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Original Article

Ultrasonic wave exposure as a novel strategy for suppressing brown planthopper (*Nilaparvata lugens*) in laboratory condition

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Abstract

The high abundance and severity of brown planthopper or BPH (*Nilaparvata lugens* Stal) attacks have resulted in losses and crop failures worldwide, including in Indonesia. Control using ultrasonic waves has the potency to inhibit BPH attacks and is safe for the environment. This study examined the effect of ultrasonic wave frequency exposed to BPH for 24 hours. The study used a completely randomized design (CRD) consisting of seven treatments and five replications. The treatments were different ultrasonic wave frequencies (0, 20 kHz, 25 kHz, 30 kHz, 35 kHz, 40 kHz, 45 kHz). The data obtained were analyzed using analysis of variance (ANOVA) and LSD at a significant level of 5%. A T-test was conducted to know the effect of treatment on males and females of BPH. A regression test determined the relationship between treatment and observation variables. The results showed that exposure to BPH using ultrasonic waves with different frequencies significantly affected the activity, mortality, longevity, number of eggs laid, and the percentage and intensity of BPH attacks. BPH behaves away from the emitter and clusters and moves passively. The higher the frequency of ultrasonic waves, the higher the adult mortality. Males were more affected by exposure than females. Conversely, high ultrasonic wave frequencies can significantly shorten adult longevity, reduce the number of eggs hatched, and reduce BPH's attack percentage and intensity. Ultrasonic waves at 30-45 kHz were the best frequency for suppressing the population and attack level of BPH.

Keywords: Adult, Attack rate, Longevity, Mortality, Ultrasound

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Introduction

Rice (*Oryza sativa* Linnaeus) is Indonesia's leading food crop commodity because almost 97% of the Indonesian population consumes rice as a staple food (National Food Agency, 2018). Rice has a nutritional content of 78.9% carbohydrates, 6.8% protein, and 0.7% fat (Chaudhari et al., 2018). The demand for rice continues to increase along with the increasing population. In 2022, the population in Indonesia will reach 275.77 million people, with a consumption requirement of 31.54 million tons per year (BPS, 2023). The government prioritized controlling attacks by various pests and diseases to support the high demand for rice, including brown planthoppers or BPH (*Nilaparvata lugens*, Hemiptera: Delphacidae).

BPH is one of the main pests in rice plants, damaging by sucking plant cell fluids. Severe attacks can cause hopperburn and crop failure (Horgan et al., 2020; Iamba and Dono, 2021). BPH attacks are more severe if they also act as vectors for the rice ragged stunt virus (RRSV) and rice grassy stunt virus (RGSV) (Kusumaningrum et al., 2020; Wang et al., 2022). BPH attacks that failed to cause harvests in several places have been widely reported, including West Sumatra, Indonesia. The area of attack tended to increase in the 2018-2020 period, namely 440.45, 628.40, and 1,103.56 ha, respectively (West Sumatra Province Food Crop and Horticulture Protection Center, 2021), even Padang City as the provincial capital was not spared from the presence of this pest (Syahrawati et al., 2019). One of the control techniques preferred by farmers is synthetic insecticides, but they impact the environment negatively (Bagariang et al., 2020; Kanaan, 2021; Ahmad et al., 2024). Control using natural enemies is recommended because it is safe and environmentally friendly, such as the use of entomopathogens (Trizelia et al., 2023), parasitoids (Minarni et al., 2018), and predators (Utari et al., 2023, Syahrawati et al., 2024).

One of the control techniques that is currently being widely tested is the use of ultrasonic waves with frequencies in the range of 0-60 kHz; it is safe for humans but not liked by insects (Habashy et al., 2018; Silakari et al., 2018; Anwar et al., 2021). Some research reported that ultrasonic waves can cause insects to avoid or be eliminated. This is because insects can hear and detect sounds produced around them (Pollack, 2017).

Using ultrasonic sound wave frequencies can affect the feeding behavior and passive movement of pests, causing pests to be still, confused, not eating, moving away from the source of the waves, and ending in death (Nair et al., 2017). Ultrasonic waves can affect the usual developmental pattern of *Corcyra cephalonica* warehouse pest larvae, inhibiting molting (66.67%) and damaging the insect's resonance tissue (Kiruba et al., 2009).

Jinham et al. (2012) tested the effect of ultrasonic waves at 900 Hz - 2 kHz *on Tribolium castaneum*. This exposure caused mechanical damage to the cuticle and setae, damaged reproductive organs, and disrupted the metamorphosis process, fecundity, and fitness of insects. Larval mortality due to this exposure ranged from 58.6-79.1%. Kalimuthu et al. (2020) reported that ultrasonic waves at a frequency of 18-30 kHz exposed for 180 seconds caused the death of *Aedes aegypti* larvae to reach 100% at a distance of 60 cm. Damage was also found in the trachea, thorax, and abdomen. Ibrahim et al. (2016) reported that sound waves at 32-38 kHz exposed for 180 seconds caused 100% mortality of Aedes aegypti larvae and 98.3% of pupae.

Habashy et al. (2018) have conducted a trial using ultrasonic waves to control *Spodoptera littoralis*. The study showed a significant decrease in appetite after 6 hours of exposure, eliminating the source of the waves and causing death in the test larvae. Darmawan (2018) reported that BPH can be controlled using an ultrasonic-LED hybrid. This tool uses ultrasonic signals at a frequency of 40 kHz. Ratnawati and Setiadi (2019) have used techno pest control, which utilizes the loT system set at 40 kHz. Universitas Andalas has designed AGRARIS equipment to control BPH using ultrasonic waves (Rahman and Arif, 2021). This study aimed to determine the effect of differences in ultrasonic wave frequencies emitted by AGRARIS on brown planthoppers at the laboratory.

Material and Methods

Research design

This research was conducted from February to April 2023 at the Insect Bioecology Laboratory and Plant Clinic, Department of Plant Protection, Faculty of Agriculture, Universitas Andalas, Padang, Indonesia.

The effect of different ultrasonic wave frequencies on BPH was carried out using a Completely Randomized Design (CRD) with 7 treatments and 5 replications. The ultrasonic wave frequencies tested were: A = 0 (Control), B = 20 kHz, C = 25 kHz, D = 30 kHz, E =

35 kHz, F = 40 kHz, G = 45 kHz. The exposure time was 24 hours.

Host provision

The variety of rice seeds used for BPH propagation was IR42. 50 g of rice seeds were soaked in water for 24 hours and air-dried for 60 minutes. Furthermore, the seeds are sprinkled evenly on a rice field mud tray and covered in a pest cage. This plant can be used as a host for BPH propagation after 7 days.

Provision of brown planthoppers

The BPH used is the 25th generation of rearing at the Insect Bioecology Laboratory, Department of Plant Protection, Faculty of Agriculture, Universitas Andalas. Ten pairs of adults were infested into cages that already contained rice plants that were 7 days old after sowing. The host plants were replaced with new ones when they showed yellowing symptoms. This activity continued until 700 pairs of adults were obtained for testing.

Research implementation

The planting medium used was a mixture of rice field soil and cow manure with a ratio of 5:1, stirred evenly. The medium was then put into a 10 cm x 20 cm x 7 cm tray, water was added until the soil condition was wet (water height = 2 mm), and then it was left for 15 days. Furthermore, 40 rice seeds were sown in the plastic trays that have been provided. After 7 days, thinning was carried out by leaving only 30 rice seedlings per tray; 10 rice seedlings will be used as destructive samples to observe eggs. A total of 20 pairs of adults are infested into trays containing 30 rice seedlings aged 7 days after sowing, then covered with a 50 cm x 40 cm x 40 cm cage. The tool used as an ultrasonic wave transmitter is AGRARIS, created by students from Universitas Andalas (Rahman and Arif, 2021) (Figure 1). The distance between the Agraris tool and all treatments is 1.5 meters. Exposure of ultrasonic waves to BPH was carried out for 24 hours. The treatment sketch is illustrated in Figure 2.

Figure-1. AGRARIS equipment: a. Complete equipment, b. Agraris part that emits ultrasonic waves

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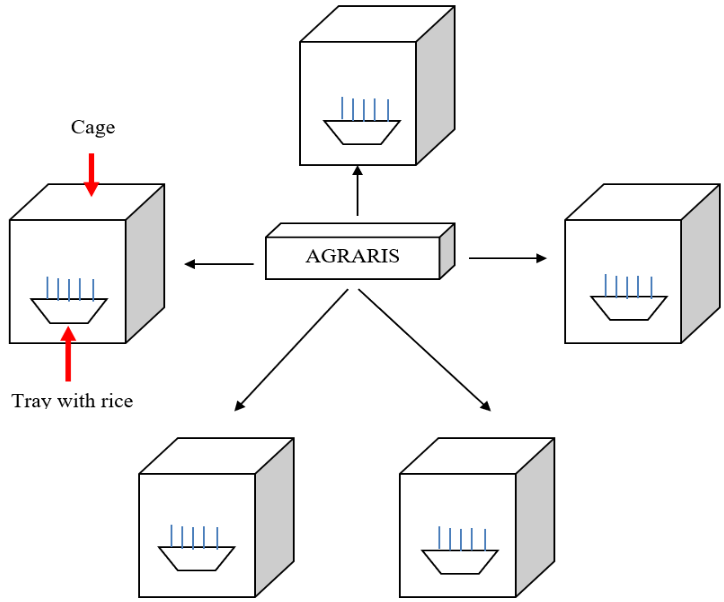

Figure-2. Illustration of a research plan using Agraris equipment, emitting ultrasonic waves.

Brown planthopper behavior

Observation of BPH behavior began after 1 hour of treatment with AGRARIS. The presence and position of BPH in the cage were observed and counted, spread out or in groups, on rice stalks or in plastic cages. All behaviors carried out by BPH have been documented and tabulated.

Brown planthopper mortality

BPH mortality was calculated every day for 7 days using the formula:

$$\mathbf{M = \frac{n}{N} \text{ X } 100\ \%} \text{ ....(1)}$$

Description: M = Mortality (%), n = Number of BPH died, N = Number of BPH treated

Adult longevity

The length of the adult stage (male and female) was observed by counting the number of males and females still alive from the first time it was done until the BPH died. Observations were carried out for 7 days.

Egg hatched

BPH lays eggs by inserting them into the lower leaf sheath of rice, which looks like a small print on the leaf, sheath, or tiller or a brown puncture. In this research, counting begins after all eggs were estimated to have hatched, and many nymphs were found emerging to the surface of the tillers. The destructive rice tillers were slashed using a razor and observed under a binocular stereo microscope. The number of eggs found on each plant was counted and recorded. The count of eggs laid consists of fertile and non-fertile eggs. Healthy eggs (fertile) are usually transparent white to light yellow at the beginning of laying and change to corrosive or slightly brownish as the embryo develops. They are oval, symmetrical, transparent, and have smooth surfaces and rounded ends. Defective eggs (non-fertile) look pale, dull, or too dark, indicating that the embryo is not developing and has an irregular shape. Fertile eggs that hatch are flat, and there is a hole where the nymphs emerge. The percentage of eggs counted is calculated using the formula:

$$\textbf{egg hatched } (\%) = \frac{\textbf{number of hatched eggs}}{\textbf{number of egg laid}} \times \mathbf{100}\ \% \text{ ....(2)}$$

Attack percentage

Observations on the percentage of BPH attacks on plants occurred every day until the 7th day after exposure. The percentage of BPH attacks is calculated using the formula:

$$P = \frac{a}{b} \times 100\% \quad (3)$$

Description: P: Percentage of attacks (%), a: Number of rice seedlings attacked by BPH, b: Number of rice seedlings observed.

Attack intensity
The attack intensity (I) was determined by observing the level of attack on the test rice plants and calculated using the formula:

$$I = \frac{\Sigma (ni.vi)}{N.Z} \times 100\% \quad (4)$$

Description: I = Attack intensity (%), ni = Number of tillers attacked by BPH, vi = Attack score of each tiller, Z = Highest score value of the specified attack category, N = Number of rice tiller observed.
The scoring used to determine the v and Z are shown in Table 1:

Table-1. Scoring for attack intensity of brown planthopper.

Score	Description
0	No damage
1	Very little damage, damage to the first and second leaf tips of the plants less than 1%
3	Most of the first and second leaves of the plants are partially yellowed
5	Plants are yellowed and stunted or 10-25% wilted
7	More than half of the plants wilted or died, and the remaining plants were severely stunted and dried out.
9	All test plants of one line/variety died

Data analysis
BPH behavioral data were presented in descriptive form. Mortality, longevity, percentage of eggs hatched, percentage of attacks, and intensity of attacks were processed using analysis of variance and continued with the Least Significant Difference (LSD) test at the 5% level. A T-test was conducted to compare the differences in mortality and longevity between males and females. The data analysis was performed using the Stat 8 application. Meanwhile, to determine the trend of the relationship between ultrasonic wave frequency and variable observations and to predict data trends, a regression test was conducted using SPSS 16.

Results

Brown planthopper behavior
BPH exposure to ultrasonic waves at different frequencies showed various reactions. In control (0 kHz), BPH activity was seen to be expected, not separated from the ultrasonic wave emitter, and moving actively. In the 20-25 kHz frequencies, BPH reacted by moving away from the emitter and tended to be passive. BPH activity was clustered in the 30-45 kHz treatment, moving away from the emitter and passive (Table 2).

Table-2. Brown planthopper behavior after being exposed to ultrasonic waves with different frequencies.

Frequency (kHz)	Behavior		
	Movement	Position	Distribution
0	Active	Normal	Spread
20	Passive	Avoid	Spread
25	Passive	Avoid	Spread
30	Passive	Avoid	Cluster
35	Passive	Avoid	Cluster
40	Passive	Avoid	Cluster
45	Passive	Avoid	Cluster

Mortality of brown planthoppers

Based on the results, the exposure of BPH to ultrasonic waves for 24 hours (1 day) caused the mortality of BPH ranging from 16-48%, with a tendency to fluctuate. Males tended to be more sensitive than females. In general, there was no difference in mortality between males and females. The highest mortality in males occurred at an exposure frequency of 35 kHz, which was not significantly different from the frequencies of 30 and 40 kHz. The highest mortality in females occurred at an exposure frequency of 40 kHz. The difference was only seen at an exposure frequency of 30 kHz, where mortality in males was higher than in females, and at 40 kHz, where mortality in males was lower than in females (Table 3).

Table-3. Mortality of brown planthopper after exposure to ultrasonic waves with different frequencies for 24 hours.

Frequency (kHz)	Mortality (%) ± Standard Error								T value
	Male				Female				
0	0.00	±	0.00	d	0.00	±	0.00	e	-
20	16.00	±	0.02	c	15.00	±	0.01	d	0.98
25	17.00	±	0.02	c	15.00	±	0.02	d	0.83
30	36.00	±	0.02	ab	21.00	±	0.01	cd	0.04*
35	48.00	±	0.02	a	41.00	±	0.02	b	0.12
40	43.00	±	0.01	a	53.00	±	0.02	a	0.01*
45	31.00	±	0.03	b	30.00	±	0.01	c	0.80

Note: Numbers followed by the same lowercase letter in the same column are not significantly different according to the LSD test at the 5% significance level.

The effect of ultrasonic waves remained visible after exposure; there was an increase in the death rate, but the effect tended to stop on the 6th day after exposure, especially in males. Males tended to be more sensitive than females. The highest mortality in males occurred at exposure to a frequency of 35-40 kHz, while the highest mortality in females occurred at 40 kHz (Figure 3).

There is a positive linear relationship between BPH mortality and ultrasonic wave frequency. This means the higher the frequency, the higher the BPH mortality. The closeness of the relationship was relatively high (r male = 0.721, r female = 0.834), but males had higher mortality than females (Table 4, Figure 4).

Table-4. Mortality of brown planthoppers after exposure to ultrasonic waves with different frequencies for 24 hours.

Regression	Male		Female	
	Equation	r value	Equation	r value
Linear	Y= 0.332 + 0.968X	0,721	Y= 0.994X - 2.794	0.834
Exponential	-	-	-	-
Logistic	-	-	-	-

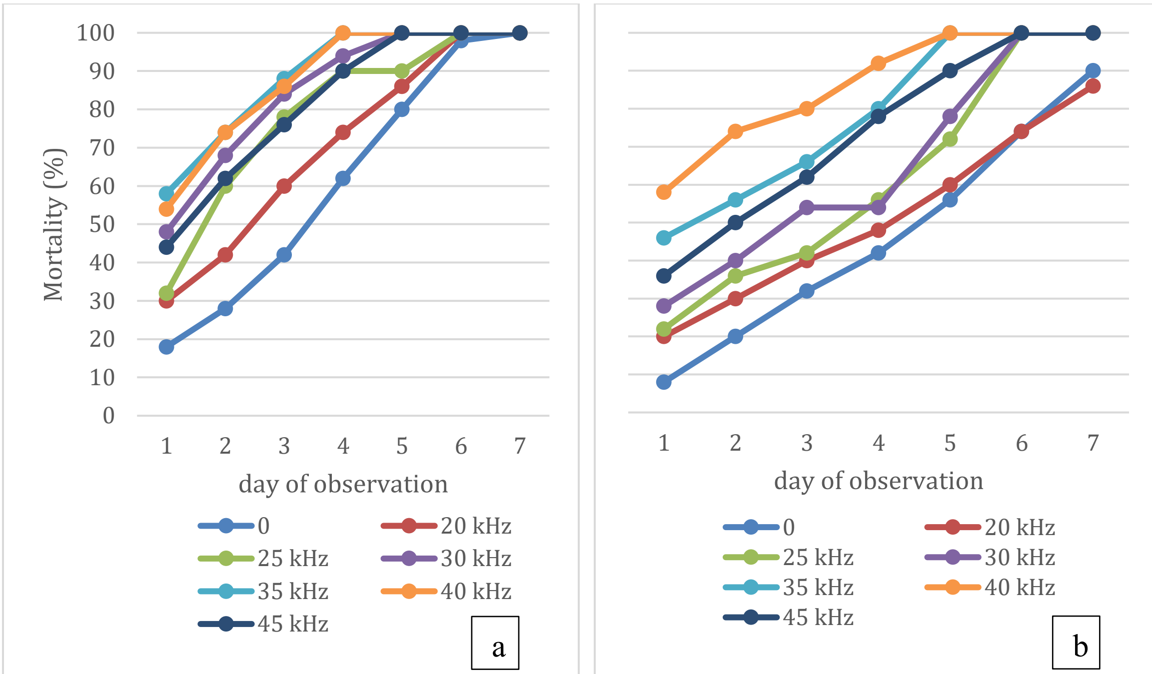

Figure-3. Mortality of brown planthoppers for 7 days after being exposed to ultrasonic waves with different frequencies, a. male, b. female.

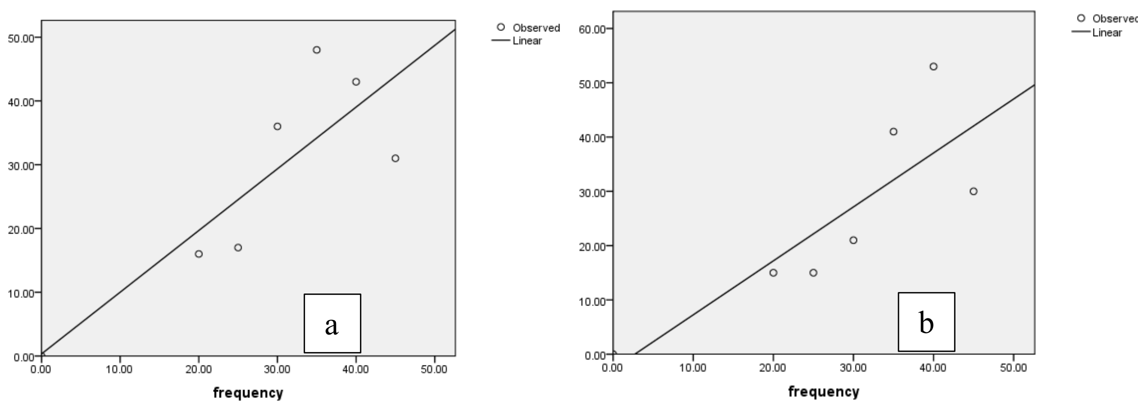

Figure-4. Regression curve showing the relationship between BPH mortality and ultrasonic wave frequency: a. male, b. female

Adult longevity

Exposure of WBC to ultrasonic waves for 24 hours (1 day) can shorten the lifespan of an adult, ranging from 1.8 to 4.42 days. The higher the frequency of ultrasonic waves given, the shorter the longevity. The shortest lifespan in males occurred at an exposure frequency of 45 kHz, which was not significantly different from the frequencies of 35 and 40 kHz. The shortest longevity in females occurred at 45 kHz. Based on the T-test, the longevity of males was shorter than that of females. This means that males tended to be more sensitive than females. An exception is seen in exposure to a frequency of 40 kHz, where there was no significant difference in lifespan between males and females (Table 5).

Table-5. Longevity of brown planthopper after exposure to ultrasonic waves with different frequencies (after 7 days of exposure).

Frequency (kHz)	Long life (Day) ± Standard Error								T Test
	Male				Female				
0	3.52	±	0.14	a	4.78	±	0.07	a	0.01*
20	3.08	±	0.05	b	4.42	±	0.05	a	0.00*
25	2.40	±	0.04	c	3.72	±	0.09	b	0.01*
30	2.28	±	0.04	cd	3.32	±	0.06	b	0.00*
35	2.06	±	0.03	cde	2.84	±	0.06	c	0.00*
40	1.86	±	0.02	de	2.66	±	0.04	c	0.23
45	1.80	±	0.04	e	1.96	±	0.07	d	0.04*

Note: Numbers followed by the same lowercase letter in the same column are not significantly different according to the LSD test at the 5% significance level.

Based on the r value of the regression test, the relationship between longevity and ultrasonic wave frequency is linear and relatively close, both males and females (r male 0.969; r female 0.950), but the relationship tended to be negative, meaning that the higher the frequency exposed, the shorter the longevity of both. The longevity of males tended to be shorter than that of females (Table 6, Figure 5).

Table-6. The lifespan of brown planthopper imago after exposure to ultrasonic waves with different frequencies.

Regression	Male		Female	
	Equation	r value	Equation	r value
Linear	Y= 3.592 – 0,042X	0.969	Y= 5.153 – 0,063X	0.950
Exponential	Y= 3.716 x $e^{(-0,016X)}$	0.967	Y= 5.531 x $e^{(-0,019X)}$	0.919
Logistic	Y= $e^{0.2691+1.016X}$	0.967	Y= $e^{0.181+1.019X}$	0.919

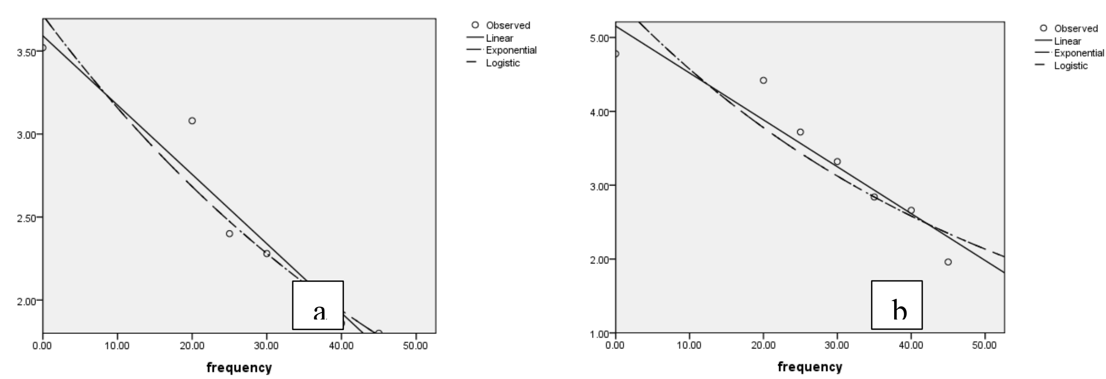

Figure-5. Regression curve showing the relationship between the longevity of brown planthopper and the frequency of ultrasonic waves: a. male, b. female

Egg laid and hatched

Exposure of BPH to ultrasonic waves for 24 hours (1 day) can reduce the number of eggs laid, with a range of 0-18.6 eggs, with the number of eggs hatching 0-13 eggs with a percentage of eggs hatching only 0 - 69.9%. The higher the frequency of ultrasonic waves, the fewer eggs were laid. At a frequency of 20%, the number of eggs released differs from the control. The effect of exposure to ultrasonic waves was clearly seen starting at a frequency of 25 kHz, even at 30-45 kHz, inhibiting no eggs being laid.

The shortest longevity in females occurs at an exposure frequency of 45 kHz. Based on the T-test, it is known that the lifespan of males is shorter than that of females. This means that males tend to be more sensitive than females. An exception is seen in exposure to a frequency of 40 kHz, where there is no significant difference in lifespan between males and females (Table 7).

Table-7. Number of eggs laid, number of eggs hatched, and percentage of eggs hatched after exposure to ultrasonic waves of different frequencies (after 7 days of exposure).

Frequency (kHz)	Number of eggs laid ± Standard Error	Number of eggs hatched ± Standard Error	Percentage of eggs hatched (%) ± Standard Error
0	37.8 ± 0.51 a	26.4 ± 0.38 a	70.1 ± 3.35 a
20	18.6 ± 0.34 b	13.0 ± 0.32 b	69.9 ± 2.50 a
25	4.8 ± 0.51 c	1.2 ± 0.40 c	13.3 ± 1.26 b
30	0 ± 0.00 c	- ± - c	- ± - b
35	0 ± 0.00 d	- ± - c	- ± - b
40	0 ± 0.00 d	- ± - c	- ± - b
45	4.8 ± 0.68 c	0 ± 0 c	0 ± 0 b

Note: Numbers followed by the same lowercase letter in the same column are not significantly different according to the LSD test at the 5% significance level. (-) no nymphs hatched from eggs

Based on the r value of the regression test, the relationship between egg laid and hatching with ultrasonic wave frequency is linear and relatively close (r egg laid 0.891; r egg hatching 0.852), but the relationship tended to be negative, meaning that the higher the frequency exposed, the lower the egg laid and hatching (Table 8, Figure 6).

Table-8. Number of brown planthopper eggs after exposure to ultrasonic waves with different frequencies.

Regression	Egg number laid		Egg hatching	
	Equation	r value	Equation	r value
Linear	Y= 33.882 – 0,842X	0.891	Y= 74.591 – 1,891X	0.852
Exponential	-	-	-	-
Logistic	-	-	-	-

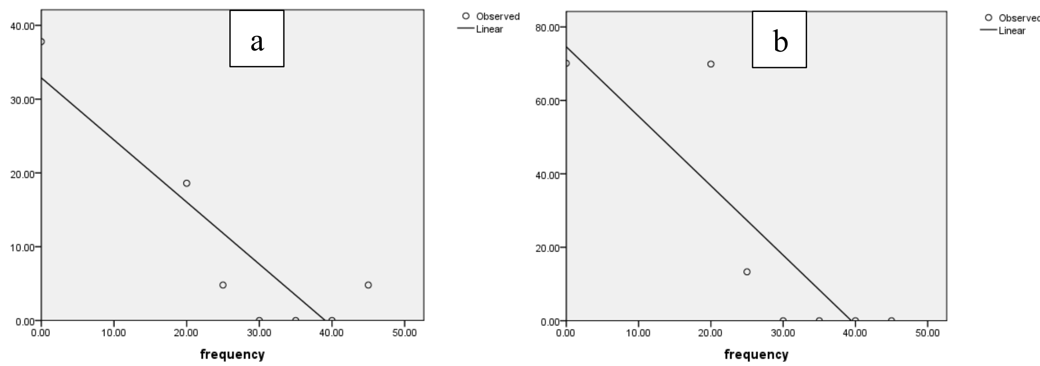

Figure-6. Regression curve showing the relationship between the number of eggs laid and the number of BPH eggs released with the frequency of ultrasonic waves: a. egg laid, b. eggs hatched (%).

Percentage and intensity of attacks

Exposure to ultrasonic wave frequencies has reduced the percentage and intensity of WBC attacks. The rate of attacks ranged from 23.33 - 42.67%, while the intensity of attacks ranged from 13.77 - 26.37%. The higher the frequency given, the lower the percentage and intensity of attacks (Table 9).

Table-9. Percentage of attacks and intensity of BPH attacks after exposure to ultrasonic waves with different frequencies (after 7 days of exposure)

Frequency (kHz)	Attack percentage (%) ± Standard Error				Attack Intensity (%) ± Standard Error			
0	50.67	±	1.95	a	29.78	±	1.69	a
20	42.67	±	1.69	b	26.37	±	1.07	ab
25	39.33	±	1.25	b	24.96	±	0.51	b
30	32.67	±	1.25	c	16.89	±	0.84	c
35	16.67	±	1.06	d	13.25	±	2.62	cd
40	20.67	±	1.25	d	12.22	±	1.10	cd
45	23.33	±	1.49	e	13.77	±	0.51	d

Note: Numbers followed by the same lowercase letter in the same column are not significantly different according to the LSD test at the 5% significance level.

Based on the r value of the regression test, the relationship between attack percentage and attack intensity was linear and classified as negative for both males and females (r male 0.900; r female 0.912). This means it has a very close relationship, but the higher the frequency exposed, the lower the intensity (Table 10, Figure 7).

Table-10. Attack percentage and intensity of brown planthopper after exposure to ultrasonic waves with different frequencies.

Regression	Attack percentage		Attack intensity	
	Equation	r value	Equation	r value
Linear	Y= 53.429 – 0,759X	0.900	Y= 31.093 – 0,441X	0.912
Exponential	Y= 57.321 x $e^{(-0,023X)}$	0.835	Y= 34.148 x $e^{(-0,022X)}$	0.891
Logistic	Y= $e^{0.017+1.023X}$	0.835	Y= $e^{0.029+1.022X}$	0.891

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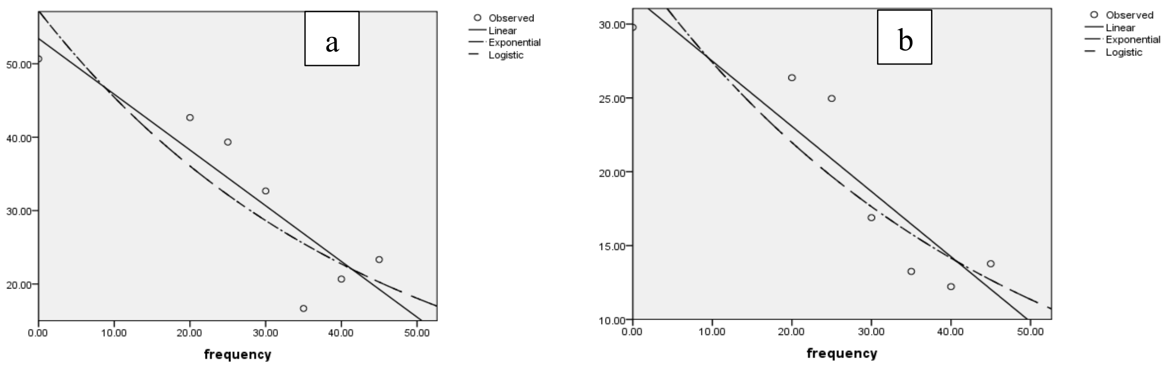

Figure-7. Regression curve showing the relationship between the attack percentage and the intensity with the difference frequency of ultrasonic waves: a. Attack percentage, b. attack intensity.

Discussion

Exposure to ultrasonic waves with different frequencies has significantly impacted the activity, mortality, longevity, number of eggs laid, and the percentage and intensity of brown planthopper attacks. The results showed that BPH activity tended to be passive when exposed to ultrasonic waves at 20-25 kHz. If the frequency was increased to 30-45 kHz, BPH would increasingly cluster, and the ultrasonic wave generator would disappear. This is likely due to the ability of ultrasonic waves to interfere with the insect's sensory system. According to Hoy et al. (1989), ultrasonic waves at specific frequencies can activate mechanosensory receptors in the tympanic organ, which are designed to detect the sounds of natural enemies, such as predators. According to Habashy et al. (2018), insects react to ultrasonic waves with avoidance behavior, such as flying away, scattering, or becoming passive. This phenomenon is to the research of Salehi et al. (2016) and Yetkin and Çikmann (2021) that exposure to ultrasonic waves in the Mediterranean flour moth (*Ephestia kuhniella*, Lepidoptera: Pyralidae) has caused changes in the behavior of the adult, which respond by avoiding the source of ultrasonic waves. Exposure to the pink stem borer, *Sesamia cretica* (Lepidoptera: Noctuidae), with ultrasonic waves, causes this pest to tend to avoid the emitter (Agah-Manesh et al., 2021). The Australian paralysis tick, *Ixodes holocyclus* (Acari: Ixodidae), also tends to prevent ultrasonic wave emitters (Panthawong et al., 2021).

The effect of ultrasonic waves with different frequencies does not affect the behavior of BPH but can also cause BPH mortality with a positive linear regression pattern; at higher frequencies, adult mortality increases. Mortality is higher in males than in females. This indicates that male BPH is more sensitive to ultrasonic exposure. In many species, male hearing organs are more sensitive than female tympanal organs, mainly because males are more active in detecting sound signals used in communication or finding mates (Pollack, 2003; Hou et al., 2017). Salehi et al. (2016) and Yetkin and Çikmann (2021) stated that male *E. kuhniella* were significantly more affected by ultrasonic waves than females.

The study showed that 40 kHz ultrasonic waves were the best in causing BPH mortality. This finding is more or less the same as several other studies. Khan-Ahmadi et al. (2023) stated that the highest rejection rate and mortality rate in German cockroaches (*Blattella germanica*, Blattodea: Blattellidae) occurred when exposed to ultrasonic waves at frequencies of 40 kHz and 75 kHz. Salehi et al. (2016) reported that exposure to ultrasonic waves on *E. kuhniella* with 43–45 kHz frequencies provided the highest ultrasonic repulsion. According to Agah-Manesh et al. (2021), the effect of ultrasonic waves on *S. cretia* was highest at frequencies of 39.5 and 37.5 kHz. In addition, exposure to ultrasonic waves significantly shortened the lifespan of BPH adults with a close negative linear relationship between longevity and ultrasonic frequency (r male = 0.969; r female = 0.950). Males have a shorter lifespan than females, indicating higher sensitivity.

The effect on BPH reproduction was also significant, where the number of eggs laid and hatching rates decreased significantly, starting from a frequency of 25 kHz. At frequencies of 30-45 kHz, almost no eggs were laid. This suggests that ultrasonic waves can interfere with the insect's reproductive system. This decrease in reproduction is relevant to research by Zha et al. (2021), which states that exposure to ultrasonic waves can negatively affect the normal juvenile hormone of insects and may further disrupt sexual maturation.

Exposure to ultrasonic waves with different frequencies has significantly reduced the percentage and intensity of BPH attacks (23.33-42.67% and 13.77-26.37%). The strong negative linear relationship (r male = 0.900; r female = 0.912) confirms the effectiveness of higher frequencies in suppressing brown planthopper attacks. The higher the frequency of ultrasonic waves, the lower the level of brown planthopper attack. This is most likely due to behavioral disturbances and increased mortality, ultimately reducing the attack rate. This is similar to what by MacLean (2016) and Peterson et al. (2009) conveyed. Susanti et al. (2022) reported that exposure to bamboo borer imago (*Dinoderus minutus*, Coleoptera: Bostrichidae) with ultrasonic waves in the frequency range of 10 - 65 kHz can cause mortality of up to 80%. This death is more influenced by behavioral changes. Exposure to ultrasonic frequencies prevents *D.minutus* from avoiding and stopping feeding activities.

Conclusion

The exposure of BPH using ultrasonic waves with different frequencies significantly affected the activity, mortality, longevity, number of eggs laid, and the percentage and intensity of BPH attacks. BPH behaves away from the emitter and clusters and moves passively (frequency of 30-45 kHz). The higher the frequency of ultrasonic waves, the higher the adult mortality. Males were more affected by exposure than females. Conversely, high ultrasonic wave frequencies can significantly shorten adult longevity, reduce the number of eggs hatched, and reduce BPH's attack percentage and intensity. Ultrasonic waves at 30-45 kHz were the best frequency for suppressing the population and attack level of BPH.

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Contribution of Authors

Syahrawati M: Involved in creating concepts and design of research, analyzing and interpreting data, responsible for data validity and compiling article drafts.

Rusydi MI: Involved in providing Agraris Equipment and ensuring that the equipment functions properly for laboratory testing, provided critical suggestions for drafting articles.

Arneti: Involved in implementing the research at laboratory according to plan, ensured the availability of brown planthopper for testing, provided critical suggestions for drafting articles.

Alvira Y: Implemented and collected research data, ensured all materials and equipment were available as needed.

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