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Disrupting *Spodoptera frugiperda* (Smith): Ultrasonic waves as a novel pest control strategy

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ABSTRACT

Chemical pesticides are widely used to control *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae), but their misuse, including non-compliance with recommended doses or improper spraying methods, leads to significant environmental harm. Pesticides can volatilize and drift onto neighboring crops, soil, and water, negatively impacting the ecosystem and reducing the overall safety and efficacy of pest control measures. This study investigates the use of ultrasonic waves as a low-cost, environmentally friendly alternative to chemical pesticides for controlling *S. frugiperda.* The impact of ultrasonic waves on the insects' activity, mobility, and feeding behavior was continuously monitored over the course of the experiment. The results demonstrated that exposure to ultrasonic waves significantly reduced the hatchability of *S. frugiperda* eggs. Ultrasonic waves at frequencies of 31 KHz and 38 KHz resulted in the lowest number of hatched eggs per female, with values of 1231 and 1233, respectively, compared to 1239 in the untreated control group. Additionally, insects exposed to these frequencies showed a decreased feeding rate relative to the control. Continuous monitoring revealed that the insects tended to cluster away from the feeding leaves when exposed to ultrasonic waves, indicating a disruption in their normal feeding behavior and activity patterns. Statistical analysis confirmed a highly significant impact of ultrasonic waves on insect activity. These findings suggest that ultrasonic waves can effectively reduce key biological parameters in *S. frugiperda*, such as adult longevity, pupal weight, and fertility rate. Therefore, ultrasonic waves at frequencies of 31 KHz or 38 KHz are recommended as a safe, effective, and eco-friendly method for controlling *S. frugiperda*, particularly under greenhouse conditions. However, further field research is necessary to determine the practical efficiency and optimize the application of ultrasonic devices for broader agricultural use.

Keywords: *Spodoptera frugiperda,* Ultrasonic technology, biological parameters, alternative pesticides.

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INTRODUCTION

Fall armyworm (FAW), *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae), is a common insect pest that has significant negative effects on the agricultural sector such as damage maize plants and other crops worldwide (Casmuz *et al.,* 2010; Montezano *et al.,* 2018). Large populations of fall armyworm can cause significant damage to crops, leading to reduced yields and cause yield quantitative losses (Kandil and Abdelkader, 2023; Kandil *et al.,* 2023).

S. frugiperda females can lay up to 1000 eggs in 4-9 days, depending on the temperature. At a constant temperature of 23°C, the egg stage incubated for 4.8 days (Gong *et al.,* 2023). However, at higher temperatures of 27°C and 32±1°C, the incubation period decreased significantly to 1.37 days. At 27°C, *S. frugiperda* had the highest fecundity 717.67 eggs/female, hatchability 94.29%, and net reproduction rate 85.38 females/female (Sabra *et al.,* 2022). The life table program predicts and offers data on the fall armyworm's developmental period, reproduction, survival, population increase, and other biological characteristics (Chen *et al.,* 2023; Hong *et al.,* 2022; Sabra *et al.,* 2022; Soujanya *et al.,* 2022).

Insecticide resistance in *S. frugiperda* is a rising problem, since the pest has demonstrated resistance to several classes of insecticides (Chawanda *et al.,* 2023). To effectively manage insecticide resistance, integrated pest management strategies should be developed, which may include alternative control methods like biological control, cultural practices, and judicious use of insecticides, to manage pests sustainably (Hobbs, *et al.,* 2023). Smallholder farmers in sub-Saharan Africa have been adapting to the pest by improving crop surveillance and developing low-cost solutions like using ash in maize whorls, which has shown efficacy in reducing the number of larvae and damage to maize (Ullah *et al.,* 2023). Additionally, the use of *Trichogramma* species as biocontrol agents and the utilization of plant extracts with bioactive compounds have shown potential in controlling S. frugiperda (Henegamage *et al.,* 2023). Implementing these control measures can help mitigate the negative impacts of *S. frugiperda* on the agricultural sector.

The use of ultrasonic waves as an alternate technique is cost-effective and environmentally useful options to control *S. frugiperda* and reduce reliance on synthetic pesticides. So, the present investigation aims to investigate the effect of ultrasonic waves on *S. frugiperda* biological characteristics and to find fertility rate under laboratory conditions.

MATERIALS AND METHODS

Insect rearing

Spodoptera frugiperda larvae were collected from infested maize fields at Nubaria district, Behaira governorate, Egypt, and transferred to the laboratory of Plant Protection Research Institute, Agricultural Research Center, Alexandria branch, Egypt. Larvae were reared in glass jars (5-liter size), lined with sawdust for pupation, and covered with muslin clothes until adult emergence, at room temperature of 25±3ºC and relative humidity of 65±10% for one generation.

Pupae were collected and separated to male and female using a stereomicroscope. After 24 hours after emergence, 10 males and 10 females were placed in cages for copulation. Another piece of muslin cloth was hung inside the cage for oviposition. Moths were given a 10% sucrose solution by suspended cotton balls within the cage for feeding (Sabra *et al.,* 2022). Egg batches were separately in jars for hatching. Larval instars were determined by larval age. The fourth instar larvae were used in the present study, according to the purpose of the experiment.

Treatments

The experiment was randomly divided into four treatments: the first treatment was exposed to ultrasonic wave at a frequency of 25 KHz (12 hours/day) for five days, the second was treated with ultrasonic wave at a frequency of 31 KHz (12 hours/day) for five days, the third was treated with ultrasonic wave at a frequency of 38 KHz (12 hours/day) for five days, and the fourth treatment was an untreated control group (which was kept more than 40 meters away to avoid exposure to ultrasonic waves). In this investigation, a completely randomized design was used with three replicates, including ten males and ten females for each replicate.

Ultrasonic generator

An ultrasonic generator (model M071N - Germany industry - Fig. 1) was used to generate pulsing ultrasonic noises similar to sirens, which many pests find extremely unpleasant and, as a result, avoid whenever feasible. The generator's frequency may be adjusted from 8 to 40 kHz (±15%) using a 7-marks regular switch. The operational voltage range is 12 VDC (10-13.8 V). The range distance is less than 40 meters with a free field. The generator was powered by a 12 VDC-8 Ah battery, according to Habashy *et al.* (2018).

Effect of ultrasonic waves on fertility, survival and hatchability

The effects of ultrasonic waves on adult female fertility and survival, as well as the hatchability of eggs laid were assessed. To study these effects, 10 mated females were exposed to ultrasonic waves under room temperature for five days. According to Kehat and Gordon (1975), the female moth becomes ready to mate on the night of emergence, so adult males and females were isolated in glass jars for mating at room temperature with male: female ratio of 1:1. After 24 h, piece of muslin cloth was hung inside the cage for egg-laying and a cotton pad soaked in 10% sucrose solution for feeding (Sabra *et al.,* 2022). Three replicates (10 females and 10 male per replicate) were incubated in each treatment. After two days of copulation, the laid eggs were counted for 4 consecutive days, using a binocular microscope to determine fertility (number of eggs/female) (Zhang *et al.,* 2021). Thereafter, the females were observed daily until the final death to calculate survival. A random subset of eggs laid by different females was returned to their previous regime to determine the hatchability percentages. Egg hatchability was counted every two days, beginning from the 4th up to 20th day, after the release of *S. frugiperda* under laboratory conditions. In the case of non-hatching, eggs were dissected to check for the fertilization.

Egg hatchability % = No. of hatching larvae/Total number of eggs x 100

Effect of ultrasonic waves on the feeding of *Spodoptera littoralis*

The effect of ultrasonic waves on *S. frugiperda* larvae (4th instar) was assessed by continually monitoring their activity, movement, and weights on maize plant leaves before at the 3rd, 6th, 12th, 24th, 48th, and 72th hour after treatments.

Statistical analysis

Data were computed as mean ± standard error and the analysis of variance (ANOVA) was calculated using the "F" value to compare it with "F" table. In addition, the least significant differences (L.S.D) at the 0.05 level were estimated using computer statistical program (Costat software, 1988).

RESULTS

Egg hatching

Data in Table (1) show that the eggs exposed to three different frequencies of ultrasonic waves were significantly affected. However, ultrasonic waves treatments at frequencies of 31 KHz and 38 KHz produced lower total number of hatched eggs/females, with values of 1231.00±14.57 and 1233.00±19.92, respectively, compared to the control group, which achieved 1239.00±1.53 hatched eggs/female. It is important to indicate that the highest hatchability was obtained with ultrasonic wave of 25 KHz, while the lowest value was obtained with the frequency of 31 KHz or 38 KHz. On the other side, data strongly showed that the percentage of eggs hatching after *S. frugiperda* release increased gradually from the fourth to the twentieth day. In general, results showed that the highest values were found at check without significance after 10, 14, 16, 18, and 20th days at 25 KHz. Furthermore, results demonstrated that the lowest number of eggs hatching after *S. frugiperda* release was detected at the highest frequency of ultrasonic wave.

Feeding of *Spodoptera frugiperda* fourth instar larvae

Results in Table (2) showed the effect of ultrasonic waves on feeding of S. frugiperda larvae (4th instar) under laboratory conditions for 3, 6, 12, 24 and 72 hrs. The results showed a decrease in the feeding rate of insects exposed to ultrasonic waves at frequencies of 31 KHz and 38 KHz compared to the untreated check for the fourth instar of larvae, with an average of 1.24±0.06 and 1.12±0.12 g per 20 larvae, respectively, with no significant differences. The highest feeding rate was achieved with an ultrasonic wave frequency of 25 KHz, compared to the untreated control, which produced6.89±0.34 g per 20 larvae, with no significant differences.

Activity of *Spodoptera frugiperda*

Results in Table (3) present some biological aspects of S. frugiperda due to exposure to ultrasonic waves. The results demonstrated a decrease in pupal weight (mg) exposed to ultrasonic waves at frequencies of 31 KHz and 38 KHz, with no significant differences compared to the untreated control, which produced 474.00±6.66 mg pupa. The ultrasonic wave treatment had no significant influence on the number of hatching eggs per female, oviposition duration, or adult longevity. Ultrasonic waves at 38 KHz produced the lowest number of laid eggs /female and fertility (egg hatch), with values of

Table 1. Impacts of Ultrasonic wave (25, 31 and 38 KHz) on percentage of egg hatching (mean ± **Standard error)** after the release of fall armyworm, *Spodoptera frugiperda* under laboratory conditions.

Treatment	Total number of hatched eggs/females	Days after release								
		4	6	8	10	12	14	16	18	20
25 KHz	1237.00±20.66[a]	5.03±0.22[b]	6.92±0.04[b]	16.49±0.06[b]	27.02±0.36[a]	31.30±0.35[b]	34.74±0.39[a]	46.64±0.17[a]	56.76±1.61[a]	84.17±5.03[a]
31 KHz	1231.00±14.57[a]	3.38±0.18[c]	5.25±0.18[c]	10.21±0.31[c]	18.90±0.58[b]	21.07±0.01[c]	27.27±1.03[b]	31.19±0.82[b]	40.29±2.42[b]	47.54±0.63[b]
38 KHz	1233.00±19.92[a]	3.27±0.07[c]	5.00±0.19[c]	10.05±0.22[c]	18.70±0.45[b]	20.79±0.22[c]	26.70±0.49[b]	30.72±0.96[b]	39.97±1.39[b]	47.23±0.97[b]
Check (Untreated)	1239.00±1.53[a]	6.21±0.28[a]	8.34±0.28[a]	17.76±0.45[a]	28.30±0.80[a]	32.50±0.29[a]	39.53±3.29[a]	47.86±0.94[a]	59.18±2.33[a]	85.54±6.08[a]
LSD0.05	14.31	0.67	0.62	0.96	1.87	0.83	5.71	2.58	6.49	13.00

Values of the same letters within a column are not significantly different at the 0.05 level.

Table 2. Effect of ultrasonic waves (25, 31 and 38 KHz) on food consumption of *Spodoptera frugiperda* larvae (4th instar) under laboratory conditions.

Treatment	Larval food consumption ± Standard error as indicated by feeding duration						
	3 hours	6 hours	12 hours	24 hours	48 hours	72 hours	Mean
25 KHz	2.67±0.33[a]	3.00±0.58[a]	4.00±0.00[b]	7.00±0.00[a]	9.33±0.33[a]	11.67±0.33[a]	6.28±0.24[a]
31 KHz	1.00±0.00[b]	0.93±0.07[b]	1.00±0.00[c]	1.17±0.17[b]	1.33±0.18[b]	2.00±0.00[b]	1.24±0.06[b]
38 KHz	0.93±0.07[b]	0.83±0.03[b]	0.97±0.03[c]	1.00±0.00[b]	1.33±0.33[b]	1.67±0.33[b]	1.12±0.12[b]
Check (Untreated)	3.00±0.58[a]	3.67±0.33[a]	5.33±0.33[a]	7.33±0.33[a]	9.67±0.33[a]	12.33±0.33[a]	6.89±0.34[a]
LSD0.05	1.09	1.09	0.55	0.61	0.98	0.94	0.71

Values of the same letters within a column are not significantly different at the 0.05 level.

Table 3. Effect of ultrasonic wave's frequency on life traits the activity of *Spodoptera frugiperda* under laboratory conditions.

Treatment	Pupal weight (mg)	Total number of hatched eggs/females	Fertility rate		Duration (day)			
			No. of eggs laid/female	Fertility (egg hatch)	Oviposition (day)	Larva (day)	Pupa (day)	Adult longevity
25 KHz	470.67±4.33[a]	1237.00±3.06[a]	884.00±2.08[a]	71.46±0.02[a]	4.33±0.33[a]	16.33±0.33[b]	8.67±0.33[b]	9.33±0.88[a]
31 KHz	267.00±4.36[b]	1231.00±4.93[a]	871.67±1.67[b]	70.81±0.17[b]	4.33±0.67[a]	14.67±0.33[c]	9.33±0.33[ab]	9.67±0.33[a]
38 KHz	256.33±6.89[b]	1233.00±4.36[a]	446.67±2.03[c]	36.23±0.04[b]	4.00±0.58[a]	14.33±0.33[c]	10.67±0.67[a]	10.00±1.00[a]
Check (Untreated)	474.00±6.66[a]	1239.00±4.93[a]	880.00±2.89[a]	71.03±0.06[a]	4.33±0.33[a]	17.67±0.33[a]	8.33±0.33[b]	9.33±0.67[a]
LSD0.05	18.55	14.31	7.21	0.30	1.63	1.09	1.43	2.49

Values of the same letters within a column are not significantly different at the 0.05 level.

DISCUSSION

The utilization of ultrasonic waves in the management of *Spodoptera frugiperda*, also referred to as the autumn fall armyworm, represents a significant development in pest control techniques. Particularly, on this pest species, ultrasonic waves with frequency between 31 and 38 KHz have demonstrated notable repulsive effects. These frequencies offer a good substitute for conventional chemical pesticides because to their biological effects and repelling effectiveness. The study conducted by Habashy *et al.* (2018) highlights the noteworthy differences between insects that were treated and those that were not, underscoring the efficacy of ultrasonic waves. The ultrasonic wave treatments and control groups' food consumption was compared using a paired T-test in the study. The outcomes showed that insects exposed to ultrasonic waves consumed much less food, indicating a change in their eating habits.

Subsequent studies by Sabra *et al.* (2022) highlight the negative impacts of ultrasonic waves on *S. frugiperda* activities. Because fewer active insects are less likely to feed, breed, or spread over the agricultural area, the disturbance of insect activity may result in reduced harm to crops. This activity decrease adds to the general decrease in insect populations. Khan-Ahmadi *et al.* (2023) investigated frequencies between 20 and 100 KHz in order to broaden the applicability of ultrasonic waves. According to their research, these frequencies in 5 KHz increments can be a useful substitute for chemical pesticides in the management of a variety of insect pests, including *S. frugiperda*. According to the study, ultrasonic waves have a major negative effect on insects' ability to reproduce, which lowers their fecundity and fertility. According to Kandil (2013), exposure to ultrasonic waves causes metabolic suppression, which is the reason for this decrease in reproductive traits.

Determining the long-term effects on pest population dynamics requires an understanding of how ultrasonic waves affect life table characteristics. According to Hosseini-Tabesh *et al.* (2015), these characteristics are crucial for managing pests. Studies of life tables shed light on the persistence, growth, and procreation of pest populations, which aids in forecasting future population trends and the efficacy of management strategies. All of these research' results point to the possibility of using ultrasonic waves especially those with frequencies between 31 and 38 KHz to effectively control *S. frugiperda* in agricultural settings. There is strong evidence to support the use of this technique in pest management due to its repellant properties, decreased activity, and detrimental effects on reproduction.

An environmentally acceptable and sustainable substitute for chemical pesticides is the application of ultrasonic waves in the management of insect pests such as *S. frugiperda*. Nevertheless, to completely realize and optimize this technology for efficient pest management, more study and field validation are required. Still, there is a critical need for more fieldwork. Real-world agricultural settings, where a variety of factors might affect the effectiveness of pest management techniques, frequently differ from laboratory settings in this regard. Conducting field testing can facilitate comprehension of the real-world obstacles and enhance the utilization of ultrasonic devices for wider applications. The potential of ultrasonic waves to control insect pests like *S. frugiperda* offers a sustainable, eco-friendly alternative to chemical pesticides. However, ongoing research and field validation are essential to fully realize and optimize this technology for effective pest management.

Based on these findings, using ultrasonic waves with frequencies of 31 or 38 KHz for control of insects is suggested as a safe, effective, and eco-friendly method. Moreover, ultrasonic waves significantly reduce biological parameters in the pest, including adult longevity, pupal weight, and fertility rate. As a result, ultrasonic waves with frequencies of 31 KHz or 38 KHz can be used to control this insect especially under greenhouse conditions. However, more field research is needed to determine the efficiency of such device.

Authors Contribution

Conceptualization, Methodology, Investigation, Validation, Formal analysis, Data curation, Writing – original draft preparation, Writing – review and editing (RSA), Methodology, Investigation, Formal analysis, Data curation, Writing – review and editing (DHK), Methodology, Formal analysis, Data curation, Writing – review and editing (KSR), Visualization, Formal analysis, Resources, Funding acquisition, Writing – review and editing (AAA).

Ethics approval and Consent

This article does not contain any research with human participants or animals performed by any of the authors.

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