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ASSESSMENT OF SELECTED INSECTICIDES AGAINST FALL ARMYWORM [*SPODOPTERA FRUGIPERDA* (J.E. SMITH); LEPIDOPTERA, NOCTUIDAE] ON MAIZE CROP IN LAHORE

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ABSTRACT

This study was focused on investigating the efficacies of insecticides that are being used locally to control fall armyworm (FAW). The experiment was laid out by using randomized complete block design having seven treatments *viz.* T_1 = Spinosad 16% + Emamectin Benzoate 4% SC @ 120 ml per acre, T_2 = Emamectin Benzoate 5% WDG @ 75 g per acre, T_3 = Chlorantraniliprole 20% SC @ 50 ml per acre, T_4 = Fipronil + Emamectin Benzoate 0.35% G @ 8 kg per acre, T_5 = Fipronil 5% SC @ 480 ml per acre, T_6 = Emamectin Benzoate 1.9% EC @ 200 ml per acre, and T_7 = Control. Each treatment was replicated four times. Maize crop was sown at the research area of Faculty of Agricultural Sciences, Punjab University, Lahore. All the recommended agronomic practices were followed. Crop was treated with all the treatments and data were recorded after 1, 3, 7, 14 and 21 days of treatment. Larvae per plant were counted by selecting random plants. Fipronil + Emamectin Benzoate 0.35% G provided the best control compared to other insecticides, as the lowest population of 2.00 larvae per plant were observed on plants treated with this insecticide after fourteen days. Chlorantraniliprole 20% SC and Emamectin Benzoate 5% WDG followed by Fipronil + Emamectin Benzoate 0.35% G managed the larval population much better as compared to rest of the insecticides with lowest population values of 3.25 and 3.25 larvae per plant, respectively. On the other hand, application of Spinosad 16% + Emamectin Benzoate 4% SC, Emamectin Benzoate 1.9% EC, and Fipronil 5% SC showed the lowest count of 5.00, 6.75, and 8.75 larvae per plant, respectively. This study suggests the use of Fipronil + Emamectin Benzoate 0.35% G and Chlorantraniliprole 20% SC against FAW larvae for their effective control under agro-ecological conditions of Lahore, Pakistan.

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INTRODUCTION

Maize is a high-return grain crop widely grown in Pakistan for human consumption and animal fodder. It is Pakistan's fourth most important crop after wheat, rice and cotton (Tariq and Iqbal, 2010), with an average yield of 2,850 kg ha^{-1} (Rehman et al., 2015). Although its consumption for human has decreased in Pakistan, its use in the feed and wet milling industries has grown far more rapidly than anyone anticipated (Naqvi and Ishfaq, 2013). Pakistan has enough maize to meet local demand. Thus, there is neither a surplus nor a shortage. With the exception of potatoes, maize is now the most profitable, dependable, and consistent agricultural crop in Pakistan (Memon et al., 2012).

Almost 250 species of insect and mite pests can damage maize crop, but only approximately half are commercially significant. Economic production losses occur all over the country due to pests such as the maize stem borer, pink stem borer, corn earworm, stalk borer, two types of shoot fly, fall armyworm, maize cob borer, maize aphid, and maize worm (Ahmad et al., 2021). *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae), often known as the fall armyworm (FAW), is native to the subtropical and tropical regions of the American continent. More than 80 crop species are attacked by this worm with maize, sorghum, rice, sugarcane, millet, and cotton constituting its most prominent hosts (Montezano et al., 2018). Due to its high reproductive capability and aggressive migratory behavior, the FAW is an invasive pest that has the potential to cause enormous economic damage (Sena Jr et al., 2003). In 2016, FAW made its first documented appearance in Nigeria. In the years since, it has spread to more than 28 countries across southern and eastern Africa (Georgen et al., 2016). Recently, it has been documented in several maize-growing locations in China, Bangladesh, Myanmar, Thailand, Yemen, India, and Sri Lanka (Ganiger et al., 2018; Sharanabasappa et al., 2018; Swamy et al., 2018). Bordering countries with existing infestations are most likely to experience an influx of this pest. India and Pakistan share a similar climate and grow cotton, corn, rice, tomatoes, potatoes, and chilies (Naeem-Ullah et al., 2019). Since FAW arrived in India in 2018, public and commercial agriculture groups were concerned in Pakistan but nothing was confirmed. However, certain alien lepidopteran larvae were observed in March 2019 in spring corn fields in Sindh. The presence of FAW larvae in Pakistan was confirmed upon careful examination (Naeem-Ullah et al., 2019; Gilal et al., 2020). Later on, its presence was reported from various maize growing areas of Pakistan (Khan et al., 2020; Ahmad et al., 2021; Ramzan et al., 2021).

After the initial invasion season of 2019–2020, widespread FAW larvae infestations were seen in maize fields in Pakistan. Various management approaches have been utilized globally to decrease crop damage from FAW. Despite causing extensive damage to maize crops, it has not yet been well managed in Pakistan (Ahmad et al., 2021). Several countries, except Pakistan, employ various chemical control strategies against FAW. Many insecticides are being used to control FAW, including emamectin benzoate, spinoteram, thiamethoxam, chlorantraniliprole, lambdacyhalothrin, fipronil and chlorfenapyr in different parts of the word (Mallpur et al., 2019; Bharadwaj et al., 2020; Kumari et al., 2020; Sustano et al., 2021; Kumar and Mohan, 2022). The present study was focused on assessing the insecticidal actions of different insecticides and their combinations available in the local market for the control of FAW population.

MATERIALS AND METHODS

Study area

The studies were carried out at the research area of Faculty of Agricultural Sciences, University of Punjab, Lahore during spring season 2022 to assess the insecticidal potential and efficacy of several insecticides available in the local market to control fall armyworm population.

Insecticides

Six insecticides namley Spinosad 16% + Emamectin Benzoate 4% SC (no brand name – under trials), Emamectin Benzoate 5% WDG (Emamectin Benzoate 5% WDG), Chlorantraniliprole 20% SC (Coragen), Fipronil + Emamectin Benzoate 0.35% G (Rector Super 0.35% G), Fipronil 5% SC (Mark Nine) and Emamectin Benzoate 1.9% EC (Emamectin Benzoate 1.9% EC), were chosen for their efficacy evaluation and were procured from different vendors.

Experimental design and treatments

The experiment was laid out in a randomized complete block design having seven treatments. Each treatment was replicated four times. Seed beds were prepared by following all the agronomic practices in the plots. Pre-irrigated fields for the experiment were prepared by ploughing. Maize seeds were sown at the rate of 10 kg per acre in each block by means of a seed drill machine by maintaining a row-to-row distance of 0.6 m. Macro nutrients were supplied by using nitrogenous and potash fertilizers at the recommended doses at sowing time, when the crop was 0.45–0.6 m tall, and after tasseling. Experimental field plots and the surrounding areas were made weed free by manual operations. Following seven treatments were applied in four replications:

T_1 = Spinosad 16% + Emamectin Benzoate 4% SC @ 120 ml per acre
T_2 = Emamectin Benzoate 5% WDG @ 75 g per acre
T_3 = Chlorantraniliprole 20% SC @ 50 ml per acre
T_4 = Fipronil + Emamectin Benzoate 0.35% G @ 8 kg per acre
T_5 = Fipronil 5% SC @ 480 ml per acre
T_6 = Emamectin Benzoate 1.9% EC @ 200 ml per acre
T_7 = Control

Data collection and statistical analysis

Data regarding fall armyworm larval population per plant were recorded at specified intervals of 1, 3, 7, 14, and 21 days after the application of insecticides by observing 4 randomly selected plants per plot. Data were subjected to two-way ANOVA followed by application of LSD test at P≤0.05. Computer software Statistix 8.1 was used for statistical analysis.

RESULTS AND DISCUSSION

ANOVA showed that there was significant variation among the time intervals (T), insecticidal treatments (I) and their interactions (T × I) with regards to population of fall armyworm larvae (Table 1). Six insecticides were selected in order to reveal their insecticidal actions and potential. Larvae count was recorded at specified intervals after the application of insecticides. Data recorded after one day of treatments was statistically analyzed and results were found to be significant. Significant differences were observed in the population on the maize plants treated with different insecticides. The lowest population (5.25 ± 0.50) was recorded on the maize plants treated with Chlorantraniliprole 20% SC (T_3), followed by T_4 = Fipronil + Emamectin Benzoate 0.35% G (5.50 ± 0.64), T_2 = Emamectin Benzoate 5% WDG (6.75 ± 0.69), T_1 = Spinosad 16% + Emamectin Benzoate 4% SC (7.50 ± 0.43), T_6 = Emamectin Benzoate 1.9% EC (7.50 ± 0.64), T_7 = Control (7.75 ± 0.32), and T_5 = Fipronil 5% SC (8.75 ± 0.42). Chlorantraniliprole 20% SC (T_3) performance was the best after 24 hours of its application at a dose rate of 50 ml per acre (Figure 1A). Villegas et al. (2019) found chlorantraniliprole effective against rice weevil larvae even when using doses that was 75% of the recommended dose. Likewise, Lutz et al. (2018) revealed the efficacy of chlorantraniliprole against *Spodoptera cosmioides* and found it effective after 48 hours of application with an LC_{50} of 0.054 µg mL^{-1} H_2O.

Table 1. ANOVA for the effect of insecticidal treatments on population of fall armyworm larvae at different time intervals after application.

Sources of variation	df	SS	MS	F values
Time intervals (T)	4	62.17	15.54	4.49
Insecticidal treatments (I)	6	1159.49	193.24	55.86
T × I	24	229.23	9.55	2.76
Error	105	363.25	3.46	
Total	139	1814.14		

*, ** = Significant at P≤0.01 and 0.001, respectively.

The larval count after three days of application showed significant results among all the treatments. Population of larvae on all the treated plants varied significantly and showed a clear difference among the efficacies of insecticides against the larvae. The highest FAW population was observed on the untreated control plants with an average larval count of 10.50 ± 0.68 per plant. On the other hand, the lowest count of larvae (3.75 ± 0.42) was recorded on those plants of T_4 = Fipronil + Emamectin Benzoate 0.35% G. The plants treated with Fipronil + Emamectin Benzoate 0.35% G were least attacked by FAW as the lowest population was recorded in this treatment. Chlorantraniliprole 20% SC and Emamectin Benzoate 5% WDG performed better than the rest of insecticides and provided good control against FAW larvae after 3 days of application (Figure 1B). Ahmed et al. (2022) found the similar results when treated the FAW larvae in laboratory conditions with 45% emamectin benzoate and 38% chlorantraniliprole. Susanto et al. (2021) studied efficacy of emamectin benzoate and other insecticides against the FAW larvae. They found emamectin benzoate very effective in laboratory, greenhouse and field studies as compared to phoxim, indoxocarb, methomyl and chlorfenapyr.

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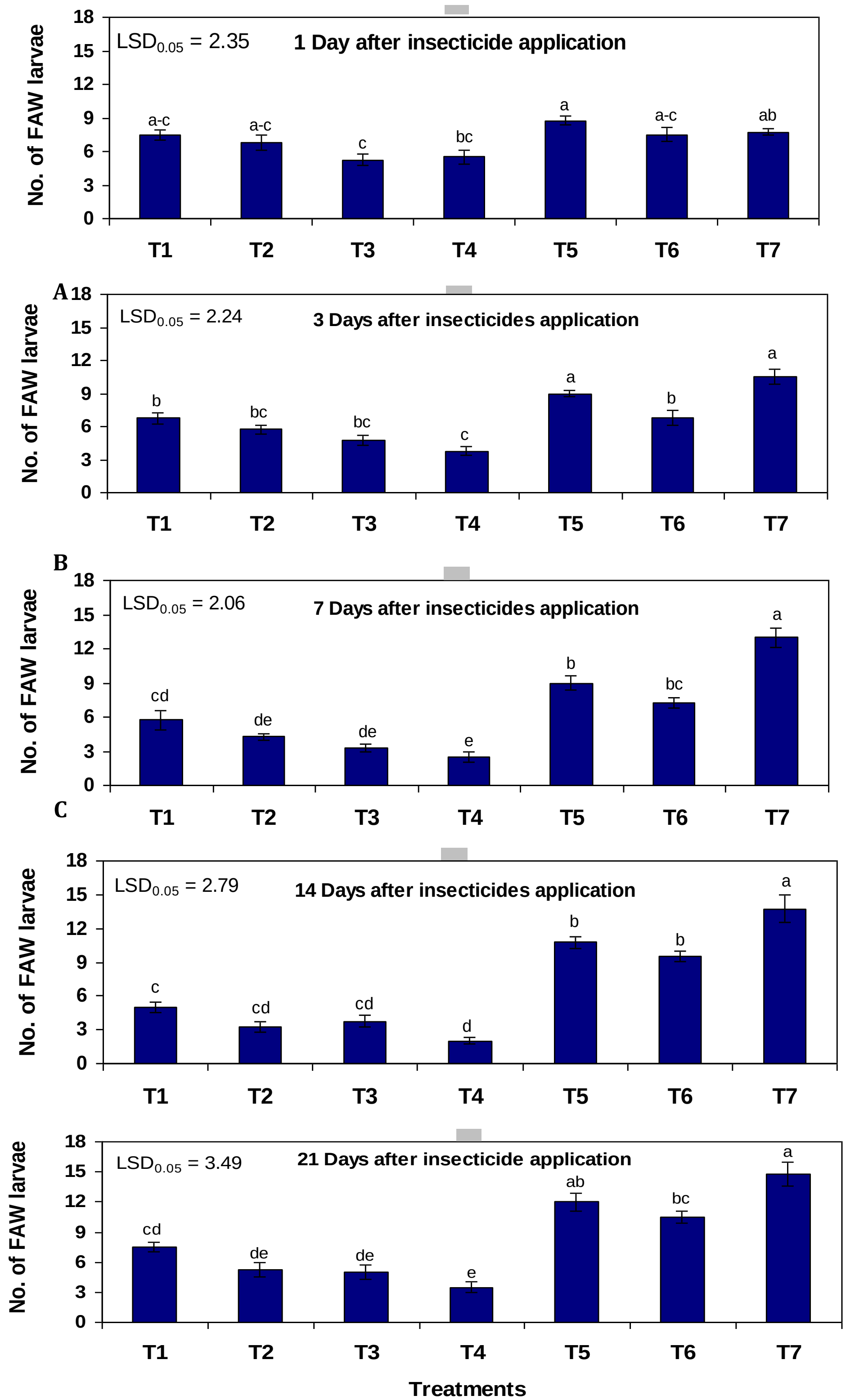

Figure 1A-E: Effect of insecticides on population of fall armyworm larvae on maize crop after different time periods of their application. T_1 = Spinosad 16% + Emamectin Benzoate 4% SC @ 120 ml per acre; T2 = Emamectin Benzoate 5% WDG @ 75 g per acre; T_3 = Chlorantraniliprole 20% SC @ 50 ml per acre; T_4 = Fipronil + Emamectin Benzoate 0.35% G @ 8 kg per acre; T_5 = Fipronil 5% SC @ 480 ml per acre; T_6 = Emamectin Benzoate 1.9% EC @ 200 ml per acre; T_7 = Control.

This testifies our results of Fipronil + Emamectin Benzoate 0.35% G being very efficacious against the FAW larvae.

Significant variation among treatments continued and after seven days of insecticidal applications, the results of all the treatments were found significant as compared to control. Major difference was seen between the larvae count on plants treated with Fipronil + Emamectin Benzoate 0.35% G (T_4). Fipronil + Emamectin Benzoate 0.35% G, Chlorantraniliprole 20% SC and Emamectin Benzoate 5% WDG were helpful in managing the FAW larvae and kept the population under control with larvae count of 2.50 ± 0.43, 3.25 ± 0.32, and 4.25 ± 0.32 per plant, respectively (Figure 1C). Bharadwaj et al. (2020) confirmed the efficacy of chlorantraniliprole and emamectin benzoate against FAW, as they studied the efficacy of several insecticides after three, seven and fourteen days of their application. Their data after seven days of treatment showed 9.73 and 4.53 larvae per 25 plants on the plants treated with chlorantraniliprole 18.5 SC @ 0.005% and emamectin benzoate 5 WG @ 0.002%, respectively, as compared to untreated plants where 42.67 larvae per 25 plants were observed.

Fortnightly data of larvae count revealed the significant variations among all the treatments. The trend was seen to be same as that of seven days post treatment results in data recorded after fourteen days of application. Fipronil + Emamectin Benzoate 0.35% G, Emamectin Benzoate 5% WDG, and Chlorantraniliprole 20% SC reduced the larvae count on maize plants with a mean larval density of 2.00 ± 0.27, 3.25 ± 0.42, and 3.75 ± 0.50 per plant, respectively. The highest larval density of 13.75 ± 1.26 per plant was recoded on maize plants that were not treated. Whereas, Spinosad 16% + Emamectin Benzoate 4% SC, Emamectin Benzoate 1.9% EC, and Fipronil 5% SC were found to be less effective with a larval count of 5.00 ± 0.47, 9.50 ± 0.43, and 10.75 ± 0.57, respectively (Figure 1D). Recently, Viteri and Linares-Ramirez (2022) revealed that emamectin benzoate (0.2 g L^{-1}) and chlorantraniliprole (0.6 ml L^{-1}) provided an adequate control of fall armyworm. Fipronil + Emamectin Benzoate 0.35% G were very effective similar to that of our study. The combination of fipronil and emamectin benzoate in granular form was the reason behind its effectiveness as compared to other insecticides.

Major differences in the population count among the treatments were observed after twenty-one days of treatments. Results were highly significant. Insecticidal effects started wearing off as after twenty-one days increase in the larval count was observed on all the maize plants treated with insecticides as compared to the earlier days' population count. The results showed the lowest population (3.50 ± 0.57 larvae per plant) on the maize plants treated with Fipronil + Emamectin Benzoate 0.35% G, followed by Chlorantraniliprole 20% SC (5.00 ± 0.72 larvae per plant), Emamectin Benzoate 5% WDG (5.25 ± 0.73 larvae per plant), Spinosad 16% + Emamectin Benzoate 4% SC (7.50 ± 0.43 larvae per plant), Emamectin Benzoate 1.9% EC (10.50 ± 0.64 larvae per plant), Fipronil 5% SC (12.00 ± 0.87 larvae per plant), and Control (14.75 ± 1.29 larvae per plant) (Figure E).

The data of each insecticide for specified intervals, namely one, three, seven, fourteen, and twenty-one days after treatment, were compared with the control in order to assess the efficacy of the insecticides over the course of the study. Results seems non-significant at the time of comparing the mean larval count per plant, when recorded for T1 = Spinosad 16% + Emamectin Benzoate 4% SC after the specified intervals of application. This revealed that the larval counts recoded on specified intervals were not significantly varied from each other. After one and twenty-one days of treatment, the larval density was somehow similar at 7.50 ± 0.43 larvae per plant, which depicted that the insecticide not offered a long-lasting control. The lowest population of 5.00 ± 0.47 larvae per plant was recorded after fourteen days of treatment. At Global level, Emamectin benzoate has been used for the management of lepidopteran pests (Zaka et al., 2014).

Significant variations were observed in the data recorded for T_2 = Emamectin Benzoate 5% WDG after specified intervals. This insecticide offered a good control over FAW larvae as the highest population was seen after one day of treatment with a mean larval count of 6.75 ± 0.68 per plant, while the lowest larval density was recorded after fourteen days of treatment with 3.25 ± 0.42 larvae per plant. Emamectin benzoate was found to be effective against *S. recurvalis* as compared to cypermethrin and imidacloprid (Cruces et al., 2021). Emamectin benzoate was 264.3 and 5707.1 times more toxic than novaluron and diflubenzuron, respectively, against cotton leafworm (Metayi et al., 2015). Emamectin benzoate was highly toxic to *Helicoverpa zea* with LC_{50} values being 0.718, 0.525, and 0.182 ppm for

24, 48 and 72 h responses, respectively (Lopez et al., 2010). During analyzing the data, result were seen non-significant when maize plants treated with T_3 = Chlorantraniliprole 20% SC. It appeared that Chlorantraniliprole 20% SC offered a consistent and good control over FAW larvae. The population was suppressed right after the application of Chlorantraniliprole 20% SC and consistently remained under a controlled range till fourteen days after application. After twenty-one days, population started bouncing back. The lowest population of 3.25 ± 0.32 larvae per plant was observed after seven days of treatment, while the highest population of 5.25 ± 0.50 larvae per plant was recorded after one day of treatment. Boukouvala and Kavallieratos (2021) found WG formulation of chlorantraniliprole more effective than SC formulation against maize pests. Even though, SC formulation provided 96.1% mortality at 10 ppm and 30°C, compared to 98.9% mortality at same dose and temperature provided by WG formulation. The insecticide promoted a decrease in the respiration rate of *Hypothenemus hampei* for up to 3 h after exposure, altering behavioral responses and locomotor activity, survivorship was also reduced to 52% when exposed to LD_{50} and 2% after exposure to LD_{90} (Plata-Rueda et al., 2019). Chlorantraniliprole also had a long-lasting effect when the *Plutella xylostella* larvae were exposed to chlorantraniliprole field sprayed on radish seedlings (Han et al., 2011).

Fipronil + Emamectin Benzoate 0.35% G provided the best control compared to all other treatments. The lowest population of 2.00 ± 0.27 larvae per plant was recorded after fourteen days of application, and this was the lowest larvae count recorded throughout the course of our study. Suppression of FAW population increased as the days passed by, however, FAW population increased after twenty-one days of treatment when larval density was 3.50 ± 0.58 per plant. Combination of emamectin benzoate either with azadirachtin, indoxacarb, or imidacloprid resulted in more negative impacts against tomato leaf miner larvae (Taleh et al., 2021). Fipronil when used in combinations with other insecticidal agents seem to be more lethal than using alone (Wakil et al., 2022).

T_5 = Fipronil 5% SC and T_6 = Emamectin Benzoate 1.9% EC were not efficacious as other insecticides used in our study. Both these insecticides offered the least control compared to the other insecticides. They were not able to suppress the FAW population as the population increased day by day even after their application.

CONCLUSION

Fipronil + Emamectin Benzoate 0.35% G provided the best control compared to other insecticides, as the lowest population of 2.00 ± 0.27 larvae per plant was observed on plants treated with this insecticide after fourteen days. Chlorantraniliprole 20% SC and Emamectin Benzoate 5% WDG followed Fipronil + Emamectin Benzoate 0.35% G and managed the larval density much better as compared to rest of the insecticides with the lowest population values of 3.25 ± 0.32 and 3.25 ± 0.42 larvae per plant, respectively. On the other hand, Spinosad 16% + Emamectin Benzoate 4% SC, Emamectin Benzoate 1.9% EC, and Fipronil 5% SC had the lowest larval count of 5.00 ± 0.47, 6.75 ± 0.68, and 8.75 ± 0.42 larvae per plant, respectively. The success of Fipronil + Emamectin Benzoate 0.35% G was due to its combination and granular formulation. Our study suggests the use of Fipronil + Emamectin Benzoate 0.35% G and Chlorantraniliprole 20% SC against FAW larvae for their effective control. Further studies are suggested to evaluate the biocontrol agents and botanicals for the control of FAW as these practices have been found very effective in controlling insects in various recent studies (Ahmad et al., 2022; Zafar et al., 2022; Maqsood et al., 2023).

AUTHORS' CONTRIBUTION

SM, MAB and MA designed the studies, did experimental work and collected data; MAB and SM contributed in paper writing; AJ prepared graphs and carried out statistical analysis; HS edited the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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