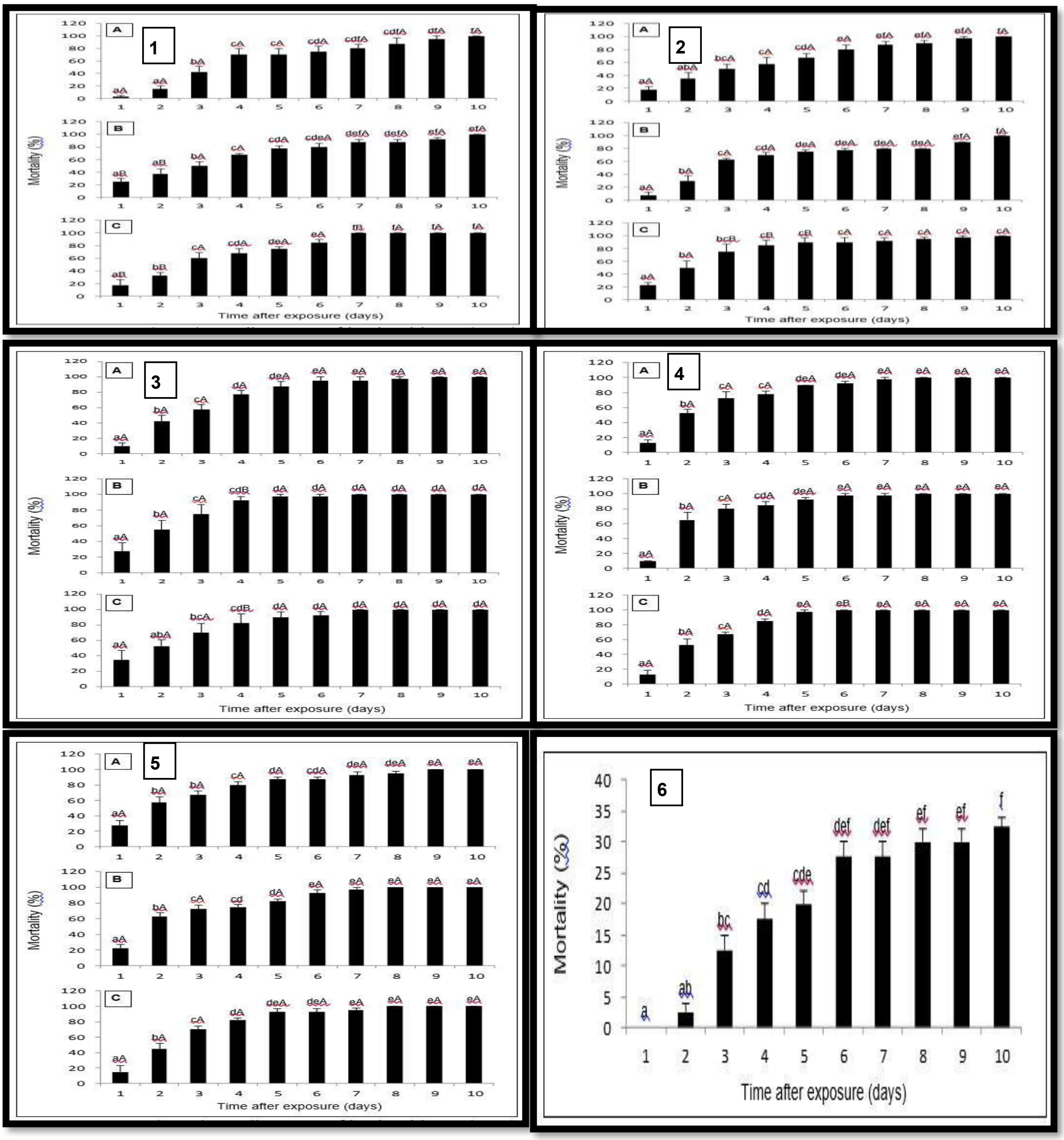

Figure 2: Average (±SEM) mortality percentage of late larval instars (L_4–L_5) of Spodoptera frugiperda by feeding on maize leaf discs treated with three different concentrations (low: A, medium: B, high: C) of Bacillus thuringiensis (1),

pyriproxyfen (2), rapeseed oil (3), abamectin (4), deltamethrin (5), and distilled water- control treatment (6)in a residual exposure test. [Different small letters above bars indicate significant differences among the different days within the same product and concentration,while capital letters above bars indicate significant differences among the different concentrations within the same product and day at P≤0.05(two-factor analysis of variance)].

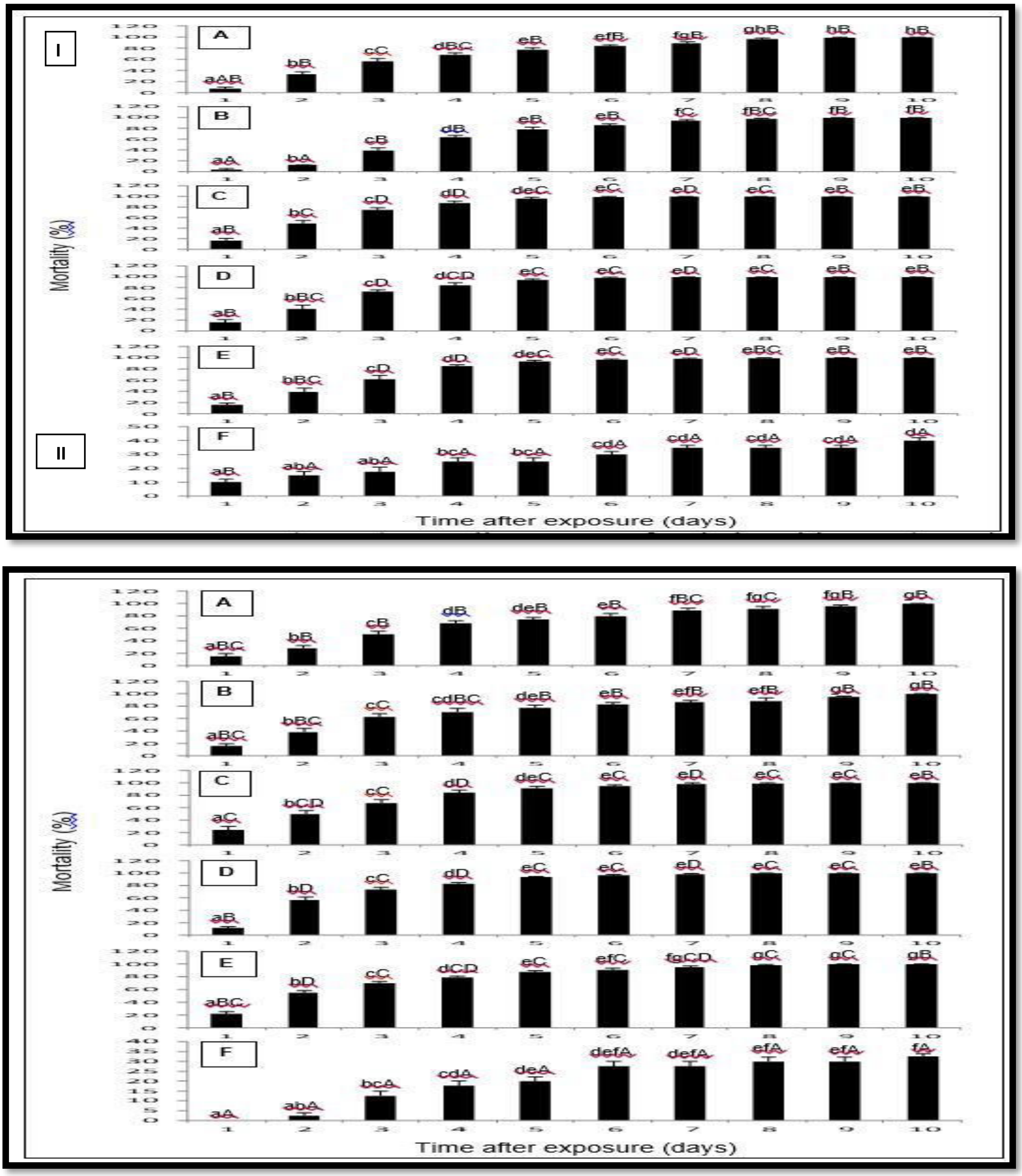

Figure 3: Average (±SEM) mortality percentage of the early (I) and late (II) larval instars of Spodoptera frugiperdaby application the three concentrations together

in the five products and the control by feeding on maize leaf discs treated with Bacillus thuringiensis (A), pyriproxyfen (B), rapeseed oil (C), abamectin (D), deltamethrin (E), and distilled water- control treatment (F)in a residual exposure test. [Different small letters above bars indicate significant differences among the different days within the same product and larval instar,while capital letters above bars indicate significant differences among the different products within the same dayand larval instar at P≤0.05(two-factor analysis of variance)].

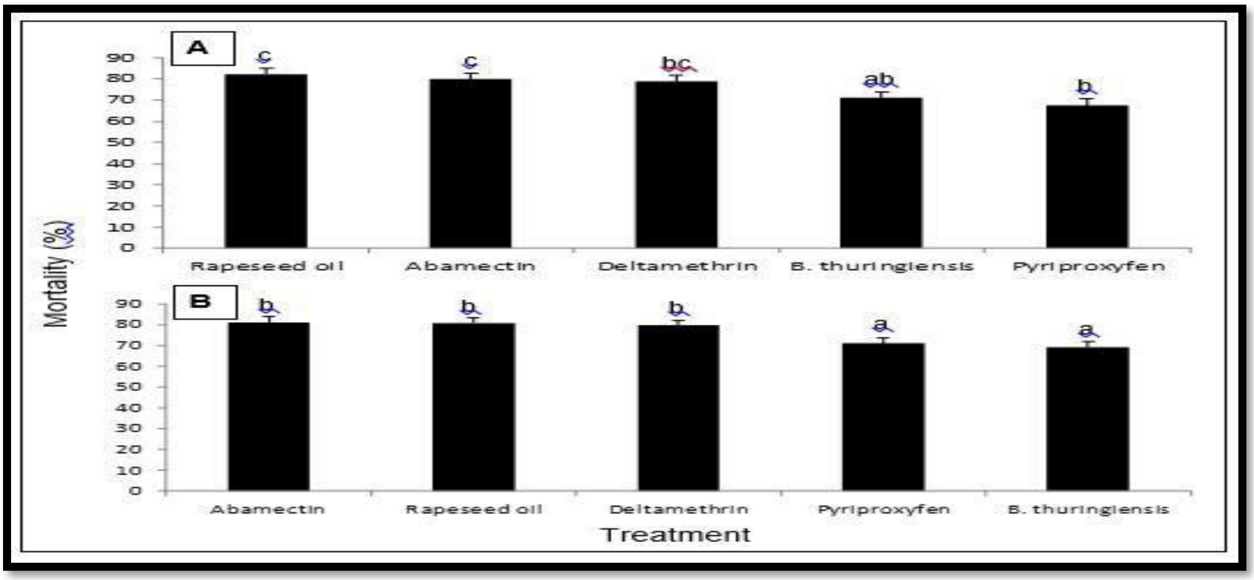

Figure 4: Average (±SEM) mortality percent of the early larval instars (L_1–L_2) (A) and late larval instars (L_4–L_5) (B) of Spodoptera frugiperda by feeding on maize leaf discs as a results of the overall effect of all treatment concentrations together (low, medium and high) and during all days (1^{st}–10^{th} day) of the five treated materials in a residual exposure test. [Different small letters above bars indicate significant differences among the different treatments at P≤0.05(one-factor analysis of variance)].

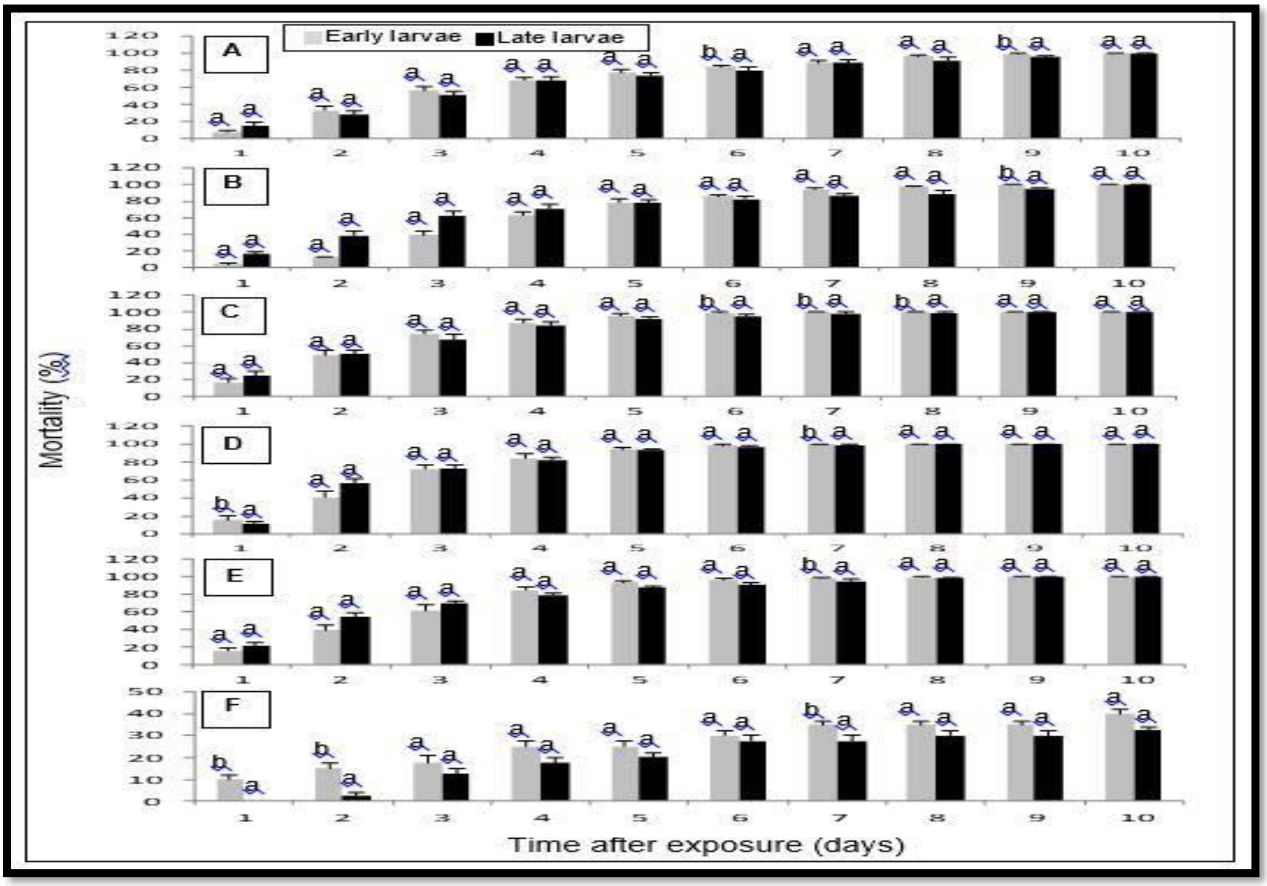

Figure 5: Average (±SEM) mortality percent of early larval instars (L_1–L_2) and late larval instars (L_4–L_5) of Spodoptera frugiperda by feeding on maize leaf discs (cv. Asgrow) treated with Bacillus thuringiensis (Biocure®) (A), pyriproxyfen (ACIPROX 10®) (B), rapeseed oil (Fytomax PX®) (C), abamectin (Biotrine 10®) (D), deltamethrin (Delta®) (E) and control (F) of the three different concentrations together in a residual exposure test. [Different small letters above bars indicate significant differences between the early and late larvae within the same day and treatment at P≤0.05 (T-test)].