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BIOPESTICIDAL POTENTIAL OF INDIGENOUS PLANT EXTRACTS AGAINST RICE WEEVIL IN STORED WHEAT

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ABSTRACT

Stored products are significantly affected by certain well-known stored grain pests, with *Sitophilus oryzae* L. (Coleoptera: Curculionidae) being one of the most destructive pests of stored products. It is a primary pest that causes substantial quantitative and qualitative losses. The present study was conducted to investigate the insecticidal efficacy of different plant extracts from four commonly grown plants in Pakistan: ginger (*Zingiber officinale*), neem (*Azadirachta indica*), clove (*Syzygium aromaticum*), and tobacco (*Nicotiana tabacum*) against *S. oryzae* infesting stored wheat. Crude extracts from these plants were applied to stored wheat at various dose rates (20 mg, 40 mg, 60 mg and 80 mg). Adults of *S. oryzae* were introduced to the treated wheat and observed for mortality, repellency, and grain damage. The results of the study indicated that the maximum mortality of *S. oryzae* (99.17%) was recorded due to the application of crude extract of *Z. officinale*, while the minimum mortality of *S. oryzae* (67.50%) was recorded due to the crude extract of *N. tabacum* at an 80 mg dose rate after a 10-day exposure interval. The maximum grain damage due to *S. oryzae* (0.19%) was observed in *N. tabacum* treated crude extract at an 80 mg dose rate, while the minimum grain damage due to *S. oryzae* (0.04%) was observed in *Z. officinale* treated crude extract at an 80 mg dose rate. *Z. officinale* also exhibited the maximum repellent effect on *S. oryzae* (95.77%). This study concluded that *Z. officinale* emerged as a potent, readily available biopesticide against *S. oryzae*, surpassing current alternatives with near-eradication efficacy, minimal grain damage, and a proactive repellent effect, paving the way for sustainable and eco-friendly pest management. Further research is needed to optimize extraction methods, dosage recommendations, and assess long-term effects on grain quality and storage stability.

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INTRODUCTION

Grain storage poses a tough challenge globally, as post-harvest losses due to insect infestations threaten food security and economic stability, particularly in agricultural-dependent nations like Pakistan (Jayas, 2012; Berhe et al., 2022). The preservation of stored grains requires effective strategies to combat pests, and the success of these strategies is crucial for sustaining the supply chain, reducing economic losses, and ensuring a stable food source for growing populations (Jayas, 2012; Kumar et al., 2021; Guru et al., 2022).

Insect pests in stored grains exert a profound global impact by causing substantial economic losses and compromising the quality of stored food (Ahmad et al., 2022; Guru et al., 2022; Stathas et al., 2023). The pervasive nature of these pests contributes to post-harvest losses, affecting food availability and exacerbating concerns about global food security (Berhe et al., 2022; Gerken and Morrison, 2022). Among these pests, rice weevil (*Sitophilus oryzae*), with its ability to infest a wide range of grains, stands out as a significant contributor to the overall challenge of managing stored grain pests on a global scale (Mehta et al., 2021; Parisot et al., 2021).

Sitophilus oryzae emerges as a major threat in stored grains, particularly wheat, due to its rapid reproductive cycle and adaptability (Trivedi et al., 2010; Zunjare et al., 2015; Cao et al., 2024). Its capacity to infest a variety of grains amplifies the economic losses associated with stored grain pests, making *S. oryzae* a crucial target for effective pest management strategies (Togola et al., 2013; Yaseen et al., 2019). The economic impact of *S. oryzae* infestation underscores the urgency to develop sustainable and targeted solutions to mitigate its detrimental effects on stored grains (Togola et al., 2013; Buffon et al., 2018; Derbalah et al., 2021; Okpile et al., 2021; Cao et al., 2024).

S. oryzae exhibits remarkable versatility in targeting a broad spectrum of grains, including wheat, rice, and barley (Mehta et al., 2021; Mehta and Kumar, 2021; Okpile et al., 2021). Its adaptability to infest diverse grains throughout the supply chain poses a significant threat to global food reserves, contributing to the challenge of preserving stored grains and exacerbating economic losses (Choudhury and Chakraborty, 2014; Zunjare et al., 2015; Derbalah et al., 2021; Kanmani et al., 2021; Kanyile et al., 2023; Mohammad et al., 2023; Cao et al., 2024). The wide-ranging impact of *S. oryzae* underscores the necessity of developing comprehensive and targeted pest management strategies to safeguard various grain crops from its pervasive infestations (Parisot et al., 2021; Ramadass and Thiagarajan, 2021).

Conventional preventive measures, primarily reliant on chemical pesticides, have shown effectiveness in controlling stored grain pests, including *S. oryzae* (Derbalah et al., 2012; Al-Harbi et al., 2021). However, the prolonged and widespread use of chemical pesticides raises environmental and health concerns, as their residual effects can have detrimental consequences on ecosystems and human well-being (Bernardes et al., 2015; Ali et al., 2021; Tudi et al., 2021). The drawbacks associated with chemical pesticides highlight the need for alternative, sustainable approaches to pest management, prompting a shift towards eco-friendly solutions such as biopesticides in the quest for a more balanced and environmentally conscious agricultural practice (Romeh, 2018; Deguine et al., 2021; Rajamani and Negi, 2021; Hezakiel et al., 2023).

In response to the limitations and drawbacks associated with chemical pesticides, there has been a growing global interest in exploring biopesticides as viable alternatives for pest management (Ayilara et al., 2023; Hezakiel et al., 2023). Biopesticides, derived from natural sources such as microorganisms, plants, and their extracts, offer the promise of effective pest control while minimizing the negative environmental and health impacts associated with traditional chemical interventions (Rajamani and Negi, 2021; Ayilara et al., 2023). This shift towards biopesticides aligns with the broader goal of fostering sustainable agriculture, promoting ecological balance, and addressing the urgent need for environmentally friendly alternatives to combat pest-related challenges in grain storage and other agricultural practices (Fenibo et al., 2021, 2022; Guru et al., 2022; Hezakiel et al., 2023).

The historical use of plant-derived materials for pest control traces back through centuries, reflecting traditional agricultural practices that harnessed the natural properties of various plants. Indigenous communities have long employed plant extracts and botanical solutions to protect stored grains from pests, showcasing a wealth of traditional knowledge and sustainable pest management practices (Rathore et al., 2021; Prakash et al., 2022). This historical foundation serves as a valuable inspiration for contemporary research endeavors aiming to explore and harness the biopesticidal potential of indigenous plant extracts against pests like *S. oryzae* in stored wheat, emphasizing a harmonious integration of traditional wisdom with modern scientific approaches (Thambi and Cherian, 2015; Derbalah et al., 2012; Shahreesh et al., 2023).

A global shift is underway towards environmentally friendly agricultural practices, recognizing the need to mitigate the ecological impact of conventional farming methods (Tal, 2018; Vidaller and Dutoit, 2022). Within this paradigm, there is a growing emphasis on integrating plant-based solutions and other eco-friendly approaches to address challenges such as pest management (Deguine et al., 2021; Jaiswal et al., 2022; Dara et al., 2023). Harnessing the biopesticidal potential of plants aligns with this broader movement, as it offers a sustainable alternative that not only combats pests effectively but also contributes to a more environmentally conscious and ecologically sustainable agricultural system, echoing the principles of integrated pest management (Ansari et al., 2012; Okwute, 2012; Hezakiel et al., 2023).

The utilization of plant extracts as biopesticides presents several advantages in pest management. These botanical solutions are characterized by biodegradability, making them environmentally friendly and reducing the risk of residual toxicity (Ngegba et al., 2022; Riyaz et al., 2022). Moreover, plant-based biopesticides often exhibit target specificity, minimizing the impact on non-target organisms and allowing for a more tailored and sustainable approach to pest control (Fenibo et al., 2021; Salimi and Hamedi, 2021; Verma et al., 2021). The exploration of indigenous plant extracts in this context holds promise for developing effective, culturally relevant, and environmentally conscious solutions against pests like *S. oryzae* in stored wheat, contributing to a holistic and sustainable agricultural ecosystem (Derbalah et al., 2012). Therefore, the present experiments were conducted to evaluate the insecticidal toxicity of four plant extracts (*Azadirachta indica, Zingiber officinale, Syzygium aromaticum* and *Nicotiana tabacum*) against the *S. oryzae* in stored wheat. Additionally, the experiments aimed to assess the repellency effect of these extracts on *S. oryzae* to prevent infestation in treated wheat. Furthermore, the research sought to determine the impact of each extract on grain damage caused by *S. oryzae*, aiming to quantify the potential reduction in food loss. The overall objective of the research was to identify effective and environmentally friendly plant-based solutions for managing *S. oryzae* infestations and minimizing grain damage in stored wheat.

MATERIALS AND METHODS

Location of study

The study was conducted at the Entomology Laboratory, Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan (31° 43′ 17″ N and 74° 16′ 14″ E).

Acquisition and rearing of *Sitophilus oryzae*

The adults of *S. oryzae* were obtained from Akbari Grain Market Lahore, Pakistan (31.5807° N, 74.3256° E). *S. oryzae* was reared on sterilized wheat and the culture maintained at 28 ± 2°C and 65 ± 5% R.H. In the laboratory, initially 50 pairs of 1-2 days old adults were placed in a jar containing wheat flour as food. The jars remained sealed for a maximum period of 7 days to allow mating and oviposition. Parental stock then was removed. The subsequent progenies of *S. oryzae* were used for all experiments.

Plant materials

Leaves of four plants (*Zingiber officinale*, *Azadirachta indica*, *Syzygium aromaticum* and *Nicotiana tabacum*) were collected from the trees planted under the boundaries of Rice Research Institute, Kala Shah Kaku, Pakistan, to conduct the study. The chemical profiles and properties of plant leaves tested for their insecticidal and repellent potential against *S. oryzae* are presented in Table 1.

Preparation of plant extracts

To prepare plant extracts, fresh leaves of *A. indica*, *Z. officinale*, *S. aromaticum* and *N. tabacum* were thoroughly washed with distilled water. Subsequently, the washed leaves were dried in the shade and finely ground into powder using an electrical grinder. In exploring the toxic effects of these extracts, four varying doses of plant powders (20 mg, 40 mg, 60 mg and 80 mg) were measured and individually placed in conical flasks.

For examining the repellent properties of the plant extracts, 10 g of plant powder was combined with 100 ml of distilled water in 250 ml conical flasks. The mixture was then heated to 60°C and stirred with a magnetic stirrer (AM4, Velp Scientifica, Italy) for 6 hours to ensure proper dissolution of the leaf powder. Solid residues were filtered out using muslin cloths, and the resulting plant extracts were filtered again (Whatman No. 1). After evaporating at 60°C under vacuum using a rotary evaporator, the dried plant extracts were brought to a constant volume in a hot air oven (60°C). These extracts were stored at 4°C until used as a stock solution.

Separate concentrations of *A. indica*, *Z. officinale*, *S. aromaticum* and *N. tabacum* extracts were prepared by diluting 20 ml, 40 ml, 60 ml and 80 ml, respectively, with distilled water from the stock solution. In the investigation of the impact of plant extracts on grain quality, four different doses (20 mg, 40 mg, 60 mg and 80 mg) were prepared using a similar procedure as in the toxic effect investigation.

Toxicity test of plant extracts for *S. oryzae*

Wheat grains (7.5 g) were measured and placed in plastic jars. Four different concentrations of crude plant extracts (20 mg, 40 mg, 60 mg and 80 mg) were individually mixed with the wheat grains. Twenty *S. oryzae* adults were gathered from rearing jars using an aspirator and released into each jar. Subsequently, the jars were covered with muslin cloth. The experiment was replicated three times and conducted in a dark room to stimulate the activity of *S. oryzae*. Mortality rates were determined and calculated after 5 and 10 days using the formula outlined by Henderson and Tilton (1995).

$$\text{Corrected mortlity (\%)} = (1 - \frac{\text{n in } C_o \text{before treatment} \times \text{n in T after treatment}}{\text{n in } C_o \text{after treatment} \times \text{n in T before treatment}} \times 100$$

Where: **n** = Insect population; **T** = Treated; $\mathbf{C_o}$ = Control

Table 1: Chemical profiles and properties of plant leaves tested for insecticidal and repellent potential against *Sitophilus oryzae*

Sr. No.	Plants		Bioactive compound	Aroma	Reason of commonly grown in Pakistan
	Common name	Scientific name			
1	Neem	*Azadirachta indica*	Azadirachtin	Bitter taste and distinct odor	Adapts well to diverse Pakistani climates, making it suitable for widespread cultivation
2	Ginger	*Zingiber officinale*	Shogaols + Gingerols	Pungent aroma	Thrives in the warmer, humid climate of Khyber Pakhtunkhwa and Swat regions
3	Clove	*Syzygium aromaticum*	Eugenol	Strong and spicy aroma	Prefers the cooler temperatures of the northern hilly areas
4	Tobacco	*Nicotiana tabacum*	Nicotine	Acrid smell	Tolerates various climates, although cultivation is limited due to regulatory restrictions

Repellence test of plant extracts for *S. oryzae*

The test began by cutting filter paper to fit the size of the Petri dish used. Half of the filter paper was immersed in four distinct doses of plant extracts individually for 5 minutes, while the other half was dipped in distilled water. This process was replicated three times. In each replication, twenty adults of *S. oryzae* were released in the center of the Petri dishes. The experiment took place in a dark room to stimulate the activity of *S. oryzae*. Repellency data were recorded after 1, 2 and 3 hour exposure interval using the formula outlined by Gillenwater and McDonald (1975).

$$\text{Repellence (\%)} = \frac{N_c - N_t}{N_c + N_t} \times 100$$

Where: $\mathbf{N_c}$ = No. of insects in control half; $\mathbf{N_t}$ = No. of insect in treated half.

Assessment of damaged grains due to *S. oryzae* exposed to crude plant extracts

Wheat grains (7.5 g) were weighed, quantified, and placed in plastic jars. Four concentrations of crude plant extracts were individually blended with the wheat grains. Twenty adults of *S. oryzae* were gathered from rearing jars using an aspirator and then released into the jars separately, each covered with muslin cloth. The experiment was replicated three times and conducted in a dark room to stimulate the activity of *S. oryzae*. After 10-day exposure interval, both damaged and undamaged wheat grains were tallied, and the data were recorded using the formula outlined by Atta et al. (2020).

$$\text{Grain damage (\%)} = \frac{N_d}{N} \times 100$$

Where: $\mathbf{N_d}$ = Number of damaged grains; **N** = Total number of grains in sample

Statistical analysis

In the conducted analysis, all parameters were subjected to an analysis of variance (ANOVA) using the statistical software Statistix (Version 8.1). This statistical method allowed for the examination of the differences among means associated with different treatments. Following the ANOVA, the next step involved the separation of treatment means through Tukey's HSD (Honestly Significant Difference) test. This post-hoc test is commonly used to identify specific pairs of treatments that exhibit statistically significant differences. The significance level chosen for these tests was set at 0.05, indicating a 5% probability of identifying a significant difference when it exists.

RESULTS

Toxicity test of plant extracts for *S. oryzae*

The main effects of extracts, dose, and exposure interval are highly significant ($P \leq 0.05$) on the percentage mortality of *S. oryzae*, while the interactions of plant extract × doses, doses × exposure interval, plant extract × exposure interval, and plant extract × doses × exposure interval are non-significant ($P \geq 0.05$) on the percentage mortality of *S. oryzae*. The crude extract of *Z. officinale* resulted in the maximum percentage mortality (93.13%) of *S. oryzae*, whereas the crude extract of *N. tabacum* recorded the minimum percentage mortality (51.04%) of *S. oryzae* (Table 2).

The highest concentration (80 mg) of crude plant extract led to the maximum percentage mortality (85.63%) of *S. oryzae*, while the lowest concentration (20 mg) resulted in the minimum percentage mortality (55.63%) of *S. oryzae* (Table 3). When exposed to plant extract, *S. oryzae* exhibited the maximum percentage mortality (77.38%) at a 10-day exposure interval, whereas the minimum percentage mortality (65.42%) occurred at a 5-day exposure interval (Table 4).

Repellence test of plant extracts for *S. oryzae*

The main effects of plant extract and exposure interval are highly significant ($P \leq 0.05$) on the percentage repellence of *S. oryzae*, while the interaction of plant extract × exposure interval is non-significant ($P \geq 0.05$) on the percentage repellence of *S. oryzae*. The plant extract of *Z. officinale* resulted in the maximum percentage repellence (95.77%) of *S. oryzae*, whereas the plant extract of *N. tabacum* recorded the minimum percentage repellence (21.88%) of *S. oryzae* (Table 5).

After 1-hour exposure interval to plant extract, *S. oryzae* exhibited the maximum percentage repellence (73.65%), while the minimum percentage repellence (47.82%) occurred after a 3-hour exposure interval to plant extract (Table 6).

Table 2: Percentage mortality (Mean ± SE, *n* = 3) of *Sitophilus oryzae* exposed to various plant extracts.

Plant extract	Percentage mortality
Z. officinale	93.13 ± 1.14 a
S. aromaticum	78.54 ± 1.83 b
A. indica	62.92 ± 1.87 c
N. tabacum	51.04 ± 2.28 d

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Table 3: Percentage mortality (Mean ± SE, *n* = 3) of *Sitophilus oryzae* exposed to various doses of plant extracts.

Doses (mg)	Percentage mortality
80	85.63 ± 1.97 a
60	76.46 ± 1.86 b
40	67.92 ± 2.26 c
20	55.63 ± 3.20 d

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Table 4: Percentage mortality (Mean ± SE, *n* = 3) of *Sitophilus oryzae* exposed to plant extracts at various exposure intervals.

Exposure Interval (days)	Percentage mortality
5	65.42 ± 1.35 b
10	77.38 ± 1.24 a

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Table 5: Percentage repellence (Mean ± SE, *n* = 3) of *Sitophilus oryzae* exposed to various plant extracts.

Plant extract	Percentage repellence
Z. officinale	95.77 ± 1.62 a
A. indica	76.84 ± 5.02 b
S. aromaticum	50.33 ± 6.58 c
N. tabacum	21.88 ± 4.77 d

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Table 6: Percentage repellence (Mean ± SE, *n* = 3) of *Sitophilus oryzae* exposed to plant extracts at various exposure intervals.

Exposure interval (hrs)	Percentage repellence
1	73.65 ± 6.63 a
2	62.15 ± 8.93 b
3	47.82 ± 8.81 c

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Table 7: Percentage grain damage (Mean ± SE, n = 3) caused by *Sitophilus oryzae* exposed to various doses of crude plant extracts.

Doses (mg)	Percentage grain damage
20	0.09 ± 0.013 b
40	0.11 ± 0.007 b
60	0.15 ± 0.019 a
80	0.16 ± 0.018 a

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Assessment of damaged grains due to *S. oryzae* exposed to crude plant extracts

The main effects of plant extract and doses are highly significant ($P \leq 0.05$) on the percentage grain damage caused by *S. oryzae*, while the interaction of plant extract × doses is non-significant ($P \geq 0.05$) on the percentage grain damage caused by *S. oryzae*. The maximum percentage grain damage (0.16%) caused by *S. oryzae* exposed to various plant extracts was recorded at the crude concentration (80 mg) of plant extract, while the minimum percentage damage (0.09%) caused by *S. oryzae* exposed to various plant extracts was recorded at the lowest crude concentration (20 mg) of plant extract (Table 7).

The highest percentage grain damage (0.18%) caused by *S. oryzae* exposed to crude extract of *N. tabacum*, while the lowest percentage grain damage (0.06%) caused by *S. oryzae* exposed to crude extract of *Z. officinale* (Table 8). The maximum percentage grain damage (0.24%) caused by *S. oryzae* exposed to crude extract of *N. tabacum* was recorded at the crude concentration of 60 mg, while the minimum percentage grain damage (0.04%) caused by *S. oryzae* exposed to crude extract of *Z. officinale* was recorded at the crude concentration of 80 mg (Table 9).

Table 8: Percentage grain damage (Mean ± SE, *n* = 3) caused by *Sitophilus oryzae* exposed to crude plant extracts

Plant extract	Percentage grain damage
N. tabacum	0.18 ± 0.012 a
A. indica	0.15 ± 0.013 b
S. aromaticum	0.12 ± 0.014 c
Z. officinale	0.06 ± 0.003 d

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

Table 9: Percentage grain damage (Mean ± SE, *n* = 3) caused by *Sitophilus oryzae* exposed to various crude plant extracts and their doses

Plant extract	Dose (mg)	Percentage grain damage
Z. officinale	20	0.04 ± 0.004 g
	40	0.04 ± 0.004 g
	60	0.06 ± 0.006 fg
	80	0.07 ± 0.002 efg
A. indica	20	0.05 ± 0.005 fg
	40	0.10 ± 0.001 cdefg
	60	0.14 ± 0.008 bcde
	80	0.18 ± 0.005 abc
S. aromaticum	20	0.08 ± 0.002 defg
	40	0.12 ± 0.002 bcdef
	60	0.18 ± 0.022 ab
	80	0.19 ± 0.008 ab
N. tabacum	20	0.13 ± 0.004 bcdef
	40	0.16 ± 0.006 bcd
	60	0.19 ± 0.001 ab
	80	0.24 ± 0.021 a

Means with different letters are significantly different (P < 0.05, Tukey's HSD test, comparisons across all treatments).

DISCUSSION

The present study investigated the biopesticidal potential of indigenous plant extracts against *S. oryzae* in stored wheat. The findings shed light on the promising prospects of utilizing these plant-based alternatives for sustainable pest management in stored grains.

The crude extract of *Z. officinale* demonstrated the highest insecticidal activity, resulting in significant mortality of *S. oryzae* compared to other tested extracts. This efficacy aligns with previous studies reporting the insecticidal properties of *Z. officinale* against various stored product pests (Lee et al., 2001; Mudrončeková et al., 2019). The observed mortality is likely attributed to the presence of bioactive compounds like α- and β-pinenes, zingiberene, and shogaol, which possess insecticidal and repellent properties (Shaaya and Kostyukovsky, 2009; Dambolena et al., 2016).

The insecticidal activity of plant extracts increased with increasing concentration, suggesting a dose-dependent response. This aligns with prior research demonstrating the concentration-dependent efficacy of plant extracts against insect pests (Koushik et al., 2019; Seni, 2023). Additionally, a longer exposure interval led to higher mortality compared to shorter intervals. This extended exposure duration likely allowed for greater absorption and interaction of bioactive compounds with *S. oryzae*, ultimately leading to increased mortality.

Similar to the insecticidal activity, *Z. officinale* extract displayed the strongest repellent effect, deterring *S. oryzae* to a greater extent than other extracts. This finding supports previous studies reporting the repellent properties of ginger against various insect pests (Edris et al., 2016; Haris et al., 2023). The repellent activity could be attributed to the volatile compounds present in the extract, which *S. oryzae* finds aversive and avoids.

Interestingly, a shorter exposure interval resulted in higher repellency compared to longer intervals. This suggests that initial contact with the extract triggers a stronger avoidance response in *S. oryzae*. As exposure time increases, the insects might acclimate or metabolize the repellent compounds, leading to decreased repellency over time.

The observed reduction in grain damage with increasing concentration of plant extracts highlights their potential for protecting stored wheat from insect infestation. This aligns with previous studies demonstrating the grain protectant properties of plant extracts against various storage pests (Papachristos and Stamopoulos, 2004; Zia et al., 2011). *Z. officinale* extract provided the best protection, minimizing grain damage compared to other extracts. This further emphasizes the superior biopesticidal potential of *Z. officinale* extract against *S. oryzae*. The varying degrees of grain damage caused by different plant extracts suggest that the specific bioactive compounds present and their modes of action differ. While *Z. officinale* extract effectively deterred *S. oryzae* and minimized grain damage.

Overall, the findings of this study demonstrate the promising potential of indigenous plant extracts, particularly *Z. officinale*, as biopesticides against *S. oryzae* in stored wheat. These plant-based alternatives offer a sustainable and eco-friendly approach to pest management, potentially reducing reliance on synthetic insecticides and their associated environmental and health risks. Future research should focus on optimizing extraction methods, identifying the most active biopesticidal compounds, and evaluating the efficacy of these extracts under long-term storage conditions and in practical storage settings.

CONCLUSION

The study investigated into assessing the biopesticidal capabilities of four indigenous plant extracts (*Zingiber officinale*, *Azadirachta indica*, *Syzygium aromaticum* and *Nicotiana tabacum*) in combating the *Sitophilus oryzae* in stored wheat. Notably, *Z. officinale* extract emerged as the most effective, achieving an impressive *S. oryzae* mortality rate and causing minimal grain damage. Moreover, *Z. officinale* extract demonstrated a robust repellent effect. In contrast, other plant extracts exhibited varying degrees of efficacy, with *A. indica* performing moderately well, while *S. aromaticum* and *N. tabacum* extracts proved less effective. The practical applications and impact of these findings underscore *Z. officinale* extract as a promising, natural, and eco-friendly alternative to conventional synthetic pesticides for safeguarding stored wheat. Its noteworthy attributes, including high efficacy, minimal grain damage, and repellent properties, suggest its potential integration into sustainable pest management strategies. This could prove particularly beneficial for farmers in resource-limited settings, offering an effective means to address pest-related challenges. The implications for pest management extend beyond the immediate findings, emphasizing the need to explore indigenous plant extracts as biopesticides. To enhance their practical application, further research is warranted. This includes optimizing extraction methods to standardize potency and efficacy, determining optimal dosages tailored to different storage conditions and target pests, and evaluating the long-term effects on grain quality and storage stability. Additionally, conducting field trials is crucial to confirm the efficacy of these plant extracts under real-world storage conditions. These steps collectively pave the way for a more sustainable and environmentally friendly approach to pest management in agriculture.

AUTHORS' CONTRIBUTIONS

BA and AMS designed and conducted the experiment, collected and analysed the data, and wrote manuscript; MAF, MDG and AN helped in apprehending the idea of this research, designing the layout of experiment and improving the write-up, format and language of this manuscript; MI, MAA, and MJN reviewed the manuscript, added and improved declaration section, edited the format of the tables according to the format of the journal; BA, AMS, MAA and MUS contributed in data setting for analysis, reviewed the final manuscript and made the format of this manuscript according to the format of the journal; This final manuscript was ultimately perused, scrutinized and approved for final submission by all the authors.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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