



Received: 07-12-2025  
Accepted: 17-01-2026

ISSN: 2583-049X

## **Evaluating the Impact of Chilli Powder (*Capsicum Frutescens*), on the Management of Common Bean Weevils (*Acanthoscelides Obtectus*)**

<sup>1</sup> Munganzi Monde Wesley, <sup>2</sup> Dr. Nkhoma Nelia Phiri

<sup>1,2</sup> Department of Agriculture and Environmental Science, Information and Communications University (ICU), Lusaka, Zambia

Corresponding Author: **Munganzi Monde Wesley**

### **Abstract**

Post harvest losses resulting from common bean weevil (*Acanthoscelides obtectus*) remain a major threat to smallholder farmers in Zambia by reducing grain quality, farmer income, and national food security. Although Synthetic pesticides are more effective in controlling the pest, they still present health and environmental risks and more often unaffordable especially for rural households. This study evaluated Chilli powder (*Capsicum frutescens*) as a potential botanical protectant against (*Acanthoscelides obtectus*). The study explored a split-plot factorial design with three experimental phases: laboratory bioassays with six treatments replicated 3 times (0g, 2g, 2.5g, 3g 3.5g, and 4g), storage trials, and field validations were conducted to determine lethal concentrations, feeding deterrence, and storage efficacy. Results revealed a clear dose-dependent

toxicity, with probit analysis estimating LC<sub>50</sub> and LC<sub>90</sub> at 2.19 g/100 g and 3.86g/100g, respectively. Chilli treatments significantly reduced adult mortality, grain perforation, weight loss, and infestation rates ( $p < 0.001$ ), with effectiveness plateauing at 3.0–3.5 g/100 g. Field validation showed that Chilli at 3.5 g/100 g provided grain weight protection comparable to Actellic Super®, and significantly outperformed traditional ash treatments commonly used by farmers. These findings demonstrate that chilli powder is an accessible, eco-friendly, and cost-effective alternative to synthetic insecticides. At optimal doses of 3.0–3.5 g/100 g, Chilli can sustainably reduce post-harvest losses, and its integration with improved storage practices offers strong potential for scaling up as a farmer-friendly pest management strategy in Zambia.

**Keywords:** Common Bean Weevils (*Acanthoscelides Obtectus*), Chilli Powder (*Capsicum Frutescens*), Botanical Insecticide, Feeding Deterrence, Bio-Pesticide, Post Harvest Losses, Zambia

### **1. Introduction**

Common beans (*Phaseolus vulgaris L.*) is one of the most important grain legume crop belonging to the family of *Fabaceae* believed to have roots traced from Central and South America (Moura *et al.*, 2022; Kumari *et al.*, 2025) <sup>[1,2]</sup>, Common beans is one of the crops that is extensively cultivated in many tropical and sub-tropical regions of the world. Latin America produces about 50% of the total global common beans coming from the region setting it as the largest producer and consumer followed by Africa with 25% (Losa *et al.*, 2022) <sup>[3]</sup>. *Phaseolus vulgaris* is a warm weather crop with typical temperatures ranging between 18°C and 24°C, as such it thrives in tropical, subtropical, and dry tropical zones, as coined by (Chávez-Servia *et al.*, 2016) <sup>[4]</sup>, based on population density, bean output is steadily increasing globally, with poor and emerging nations using the most beans since they are a cheaper source of protein than meat. Studies indicate that in most African developing countries, beans are largely grown for subsistence. They are a delicacy that widely eaten as mature grain and immature seeds as well as green pods and leaves taken as vegetables, (Jevremović *et al.*, 2019) <sup>[5]</sup>. Huge (proportion) of bean crops is for home consumption in smaller gardens and backyards and they are frequently intercropped with maize by smallholder farmers as secondary crops (Maredia, 2015) <sup>[6]</sup>. Bean weevil (*Acanthoscelides obtectus*) poses a significant threat to stored legumes, this leads to substantial economic losses to farmer's world over. This pest lays its eggs on legume seeds, and the larvae in turn drill tunnel into the seeds, damaging them and making the loose both economic value for sale and also loss of being desirable to be consumed. 20 % to 100% postharvest losses in common bean production are directly linked to common bean weevil infestation depending on storage conditions and pest prevalence (Ogbuefi *et al.*, 2023) <sup>[7]</sup>. These losses not only impact farmers' livelihoods but also contribute to food insecurity and economic instability in regions reliant on legume production. Recently

there has been a move towards finding utilizing natural, plant-based insecticides as significant alternatives for pest control. In this regard Chilli Pepper (*Capsicum frutescens*) is among the promising plants. Chilli Pepper, a common ingredient in many dishes around the globe, and has earned a name as a spicy flavor with insecticidal properties. The key bioactive compound in Chilli Pepper responsible for its pungency is capsaicin (Hernández-Pérez *et al.*, 2020) [8].

Common beans (*Phaseolus vulgaris*) are an important and affordable source of dietary protein for many households in Zambia, especially when compared to animal protein and higher-value plant proteins like soybeans. In recent years, bean production has increased in both cultivated area and yield (Mulube, 2023). However, this development is threatened by the widespread infestation of common bean weevils (*Acanthoscelides obtectus*), which cause significant post-harvest losses. These pests attack beans both in the field and during storage, leading to reductions in grain quality and quantity that can range from 20% to 100% under favorable conditions (Maredia, 2015) [6]. Such losses not only reduce farmers' income but also exacerbate food and nutritional insecurity and contribute to broader economic instability (Mulenga, 2020). The conventional use of synthetic pesticides to control weevils presents serious challenges. These chemicals can be harmful to human health and the environment and may not be sustainable or affordable for smallholder farmers (Philip *et al.*, 2023) [11]. As a result, there is growing interest in safer, cost-effective, and environmentally friendly alternatives. Chilli peppers (*Capsicum spp.*) have shown potential as natural insecticides due to their repellent and toxic effects on storage pests (Okafo *et al.*, 2024). Despite this promise, the effectiveness of chilli in controlling common bean weevils under Zambian storage conditions remains largely understudied.

This research seeks to evaluate the efficacy of chilli as a botanical insecticide in controlling common bean weevils in Zambia, with the aim of offering a practical, sustainable alternative for small-scale farmers.

## 2. Materials and Methods

### 2.1 Study Site

First, The experiment was conducted at Rephidim Institute Limited situated in Kasupe ward of Chilanga district in Lusaka Province which lies in region IIa of Agro-Ecological zones of Zambia which receives annual rain fall of 800-1000mm with temperatures ranging between 18-28°C. Consultations and data validation was conducted at Information and Communications University Laboratory.

### 2.2 Experimental Design

The experiment used a split plot factorial design with six treatments of Chilli (0g, 2g, 2.5g, 3g, 3.5g, 4g) replicated three time in a Complete randomized Design (CRD). The experiment included three phases namely; Laboratory Bioassays to determine the lethal concentration that will give the LC<sub>50</sub> and LC<sub>90</sub>, secondly storage trial for bean damage and weight loss, thirdly field validation against ash and Actellic Super®. Properly selected mature *Capsicum frutescens* fruits were sun dried until brisk and were pounded and sieved using a 2mm sieve. Experimental *Phaseolus vulgaris* were selected without any perforations and sterilized by freezing at -4°C.

### 2.3 Insect Rearing

The laboratory culture of insects (*Acanthoscelides obtectus*) where collected from Soweto market from a colony of infested common beans. The common beans infested with common bean weevils where then stored in perforated containers for one week until oviposition was achieved on the grains, then the adult Weevils where removed by use of a 2.00mm sieve. The oviposited grain with ova was then left under laboratory condition (28±2oC and 70±5% relative humidity) until the emergence of F1 progeny that was used for the experiment (Rosulu *et al.* 2022b).

### 2.4 Toxicity Testing

A contact filter paper method was used to apply Chilli powder. Beans (100g) were treated with different concentrations in jars, (0g, 2g, 2.5g, 3g 3.5g, and 4g) and adult weevils were introduced, as described by Paramasivam, *et al.*, (2017) [14]. Mortality was recorded at 24-hour intervals for up to a week, and the lethal concentrations (LC<sub>50</sub> and LC<sub>90</sub>) were calculated using probit analysis, (Makgoba *et al.* 2021) [15].

### 2.5 Feeding Deterrence Assay

The feeding behavior of weevils was determined by counting number of bean perforation and weight loss in treated versus untreated samples as coined by Yamkoulga, *et al.*, (2021) [16].

### 2.6 Storage Trial

The beans treated with Chili (*Capsicum frutescens*) where stored for 60 days and variables weight loss %, Infestation rate % and visual damage levels where assessed.

### 2.7 Data Analysis

ANOVA, LSD (5%) and Probit Analysis where carried out.

## 3. Results and Interpretations

The results are presented according to the study objectives. Statistical analyses were conducted using ANOVA, Probit regression, and Turkey HSD tests to assess treatment effects of different Chilli powder *Capsicum (frutescens)* concentrations (0–4 g/100 g) on adult mortality, feeding damage, and storage performance.

### 3.1 Mortality and Toxicity

The one-way ANOVA for cumulative mortality (Table 1) shows a highly significant effect of chilli powder concentration on adult mortality of *Acanthoscelides obtectus* (F(5,12) = 216.10, p < 0.001).

**Table 1:** Anova Cumulative Mortality

Source of Variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment g per 100g	5	600.2778	120.0556	216.10	<.001
Residual	12	6.6667	0.5556		
Total	17	606.9444			
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Figure 1 below Cumulative Mortality Day 7 shows a clear dose-dependent increase in adult mortality of *Acanthoscelides obtectus* with rising Chilli powder concentrations. Mortality remains very low in the untreated

control (0 g/100 g) but increases sharply from 2 g upwards, reaching the highest levels at 3.5–4 g/100 g. This trend confirms that Chilli powder exhibits a strong toxic effect on the weevils, with higher doses achieving greater cumulative mortality by Day 7. The trend visually supports the ANOVA and Probit results, indicating that chilli concentration is a major determinant of mortality in this study.

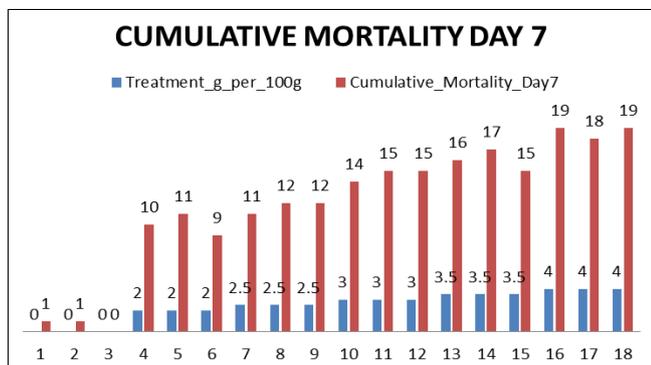


Fig 1: Cumulative mortality

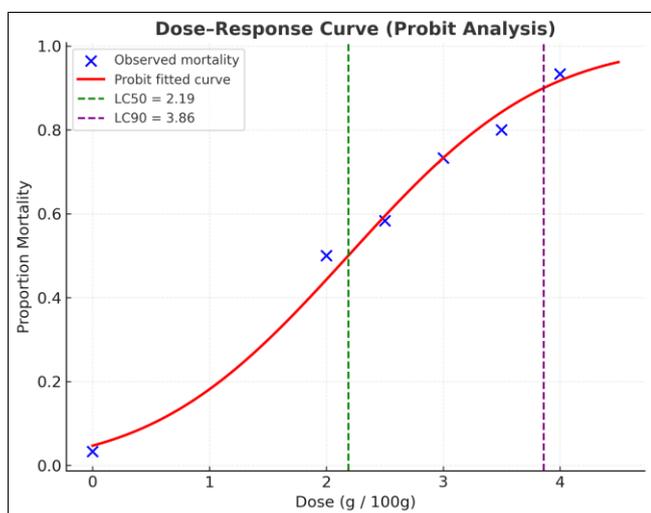


Fig 2: Dose-Response curve (Probit Analysis)

Estimated Lethal Concentrations being the region between LC50 (dose causing 50% mortality) which is 2.19 g/100g and LC90 (dose causing 90% mortality) 3.86 g/100g as depicted in figure 2.

Probit analysis confirmed this pattern, estimating  $LC_{50} = 2.19$  g/100 g and  $LC_{90} = 3.86$  g/100 g, with an excellent model fit (Pseudo  $R^2 = 0.9996$ ). These results demonstrate that chilli powder induces significant adult mortality, with lethal concentrations established between 2.0 and 4.0 g/100g.

The Least significant differences of means (5% level) was calculated to be 1.326, even though the numerical difference between 3.5 g and 4.0 g is statistically significant (greater than  $LSD_{0.05} = 1.326$ ), the biological response shows diminishing returns, confirming that the optimal practical range is 3.0–3.5 g/100 g.

The coefficient of variation for cumulative Mortality was calculated to be 6.2% indicating low experimental variability (Cawood, 2022) [17] and showing high consistence among replicates indicating high reliability of mortality data (Statology, 2021) [18].

### 3.2 Feeding Deterrence

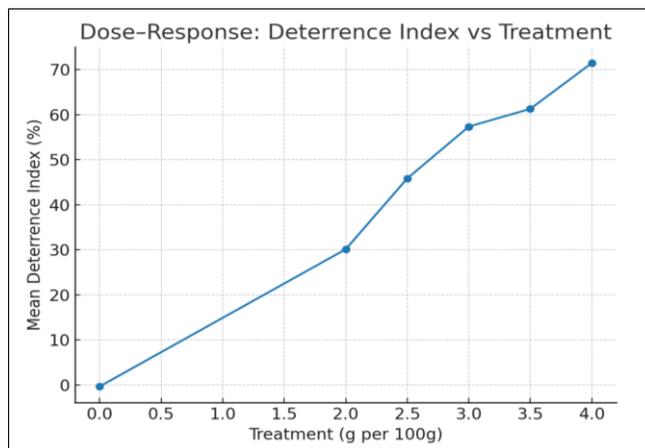


Fig 3: Feeding Deterrence

The deterrence index (DI) significantly increased with dose ( $F(5,12)=167.5, p<0.0001$ ), showing a plateau beyond 3.0 g/100 g. Increasing concentration reduced feeding damage: Sharp decline in DI between 2 g and 3 g creating a Plateauing effect beyond 3.5 g

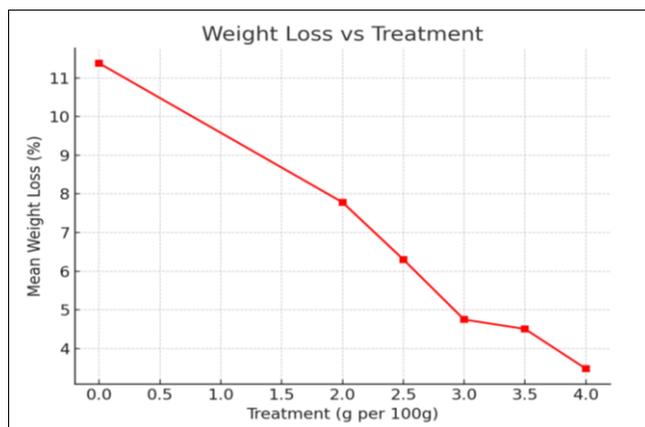


Fig 4: Weight losses against treatments

- Number of holes per 100 beans decreased markedly with increasing chilli concentration ( $F(5,12)=71.53, p<0.001$ ), dropping from 34 holes (control) to 7 holes (4.0 g). Weight loss followed a similar trend ( $F(5,12)=107.2, p<0.001$ ), declining from 22.9% in untreated beans to 13.4% in chilli-treated beans (3.5 g/100 g). Untreated beans recorded the highest weight loss (up to 18%). Chilli at 3.5 g reduced weight loss to < 4%, similar to Actellic Super®
- Least Significant Differences (LSD) was calculated to be 3.558 and most differences in pairs are greater than  $LSD_{0.05} = 3.558$ , which confirms that chilli treatments produce statistically significant reductions in grain damage compared to the control, with 3.0g vs 3.5g that is not significant creating a plateau, thus suggesting that 3.0-4.0g/100g is optimal range for preventing bean perforation by *Acanthoscelides obtectus*.

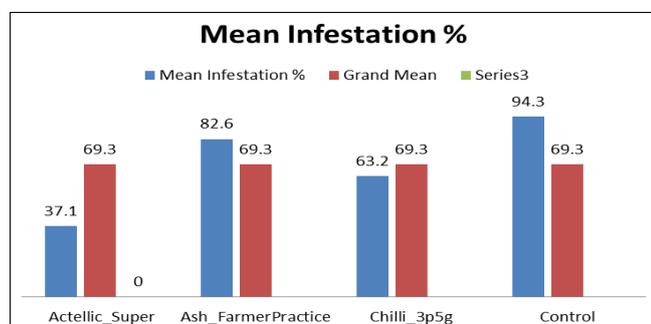
### 3.3 Infestation Rate

**Table 2:** ANOVA Infestation rate

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	11274.66	3758.22	49.93	<.001
Residual	20	1505.42	75.27		
Total	23	12780.07			

According to table 2 Differences among treatments were significant at  $F(3,20)=49.93$ ,  $p<0.001$

Under on the farm storage conditions, chilli (3.5 g/100 g) performed comparably to Actellic Super® as it equally reduced infestation rates and weight loss like Actellic Super®. When it comes to infestation rates (%): Control representing 94.3%, with Ash (farmer practice) at 82.6%, while Chilli had 63.2% followed by Actellic representing 37.1%. while Weight Loss (%): Control = 22.9; Ash = 18.6; Chilli = 13.4; Actellic = 11.2 With chilli outperforming the traditional ash method and showing statistical similarity with the chemical control in grain weight preservation.



**Fig 5:** Mean Infestation Rates

As can be seen in figure 5 above in terms of infestations, Actellic Super outperformed all treatments by reducing infestation rate by 37.1% with chilli having reduced the infestation rates by 63.3% with control being the least at 94.3% with chilli outperforming the traditional ash method and showing statistical parity with the chemical control in grain weight retention.

### 3.4 Results interpretation Some

Chilli powder created a clear, dose-dependent toxicity to adult *A. obtectus* over a period of one week (ANOVA  $F(5,12)=216.10$ ,  $p<0.001$ ), with probit estimates  $LC_{50}=2.19$  and  $LC_{90}=3.86$  g/100 g (excellent fit), and strong behavioural effects that reduced feeding and damage (DI↑; weight loss and perforation↓), plateauing at ~3.0–3.5 g. In storage validation, Chilli 3.5 g/100 g significantly lowered infestation versus control and farmer ash and, critically, matched Actellic on grain weight protection (no significant difference), despite higher infestation counts evidence of potent anti-feeding action. Overall results support 3.0–3.5 g/100 g as a suitable, botanically based dose that yields the most desirable gains of efficacy, while 4.0 g/100 g can be reserved in circumstances where one needs a rapid knockdown, and recommend integration with good storage hygiene mixed with hermetic containment for best outcomes.

### 3.5 Synthesis Against Objectives

#### Determine lethal concentrations ( $LC_{50}/LC_{90}$ )

$LC_{50}\approx 2.19$  and  $LC_{90}\approx 3.86$  g/100 g with excellent model fit.

Implication: For rapid knockdown, target nearer  $LC_{90}$ ; for routine protection, 3.0–3.5 g balances efficacy and economy.

### Assess feeding deterrence & damage mitigation

Weight loss, and hole counts all improved strongly with dose, plateauing at ~3.0–3.5 g. This plateau explains why weight-loss protection under storage was on par with Actellic even when infestation counts were higher chilli discourages feeding.

### Evaluate field efficacy in storage

Partially met (short timeframe): At 3.5 g/100 g, chilli significantly reduced infestation and weight loss vs control/ash; weight loss protection was statistically indistinguishable from Actellic. Further, longer storage (6–8 weeks) and progeny counts will complete this objective, as planned in your methods.

### 3.6 Practical Guidance

Recommended working dose: 3.0–3.5 g per 100 g beans (i.e., 30–35 g per kg). This captures most efficacy (mortality + deterrence) with diminishing returns above 3.5–4.0 g. If rapid adult knockdown is essential, push towards ~4.0 g/100 g ( $\approx LC_{90}$ ).

Expectation management: Chilli may allow some survivors but still protects grain well via reduced feeding; this is why weight loss can match Actellic even when infestation counts are higher. Pairing Chilli with sanitation and tight containers/hermetic bags should further cut survivorship and progeny.

Ash (farmer practice) offered modest protection; Actellic best suppressed infestation; Chilli provided near-Actellic protection on weight loss at 3.5 g/100 g—thus a credible botanical option when synthetic residues, cost, or access are concerns.

### 3.7 Limitations & next steps

- Extend storage duration ( $\geq 6-8$  weeks) and include  $F_1$  emergence to capture multigenerational effects.
- Record seed viability/germination post-treatment (planned) to ensure no adverse effects at 3–4 g/100 g.
- Consider grind size, capsaicinoid quantification, and bean variety as covariates; these can refine dose recommendations for smallholder conditions.

## 4. Discussion

This study investigated the insecticidal and deterrent potential of chilli powder (*Capsicum frutescens*) against the common bean weevil (*Acanthoscelides obtectus*). Findings from this study shows a clear dose-dependent mortality trend, with  $LC_{50}$  and  $LC_{90}$  values estimated at 2.19 g/100 g and 3.86 g/100 g, as demonstrated in figure 4 and 5 above respectively. Treated beans recorded fewer perforations, reduced weight loss, and also showed lower infestation rates, thus confirming chilli's feeding deterrence attributes. Concentrations of 3.0–3.5 g/100 g gives the most effective protection, while doses higher than 3.0g provided limited additional benefits. Field validation supported these findings: although Actellic Super® achieved the lowest infestation levels overall, chilli powder preserved grain weight more effectively and outperformed the traditional farmers' practice of ash application. For instance, as shown in Table 10, chilli-treated beans had an average infestation

of 63% compared with 83% under ash treatment. After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

## Comparison with Previous Studies

### 4.1 Chilli Pepper Studies

Findings from this study matches with Okafor *et al.* (2024)'s [12], who equally demonstrated dose-dependent insecticidal effects of *C. frutescens* and *Xylopiya aethiopica* on *Callosobruchus maculatus*. Both studies highlight capsaicin's as both a toxicant and also a repellent, thus giving a reason as to why grain quality maintained despite some insects surviving after treatments. Similarly, Rosulu *et al.* (2022) [13] observed that 3.0 g chilli powder reduced oviposition, adult emergence, and weight loss in cowpea, with effects also plateauing at higher doses. The plateau observed in this study above 3.0 g supports their findings of diminishing returns at elevated concentrations.

### 4.2 Other Botanicals

There is a clear connection between this research and Muzusa (2023) [19], who investigated neem and garlic powders against *A. obtectus*. In his findings, Neem showed superior mortality effects, and yet chilli powder in this study achieved outcomes similar to synthetic insecticides in weight loss prevention. This suggests that chilli may compete with neem in effectiveness, especially that Chilli is locally more available and culturally acceptable in Zambia.

### 4.3 Genotypic Resistance Integration

Tlale (2022) [20] demonstrated that resistant bean genotypes (CAL96, DAB520, X-genotype) when combined with botanical powders such as garlic, peppermint, and marigold achieved complete suppression of *C. maculatus*. Despite the present study focusing solely on chilli, results pointed to a similar potential: chilli powder at 3.5 g/100 g equaled Actellic Super® in weight protection. Integration of chilli with resistant varieties, as suggested by Tlale, could further improve protection and reduce application rates, making it a valuable component of integrated pest management (IPM) strategies.

## Implications for Pest Management

### 4.4 Implications For Pest Management

1. Practical Application Rates: The most favorable working dose to use when using chilli powder as an insecticide to control Common bean weevils in stored Common beans is 3.0–3.5 g/100 g (~30–35 g/kg). Beyond this, additional protection is minimal, though ~4.0 g/100 g may be required for rapid knockdown to be achieved.
2. Alternative to Synthetic Insecticides: Despite Actellic achieving the highest reductions of infestations, chilli equally provided significant statistically comparable grain weight protection. This is extremely important to small holder farmers of Zambia with concerns of high costs of synthetic chemicals, with health risks and environmental hazards associated with them.

3. Farmer Practice Comparison: The local small scale farmers relying on Traditional ash treatment can adopt Chilli which is significantly more effective than traditional ash. This Adoption of chilli could substantially reduce post-harvest losses for Zambian farmers.
4. IPM Integration: Chilli can be used in combination with resistant bean varieties and improved storage practices (e.g., hermetic bags) to maximize efficacy.

### 4.5 Limitations of the Study

- The storage trials were relatively short (8weeks), this limited the assessment of multi-generational weevil pressure beyond the 8weeks.
- After treatment of the seed, Germination and seed viability tests were not done in this phase, leaving speculations, though prior studies (e.g., Tlale, 2022) [20] indicated no negative effects of botanical powders.
- Variability in Chilli variety and capsaicin concentration was not quantified, which could affect reproducibility in different regions.

## 5. Conclusion

This study confirms that chilli powder is a highly effective botanical protectant against *A. obtectus*. At doses of 3.0–3.5 g/100 g, chilli significantly reduces mortality, feeding damage, and weight loss, with protection levels statistically comparable to synthetic insecticides and superior to traditional ash treatment. These findings, consistent with regional studies on chilli, neem, and resistant genotypes, underscore the promise of chilli as a low-cost, eco-friendly, and farmer-accessible alternative for sustainable bean storage management in Zambia.

## 6. Recommendations for Future Research

- Long-term storage trials (3–6 months) should be conducted to assess chilli's efficacy under extended farmer storage conditions.
- Another study to be conducted to assess chilli's compatibility with different bean varieties widely grown in Zambia, including Kablangeti, Solwezi, White and Yellow which are widely consumed.
- Assess seed viability and germination after treatment to ensure no trade-off between protection and crop quality.

## 7. Acknowledgment

I wish to express my deepest gratitude to my supervisor, Dr. Nelia Nkhoma Phiri, for her invaluable guidance, constructive criticism, and constant encouragement throughout the course of this research. Her expertise and mentorship have been very helpful in building the direction and quality of this project.

My sincere appreciation also goes to Dr. Musenge Danny, the Dean of the School of Engineering, Information and Communication University (ICU), for his continuous academic support and leadership which created an environment that was favorable for this research.

Special thanks are extended to Mr. Silombe Mwenya, Head of the Department of Agriculture and Environmental Science (ICU), for his administrative and academic guidance, and to Ms. Mutale Mwamba, Laboratory Technician (ICU), for her technical assistance and practical support during the laboratory experiments.

I am equally grateful to Mr. Otton Muyabi, Lecturer at ICU, for his insightful academic contributions, and to Mr. Mulondiwa Maxwell, Executive Director of Rephidim Institute Ltd, for his cooperation and for allowing access to facilities that made part of this study possible.

Lastly, I extend heartfelt appreciation to my family and friends for their unwavering love, patience, and moral support during the entire period of this study. Their encouragement has been a constant source of strength and motivation.

## 8. References

- Moura MC, Pinheiro PV, Vianello RP, Sousa NL, Faria JCC. Genetic Transformation of Common Beans (*Phaseolus vulgaris* L.): Achievements and Challenges. *Agriculture*. 2022; 14(11):2060. <https://www.mdpi.com/2077-0472/14/11/2060>
- Kumari M, Thakur PK, Kumari P, Sood R, Singh M, Rana JC. Common Bean (*Phaseolus vulgaris* L.) Breeding. In *Fundamentals of Legume Breeding: A Text for Students and Practitioners*. Singapore: Springer Nature Singapore, 2025, 19-32.
- Losa A, Vorster J, Cominelli E, Sparvoli F, Paolo D, Sala T, *et al.* Drought and heat affect common bean minerals and human diet, 2022. Doi: <https://doi.org/10.1002/fes3.351>
- Chávez-Servia JL, Heredia-García E, Mayek-Pérez N, Aquino-Bolaños EN, Hernández-Delgado S, Carrillo-Rodríguez JC, *et al.* Diversity of Common Bean (*Phaseolus vulgaris* L.) Landraces and the Nutritional Value of their Grains. *IntechOpen*, 2016. <https://www.intechopen.com/chapters/50923>
- Jevremović S, Lazarevid J, Kostid M, Krmjajid S, Ugrenovid V, Radonjic A. Contact application of Lamiaceae botanicals reduces bean weevil infestation in stored beans. 2019; 71(4):665-676.
- Maredia M. Global and regional trends in production, trade, and consumption of food legume crops. Department of Agricultural, Food and Resource Economics, 2015.
- Ogbuefi EO, Uzochukwu UC, Chukwudike CO, Okechi II. A comparative study of weevil infestation in different bean species sold at selected markets in Awka, Nigeria. *International Journal of Research*. 2023; 7(1):1-7.
- Hernández-Pérez T, Gómez-García MDR, Valverde ME, Paredes-López O. *Capsicum annuum* (hot pepper): An ancient Latin-American crop with outstanding bioactive compounds and nutraceutical potential. *Comprehensive Reviews in Food Science and Food Safety*. 2020; 19(6):2972-2993.
- Mulube M, Lungu R, Aseete P, Kalemera S, Cheyo E, Nkhata W, *et al.* Demand-led system approaches boost early generation seed production in Zambia, 2023.
- Mulenga BP, Banda A, Chapoto A. Securing food systems and trade in Zambia during the COVID-19 pandemic. IAPRI Issue No. 3. Lusaka, Zambia: IAPRI, 2020.
- Philip T, Gurney-Smith H, Wollenberg E. Alternative sources of protein for food and feed. *Current Opinion in Environmental Sustainability*. 2023; 62:101277. Doi: <https://doi.org/10.1016/j.cosust.2023.101277>
- Okafor KP, Akunne CE, Nwaoke AJ, Nlemchi CJ, Okeke TE, Chidi CA, *et al.* Evaluation of insecticidal potentials of *Capsicum frutescens* and *Xylopiya aethiopica* in control of bean weevil. *Multidiscipline Journal of Multidisciplinary Science*. 2024; 1(2):51-66. Doi: <https://doi.org/10.59631/multidiscipline.v1i2.202>
- Rosulu HO, Oni MO, Ofuya TI, Adebayo RA. Efficacy of chilli pepper (*Capsicum frutescens* L.) for the control and management of cowpea weevil (*Callosobruchus maculatus* F.) infesting cowpea (*Vigna unguiculata* L. Walp) in storage environment. *East African Scholars Journal of Agriculture and Life Sciences*. 2022; 5(2):44-52. Doi: 10.36349/easjals.2022.v05i02.003
- Paramasivam M, Selvi C. Laboratory bioassay methods to assess the insecticide toxicity against insect pests-a review. *Journal of Entomology and Zoology Studies*. 2017; 5(3):1441-1445.
- Makgoba M, Tambo JA, Magorokosho C, Subramanian S. Fall Armyworm (*Spodoptera frugiperda*) management in Zambia: Bioassay evaluation of synthetic insecticides and biopesticides under smallholder conditions. *Journal of Economic Entomology*. 2021; 114(4):1501-1512. Doi: <https://doi.org/10.1093/jee/toab123>
- Yamkoulga M, Waongo A, Ilboudo Z, Traoré F, Sanon A. Effectiveness of hermetic storage using PICS bags and plastic jars for post-harvest preservation of *Acacia macrostachya* seeds. *Advances in Entomology*. 2021; 9(1):20-29. Doi: <https://doi.org/10.4236/ae.2021.91002>
- Cawood. Technical Information: Mixer Dispersion Testing, 2022. Available at: <https://cawood.co.uk/wp-content/uploads/2022/04/MixerDispersionTesting-TechnicalInformation.pdf> (Accessed: 15 November 2025).
- Statology. What is Considered a Good Coefficient of Variation?, 2021. Available at: <https://www.statology.org/what-is-a-good-coefficient-of-variation/> (Accessed: 15 November 2025).
- Muzusa M. Efficacy of selected plant powders on bean weevil (*Acanthoscelides obtectus*) management in common beans. MSc dissertation, Busitema University, Department of Crop Production, 2023. Available at: Busitema University Repository (Accessed: 8 December 2025).
- Tlale OL. Bio-efficacy of selected bean genotypes and some plant powders as protectant against the seed beetle, *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) in storage. MSc dissertation, Botswana University of Agriculture and Natural Resources, Department of Crop and Soil Sciences, 2022. Available at: ResearchHub BUAN PDF (Accessed: 8 December 2025).
- Eason G, Noble B, Sneddon IN. On certain integrals of Lip