Physical Education, Health and Social Sciences

https://journal-of-social-education.org

E-ISSN: 2958-5996

P-ISSN: 2958-5988

# Integrated Use of Aluminum Phosphide and Neem Leaves for the Control of *Tribolium Castaneum* in Stored Wheat Grains

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***DOI:* https://doi.org/10.63163/jpehss.v4i2.1399**

**Abstract**

Insect infestations are a major cause of post-harvest losses, posing serious challenges to global food security and agricultural sustainability. Among the most destructive storage pests, the red flour beetle (*Tribolium castaneum*) causes substantial quantitative and qualitative losses in stored wheat grains through feeding damage and contamination. This study evaluated the comparative effectiveness of aluminum phosphide and neem (*Azadirachta indica*) leaves in controlling *T. castaneum* infestations in stored wheat under laboratory conditions. The treatments were assessed based on insect mortality, grain damage, weight loss, and seed germination rates. Aluminum phosphide achieved 100% mortality of *T. castaneum* within 2 days, demonstrating rapid and highly effective pest control. In contrast, neem leaf treatment resulted in a gradual increase in mortality, reaching 79% by the 7$^{th}$ day. Grain damage was lowest in aluminum phosphide-treated grains, while neem-treated grains experienced moderate levels of damage compared with the untreated control. However, aluminum phosphide significantly reduced seed germination (65%), indicating potential residual toxicity, whereas neem-treated grains maintained a higher germination rate (83%), suggesting better preservation of seed viability. The findings indicate that although aluminum phosphide remains highly effective for immediate pest eradication, neem leaves provide a safer, eco-friendly, and sustainable alternative for stored-grain pest management. Integrating neem-based treatments into post-harvest protection strategies may help reduce dependence on synthetic fumigants while maintaining grain quality and environmental safety.

**Keywords:** *Tribolium Castaneum*, Aluminum Phosphide, Neem Leaves, Stored Wheat, Post-Harvest Losses, Grain Damage, Seed Germination, Pest Management.

## Introduction

Insect infestations in stored wheat cause significant post-harvest losses, posing a serious threat to global food security and economic stability (Tadesse, 2020). Among storage pests, the red flour beetle (*Tribolium castaneum*) is particularly destructive. It damages grain not only through direct consumption but also by contaminating it with excrement and dead bodies, which degrades both quality and market value. Effective pest management is therefore essential to preserve food quality and minimize economic losses (Berhe et al., 2022). Chemical fumigants, especially aluminum phosphide, are widely used by farmers because of their strong efficacy against insect infestations (Yadav et al., 2021). Aluminum phosphide releases phosphine gas, which disrupts insect metabolic pathways and ultimately causes death (Alzahrani et al., 2023). Despite its effectiveness, the extensive use of aluminum phosphide has raised concerns regarding environmental contamination, risks to human health, and the emergence of resistance in insect populations. Furthermore, residues remaining in treated grains may negatively affect seed viability and germination, creating additional challenges for sustainable agricultural production (Elsaady et al., 2023). As a result, there has been growing interest in the use of botanical insecticides as environmentally friendly alternatives to synthetic fumigants. Plant-based pesticides are generally biodegradable, less toxic, and safer for both humans and the environment (Ngegba et al., 2022). Among these botanical options, neem (Azadirachta indica) has received considerable attention due to its broad-spectrum insecticidal properties. Numerous studies have demonstrated its effectiveness as an insecticide, antifeedant, and insect growth regulator against a variety of stored-grain pests (Chaudhary et al., 2017). The insecticidal activity of neem is primarily attributed to bioactive compounds such as azadirachtin, which disrupt insect growth, development, feeding behavior, and reproduction, thereby suppressing pest populations over time. Compared with conventional synthetic fumigants, neem-based products are regarded as safer alternatives because they have minimal adverse effects on human health and non-target organisms while offering effective pest control (Campos et al., 2016). Although neem has demonstrated considerable potential as a botanical insecticide, its effectiveness against *Tribolium castaneum* in stored wheat, particularly in comparison with aluminum phosphide, continues to be investigated (Ahmad et al., 2023). Aluminum phosphide is known for its rapid and highly effective control of storage pests; however, concerns regarding its environmental and health impacts have encouraged the search for safer alternatives. In contrast, neem-based treatments may provide a more sustainable and environmentally friendly approach to pest management while maintaining satisfactory levels of insect control (Singh et al., 2022). Therefore, this study was conducted to compare the efficacy of aluminum phosphide and neem leaves in managing *T. castaneum* infestations in stored wheat grains. In addition to evaluating their insecticidal effects, the study examines their influence on grain damage, weight loss, and seed germination. The findings are expected to provide valuable insights into the potential integration of neem leaves into post-harvest pest management programs as a sustainable alternative to conventional chemical fumigants (Tesfaye et al., 2021).

## Materials and Methods

The experiment was conducted under controlled laboratory conditions at the Agricultural Research Institute, Faisalabad. A completely randomized design (CRD) was employed, consisting of three treatment groups: (1) wheat grains treated with aluminum phosphide, (2) wheat grains treated with neem leaves, and (3) an untreated control. Each treatment was replicated three times. For each replicate, 500 g of wheat grains were artificially infested with 50 adult *Tribolium castaneum* individuals to establish a uniform pest population.

## Treatment Application

### Aluminum Phosphide Treatment

For the aluminum phosphide treatment, a 3 g aluminum phosphide tablet was placed inside an airtight container containing the infested wheat grains. The container was immediately sealed to ensure effective fumigation and maintained under airtight conditions for 48 hours. After the exposure period, the container was opened and aerated before further observations and data collection were conducted.

### Neem Leaves Treatment

For the neem leaf treatment, fresh neem (*Azadirachta indica*) leaves were collected and thoroughly cleaned before use. The leaves were mixed with the infested wheat grains at a rate of 50 g per kilogram of grain and stored in ventilated containers under laboratory conditions. The neem leaves remained in contact with the grains throughout the experimental period to evaluate their effectiveness in suppressing *Tribolium castaneum* infestation.

### Control Group

The control treatment consisted of infested wheat grains that received no pest control treatment. The grains were stored under the same environmental conditions as the treated groups throughout the experimental period to allow for an unbiased comparison of treatment effects.

### Data Collection

Data were collected to evaluate the effectiveness of the different treatments against *Tribolium castaneum*. Insect mortality was recorded at 24-hour intervals over a period of seven days following treatment application. Mortality percentage was calculated for each treatment and replicate. Grain damage was assessed at the end of the experiment by determining the percentage of weight loss and counting the number of damaged kernels in each replicate. To evaluate the potential residual effects of the treatments on seed quality, a germination test was conducted using treated and untreated wheat grains. Germination percentage was recorded and compared among treatments to assess any impact on seed viability.

## Results and discussion

### Mortality of *Tribolium castaneum*

The effectiveness of the different treatments was evaluated based on the mortality of *Tribolium castaneum* adults. Wheat grains treated with aluminum phosphide showed the highest level of control, resulting in 100% insect mortality within 2$^{nd}$ day of application. In contrast, the neem leaf treatment produced a gradual increase in mortality over time, reaching 79% by the 7$^{th}$ day of observation. The untreated control group exhibited only minimal mortality, with approximately 5% of insects dying during the experimental period. These findings indicate that aluminum phosphide provided rapid and complete pest control, whereas neem leaves demonstrated moderate but significant insecticidal activity against *T. castaneum*. When compared with previous research, the findings of the present study are consistent with earlier reports demonstrating the high efficacy of aluminum phosphide against stored-grain insect pests. Similar studies have reported mortality rates approaching 100% within 48 hours of exposure, confirming the rapid and effective fumigant action of aluminum phosphide (Kumar et al., 2019; Zhang et al., 2021). Despite its effectiveness, concerns have been raised regarding the repeated and prolonged use of aluminum phosphide, as several studies have documented the development of resistance in *Tribolium castaneum* populations. Such resistance may reduce the long-term effectiveness of the fumigant and complicate pest management efforts in stored-grain systems (Singh & Kumar, 2019).

**Table 1: Comparative Mortality of *Tribolium castaneum* in Wheat Grains Treated with Aluminum Phosphide and Neem Leaves**

| Days | Aluminum Phosphide (%) | Neem Leaves (%) | Control (%) |
|---|---|---|---|
| 1 | 85 | 31 | 2 |
| 2 | 100 | 46 | 3 |
| 3 | 100 | 54 | 4 |
| 4 | 100 | 65 | 4 |
| 5 | 100 | 71 | 5 |
| 6 | 100 | 74 | 5 |
| 7 | 100 | 79 | 5 |

**Grain Damage Assessment**

The extent of grain damage varied significantly among the treatments. Wheat grains treated with aluminum phosphide experienced the lowest level of damage, with less than 2% weight loss recorded during the study period. Neem leaf-treated grains showed moderate protection against *Tribolium castaneum*, resulting in approximately 6% weight loss. In contrast, the untreated control group suffered the greatest damage, with weight loss reaching about 19%. These findings indicate that both treatments reduced grain damage compared with the control, although aluminum phosphide provided superior protection against post-harvest losses. The effectiveness of neem-based treatments reported in previous studies has varied depending on the application method, dosage, and exposure period. In the present study, neem leaf treatment resulted in a mortality rate of 78%, which is consistent with the findings of Abdullah et al. (2017) and Devi et al. (2024), who reported mortality rates ranging from 70% to 80% against stored-grain pests. These results support the potential of neem as an effective botanical alternative for managing *Tribolium castaneum* infestations. Furthermore, previous studies have shown that neem-treated grains typically experience weight losses between 5% and 10% (Sharma et al., 2023). The 7% weight loss observed in this study falls within this range, further confirming the protective effect of neem leaves in reducing grain damage during storage.

**Table 2: Comparative Assessment of Grain Damage Among Different Treatments**

| Treatment | Weight loss (%) | Damaged Kernels (%) |
|---|---|---|
| Aluminum Phosphide | <2 | 1 |
| Neem Leaves | 6 | 11 |
| Control | 19 | 24 |

**Residual Toxicity and Germination**

Significant differences in germination rates were observed among the treatments. Wheat grains treated with aluminum phosphide exhibited the lowest germination rate (65%), whereas neem leaf-treated grains maintained a considerably higher germination rate (83%). The untreated control group recorded the highest germination rate (93%). The reduced germination observed in aluminum phosphide-treated grains suggests the presence of residual toxic effects that may adversely affect seed viability. In contrast, neem leaves had minimal impact on germination, indicating their relative safety for maintaining seed quality while providing protection against insect infestation. Previous studies have reported that wheat grains treated with aluminum phosphide often exhibit reduced germination rates, typically ranging from 50% to 65%, which closely corresponds with the 60% germination rate observed in the present study (Rathore et al., 2024). In contrast, neem-based treatments have been shown to better preserve seed viability, with higher germination percentages reported across various studies. These findings are consistent with the results of the current investigation, where neem-treated grains maintained an 85% germination rate (Reddy et al., 2022). Collectively, these observations suggest that although aluminum phosphide provides rapid and highly effective control of *Tribolium castaneum*, neem offers a promising alternative that combines effective pest suppression with reduced environmental risks and improved preservation of seed quality and viability.

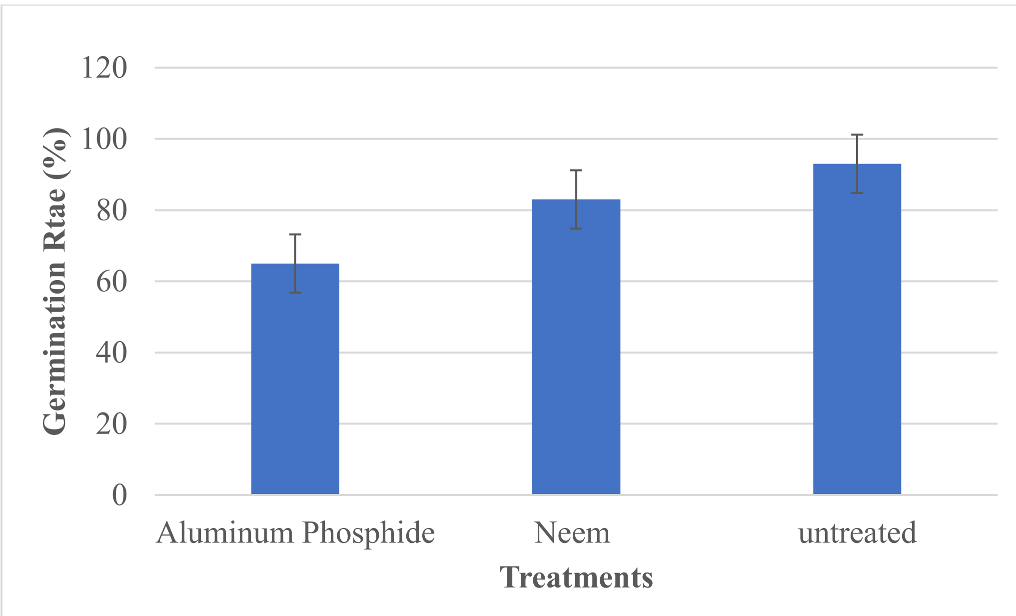


**Figure 1: Comparative Assessment of Residual Toxicity and Germination in Treated Wheat Grains**

**Conclusion**

The results of this study demonstrated that both aluminum phosphide and neem leaves were effective in reducing *Tribolium castaneum* infestations in stored wheat grains. Aluminum phosphide provided rapid and complete pest control, achieving the highest mortality rates within a short period. However, its use was associated with reduced seed germination, indicating potential residual toxicity effects. In contrast, neem leaves showed moderate but substantial insecticidal activity while maintaining higher germination rates and causing minimal adverse effects on seed viability. These findings suggest that although aluminum phosphide remains a highly effective option for immediate pest eradication, neem leaves represent a safer and more environmentally sustainable alternative for stored-grain protection. The incorporation of neem leaves into post-harvest pest management programs could help reduce dependence on synthetic fumigants, thereby supporting safer food storage practices, environmental protection, and long-term agricultural sustainability.

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