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# Integrated Management of Zabrotes subfasciatus in Common Bean (*Phaseolus vulgaris*), Challenges and Control Strategies for Food Security

## Manejo integrado de Zabrotes subfasciatus en el frijol común (*Phaseolus vulgaris*), desafíos y estrategias de control para la seguridad alimentaria

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**Abstract**

Integrated management of *Zabrotes subfasciatus* in common bean (*Phaseolus vulgaris*) is crucial due to its wide distribution and the significant damage it causes to stored grains. The goal of integrated management is to reduce losses and ensure food security. This review aimed to understand the biology of *Z. subfasciatus*, identify effective control methods, and propose an integrated model that minimizes the use of chemical insecticides. A systematic review of scientific literature published since 2000 was conducted, evaluating 653 initial studies, of which 61 met the inclusion criteria. Key aspects such as taxonomy, geographic distribution, life cycle, and pest control methods were addressed using information from databases such as ScienceDirect, Elsevier, and SciELO. The main findings showed that an integrated management approach combining cultural, physical, chemical, and genetic methods is effective in controlling the pest without relying solely on chemical insecticides, whose indiscriminate use poses risks to human health and the environment. Monitoring and the development of resistant bean varieties stand out as fundamental practices in pest management. In conclusion, integrated management of *Z. subfasciatus* significantly contributes to the protection of stored grains and, consequently, to the food security of farming communities. It is recommended to strengthen farmer training in sustainable control techniques and to promote research on alternative management methods.

***Keywords***: Storage, pest control, entomology, bean, insect.

**Resumen**

El manejo integrado del *Zabrotes subfasciatus* en frijol común (*Phaseolus vulgaris*) es crucial, debido a su amplia distribución y el daño significativo que causa en granos almacenados. Su manejo integrado busca reducir las pérdidas y garantizar la seguridad alimentaria. El objetivo de esta revisión es comprender la biología de *Z. subfasciatus*, identificar métodos de control eficaces y proponer un modelo integral que reduzca el uso de insecticidas químicos. Se realizó una revisión sistemática de literatura científica publicada a partir del año 2000, evaluando 653 estudios iniciales, de los cuales 61 cumplieron con los criterios de inclusión. Se abordaron aspectos como la taxonomía, distribución geográfica, ciclo de vida y métodos de control de la plaga, a partir de información recopilada en bases de datos como ScienceDirect, Elsevier y SciELO. Los resultados principales evidenciaron que un enfoque de manejo integrado, que combine métodos culturales, físicos, químicos y fitogenéticos, es eficaz para controlar la plaga sin depender exclusivamente de insecticidas químicos, cuyo uso indiscriminado representa un riesgo para la salud humana y el ambiente. El monitoreo y el desarrollo de variedades resistentes de frijol se destacan como prácticas fundamentales en el manejo de la plaga. En conclusión, el manejo integrado de *Z. subfasciatus* aporta significativamente a la protección de los granos almacenados y, por ende, a la seguridad alimentaria de las comunidades agrícolas. Se recomienda fortalecer la capacitación de los agricultores en técnicas sostenibles de control y promover la investigación en métodos alternativos de manejo.

***Palabras clave***: Almacenamiento, control de plaga, entomología, frijol, insecto.

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# 1 Introduction

The common bean (*Phaseolus vulgaris*) is the most important legume used for direct human consumption (Didinger et al., 2022). A member of the Fabaceae family, the common bean is a predominantly self-pollinating species native to Mesoamerica (Bitocchi et al., 2017). Due to its wide geographic distribution, this ancient legume split and evolved into two domesticated gene pools: the Mesoamerican and the Andean. The highest-quality varieties were developed and domesticated in South America, based on the Andean gene pool, while the lower-quality varieties originated in Mexico and Central America, with roots in the Mesoamerican gene pool (Wilker et al., 2020). Thanks to this genetic diversity and its adaptability, the common bean has established itself as one of the most important crops for human consumption worldwide (Refaay et al., 2021). Its high nutritional value makes it an essential food, especially in Latin America and developing countries (Hernández-Ochandía et al., 2018), where it constitutes an important source of protein, vitamins, and minerals. Dried beans contain approximately 22 % protein, complex carbohydrates (62 %), soluble fiber (15 %), and various micronutrients such as calcium, iron, magnesium, phosphorus, potassium, and folate, positioning them as a key food in balanced and healthy diets (Myers and Kmiecik, 2017).

In terms of production, *P. vulgaris* accounts for 85 % of global bean production, making it the most widely cultivated legume on the planet (Mamo et al., 2023). Annually, more than 27 million tons of beans are harvested on approximately 29 million hectares worldwide, feeding more than 300 million people who depend on agricultural economies in various regions of the world (Nasar et al., 2023). Latin America stands out as the region with the highest production and consumption, accounting for 45 % of global production (IICA / Proyecto Red SICTA, 2013). In this region, beans are not only a staple food but also a vital crop for the economy of smallholder farmers. Particularly in Central America, beans occupy a strategic position in food security and the rural economy. According to FAOSTAT data, in 2022 Honduras produced 130 906 tons of beans, with an average yield of 802 kg/ha, which highlights their importance within the region's agricultural economies (FAO, 2022).

Despite its importance of economic and food security, the crop faces various biotic and abiotic stresses that limit its productivity. Among biotic factors, the storage pests *Zabrotes subfasciatus* and *Acanthoscelides obtectus* stand out as the most destructive during the postharvest stage (Tigist et al., 2021). In particular, *Z. subfasciatus* represents one of the main threats to producers, causing significant losses that affect both commercialization and the availability of seeds for future plantings (Mukankusi et al., 2019). The management of these pests in stored grains has traditionally relied on the application of synthetic insecticides such as phosphine, pyrethroids, and organophosphate compounds. However, many of these products have limited availability to farmers in developing countries (Agrafioti et al., 2019; Gourgouta et al., 2019). Furthermore, the continued and indiscriminate use of pesticides has generated growing global concern due to the risks it poses to human health and the environment, highlighting the urgency of implementing more sustainable strategies for pest management in stored products (Souza et al., 2010).

Given its fundamental role in food security, the rural economy, and the nutrition of millions of people in developing countries, the common bean faces the challenge of maintaining its productivity in the face of threats such as *Zabrotes subfasciatus*, one of the main postharvest pests. Ensuring its sustainable management is key to reducing losses, preserving grain quality, and strengthening the livelihoods of smallholder farmers. In this context, this study aims to understand the biology of *Z. subfasciatus*, identify effective control methods, and propose an integrated management model that minimizes the use of chemical insecticides, thereby contributing to crop protection and the sustainability of agricultural systems.

# 2 Materials and Methods

## 2.1 Selection of Studies

Initially, a selection of inclusion criteria was carried out, identifying topics of interest within the field of bean pest control, with an emphasis on *Zabrotes subfasciatus*. Based on this identification, the key parameters for the literature search were defined. The inclusion criteria considered were: a) articles addressing the taxonomy of *Z. subfasciatus*, b) studies on its biology and life cycle, c) research related to its geographic distribution, and d) control methods (cultural, phytogenetic, physical-mechanical, and chemical). In general, priority was given to literature published since 2000; however, for specific topics such as taxonomy, morphology, and physiology, earlier studies were included if they were relevant in terms of content and scientific validity.

## 2.2 Identification of Databases

The repositories used to identify scientific articles were ScienceDirect, Elsevier, and SciELO. Once an article met the inclusion criteria, the literature was analyzed and synthesized, involving a critical evaluation, the extraction of relevant data and scientific evidence, and the identification of trends and fundamental information about the species.

## 2.3 Analysis Structure

A basic structure was defined to organize the collected information, covering aspects such as taxonomy, morphology, geographic distribution, biology and life cycle, monitoring, as well as control methods in storage: cultural, phytogenetic, physical-mechanical, and chemical. This organization allowed for a comprehensive approach to the management of *Zabrotes subfasciatus* in *Phaseolus vulgaris*.

## 2.4 Final Selection of Studies for the Analysis

For the selection of articles, the PRISMA approach was used to guide the process of identifying, selecting, and documenting the studies included in this systematic review, following the methodology framework of Page et al. (2021), initially identifying 653 records through searches in scientific databases. Subsequently, the methodological quality of these studies was assessed using a checklist. This tool allowed us to identify potential biases and evaluate the internal validity, methodological clarity, and relevance of the studies. After removing duplicate articles, those that did not meet the thematic or methodological criteria were excluded, resulting in a total of 61 studies included for analysis (Figure 1).

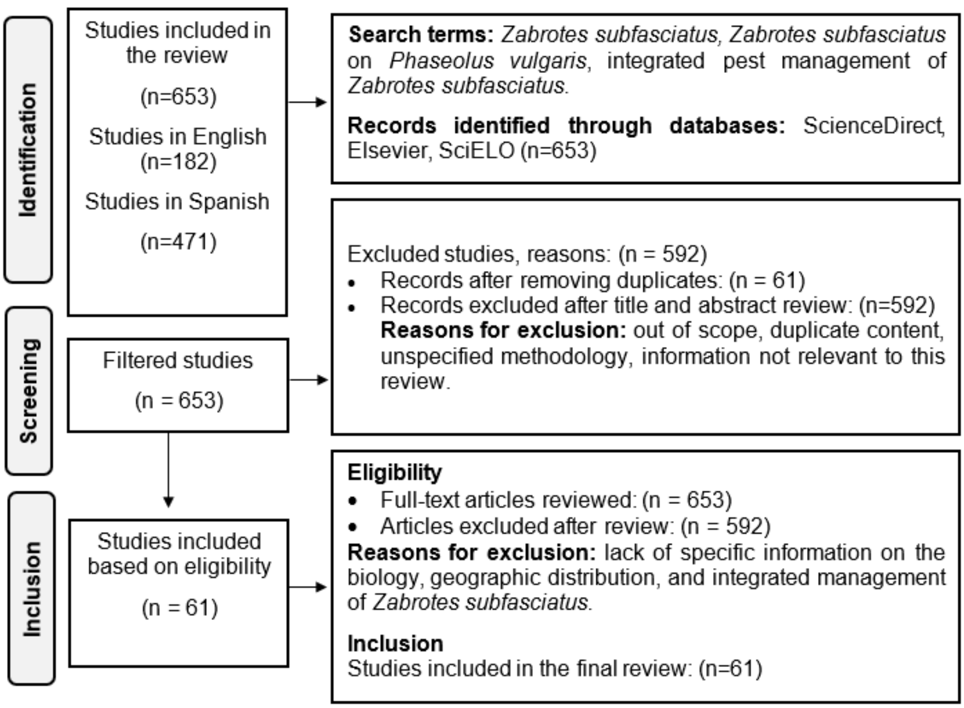


**Figure 1.** PRISMA flow diagram for the systematic review of *Zabrotes subfasciatus* in beans.

# 3 Results and Discussion

## 3.1 General characteristics of bean cultivation

The genus *Phaseolus* spp. consists of 76 species, 5 of which are domesticated species, including *P. vulgaris* (Kaplan, 2003). This genus is notable for its cultivated species, which occupy 90 % of the land dedicated to bean cultivation worldwide (Singh, 2013). It is a herbaceous plant that was independently domesticated in ancient Mesoamerica and the Andes (Kaplan, 1981). It is classified within the group of dicotyledonous plants (Katungi et al., 2009). The seeds can be consumed immature (tender), mature, fresh, or dried (Morales-Santos et al., 2017).

There are two bean planting cycles per year, but farmers mainly choose to plant during the late season (October–December). Planting during the early season (May–September) is less common, as it leads to grain losses due to germination or rot (Torres-Treminio and Mendoza-Montoya, 2002). Post-harvest handling of common beans is a critical stage in the agricultural production chain, where beans are exposed to various factors that can compromise their quality and quantity. In Central America and Mexico, losses of up to 35 % of stored beans are estimated (Espinal et al., 2021).

## 3.2 Taxonomy of *Zabrotes subfasciatus*

The Mexican bean weevil or bean beetle, *Zabrotes subfasciatus*, belongs to the order Coleoptera, a species of leaf beetle in the family Chrysomelidae. It is the primary phytosanitary problem affecting stored beans in areas below 1 500 meters in altitude (Cárdenas-Morales et al., 2019). It is characterized by complete metamorphosis and feeds exclusively on seeds (Dobie et al., 1991).

Members of this family are easily recognizable; the body, covered with small hairs, is compact and globular, the elytra are short, and the pygidium is exposed (Rees, 2018). Their primary host is *Phaseolus vulgaris* in its seed stage; however, they can also feed on other legume species under isolated conditions, such as *Vigna unguiculata* L. (Ramírez Cariño et al., 2017).

**Table 1.** Taxonomy of *Zabrotes subfasciatus*.

| **Taxonomic classification** | |
|---|---|
| **Taxonomic category** | **Taxon to which it belongs** |
| Domain | Eukarya |
| Kingdom | Animalia |
| Phylum | Arthropoda |
| Class | Insecta |
| Order | Coleoptera |
| Suborder | Polyphaga |
| Superfamily | Chrysomeloidea |
| Family | Chrysomelidae |
| Genus | *Zabrotes* |
| Species | *Z. subfasciatus* (Boheman, 1833) |
| Common name | Mexican or pinto weevil |

*Source:* Population increase of *Zabrotes subfasciatus* in common bean cultivars (Cárdenas-Morales et al., 2019).

## 3.3 Morphology of *Zabrotes subfasciatus*

This beetle exhibits distinctive characteristics in both males and females, which are crucial for its identification and study. The adult body is oval-shaped, thick, convex, and gray-brown or black in color, except for the base of the antennae and the tips of the tarsi. The body measures approximately 2 to 3 mm in length and 1 to 2 mm in width. Its antennae are long and can reach 1.45 mm in length; the segments are long and black, except for the first two, which are reddish (Dell'Orto and Arias-Velásquez, 1985). The elytra are short and relatively wide, square in shape, with the hind wings concealed (Dobie et al., 1991).

The female is larger than the male and is characterized by four white spots on the elytra (Figure 2) (Arnal and Ramos, 2006). The male is a uniform gray-brown color (Figure 3). Its hind femur is smooth, without protuberances or teeth. The part of the tibia near the femur has two movable spurs (Dobie et al., 1991). The larvae are robust, curved, and ivory-white. They are very voracious, and several may be found in a single grain (Figure 4) (Carrera-Rodríguez et al., 2009).

**Figure 2.** Dorsal and lateral view of the female *Zabrotes subfasciatus* (Johnson, 2019).

**Figure 3.** Dorsal and lateral views of the male *Zabrotes subfasciatus* (Johnson, 2019).

**Figure 4.** Larva of *Zabrotes subfasciatus* (Johnson, 2019).

## 3.4 Morphology of the Male

A beetle with a mostly black body, with some lighter areas in certain individuals. The head has white pubescence with a yellowish-brown spot on the *vertex*. The pronotum and elytra have small, scattered brown and yellow spots. The abdomen is mostly white, with brown patches on the sides. The head structure shows fine punctures, with a semicircular pronotum and uniformly punctured elytra. Measurements vary, but the beetle generally has a length of 1.56 to 2.16 mm and a width of 1.26 to 1.62 mm. Regarding the genitalia, the median lobe is wider at the base and has a subtriangular ventral valve. The lateral lobes are shorter and feature an apical cleft (Nápoles, 2018).

## 3.5 Morphology of the Female

Sexual dimorphism is present in this species, with females having a median band on the pronotum and a small white spot in each corner, as well as a transverse white band on the elytra. However, pubescence is generally similar to that of males. Antennal length is slightly shorter, ranging from 0.6 to 0.63 times body length. Typical measurements of length (pronotum-elytra) range from 2.28 to 2.46 mm, with a width of 1.74 to 1.86 mm and a maximum thoracic depth of 1.26 to 1.32 mm (Nápoles, 2018).

## 3.6 Geographic Distribution of *Zabrotes subfasciatus*

This species' ability to thrive under storage conditions has made it widely available worldwide (Del Obregón and Gómez-Gutiérrez, 2023). This insect is widely distributed in the tropical and subtropical regions of Africa, Madagascar, India, and the Americas, where it is believed to be native (Dobie et al., 1991). In the Americas, it is distributed from the United States to Brazil (Arnal and Ramos, 2006). It is mainly found in warm, humid climates at low elevations above sea level (Dell'Orto and Arias-Velásquez, 1985).

## 3.7 Reproductive Habits of *Zabrotes subfasciatus*

The female mates with the male, and this mating appears to be influenced by bean seeds. Upon contact with these, the number of sexual encounters increases, stimulating oogenesis (egg development) and oviposition activity. It has been documented that olfactory, gustatory, and tactile chemoreceptors regulate or control the reproductive activity of females (Pimbert and Pierre, 1983).

Females oviposite on the naked seed, never on the pods (Credland and Dendy, 1992). However, Pimbert and Pierre (1983) note that they are capable of reproducing on both parts in the field and in storage. When the pods of *P. vulgaris* and *P. lunatus* are partially or fully dehiscent, this allows the female to encounter the seeds to lay eggs. These same authors note that *Z. subfasciatus* cannot pierce the pods to lay eggs on the seeds, nor can it lay eggs inside the pods as other members of the family can. If the female deposits the eggs on the walls of the pods, they adhere, and the larva can penetrate the walls but dies inside the pod since it cannot penetrate the seed (Del Obregón and Gómez-Gutiérrez, 2023).

## 3.8 Life Cycle of *Zabrotes subfasciatus*

### 3.8.1 Eggs

Females lay between 35 and 60 eggs and infest up to 36 grains during their reproductive cycle; the incubation period can range from four to eight days, followed by the larval stage (12 days). The eggs measure approximately 0.3 mm in diameter and are rounded. Two days after emerging, the female *Z. subfasciatus* usually begins to lay eggs (Credland and Dendy, 1992). Studies by Golob and Kilminster (1982) indicate that the female has a 1-day preoviposition period; subsequently, the female lays 50 eggs during her 13-day lifespan, with the majority laid after the fourth day. The egg is strongly attached to the grain's testa by a viscous, brightly colored, translucent substance that acts as glue. This glue or secretion that attaches the eggs is generally deposited a few seconds before oviposition (Credland and Dendy, 1992).

### 3.8.2 Larvae

They are vermiform and apodal, measuring 3 to 3.5 mm in length. Their body tends to be curved, with several folds, whitish in color, and a reduced head embedded in the prothorax (Ascencio-Alvarado, 2012). Newly emerged larvae penetrate the interior of the grain after consuming most of the cotyledon, constructing a tunnel and leaving only a covering over the grain's pericarp through which the adult subsequently emerges (Dell'Orto and Arias-Velásquez, 1985).

### 3.8.3 Pupae

They measure about 3 mm in length. They are of the exarate type, with appendages. The difference between the sexes can be noted at this stage by the shape of the last abdominal segment, which is straight in the female and arched in the male (Bonet et al., 2005; Ascencio-Alvarado, 2012). This stage lasts between four and nine days, after which the larva enters the adult stage and subsequently emerges through a hole it makes in the testa of the grain (González et al., 1984; Bonet et al., 2005).

### 3.8.4 Adults

Females, which are larger than males, can be easily distinguished by the presence of four light spots on the pronotum, which contrast with the dark, shiny color of the body. They have well-developed wings, and their body is oval-shaped with a free-standing head. The eyes are well-developed, and their antennae have 11 segments. The hind legs are thicker than the front ones (Bonet et al., 2005; Ascencio-Alvarado, 2012).

The exit point of the adult resembles a circular window on the seed surface (Rees, 2018). Emerging adults do not need to feed before or after mating, as they acquire all the necessary nutrients to complete their life cycle during their larval development. They are highly active, capable of running and flying quickly, and are frequently observed moving across the surface of infested seeds.

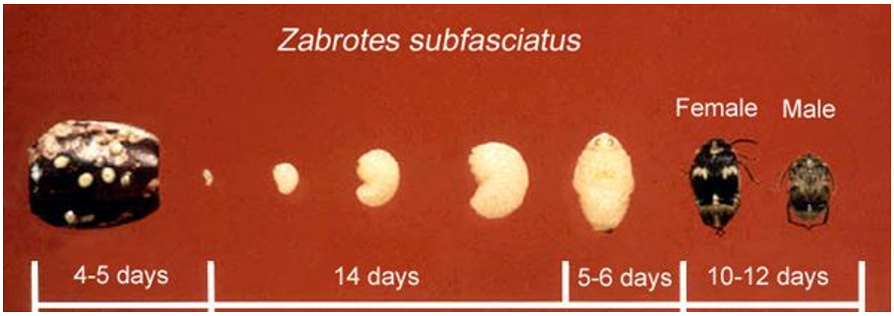


**Figure 5.** Life cycle of *Zabrotes subfasciatus* (CABI, 2019).

## 3.9 Infection Conditions

Its life cycle lasts 24 to 25 days under conditions of 32 °C and 70 % relative humidity (Dobie et al., 1991). However, other authors indicate that it takes more than 30 days from egg to adult (Golob and Kilminster, 1982; Credland and Dendy, 1992; Barbosa et al., 1999). The optimal temperature for development is 37–38 °C, with a minimum slightly below 20 °C (Dobie et al., 1991). Adults have a short lifespan. Various authors have determined the average lifespan of adults. For example, Dell'Orto and Arias-Velásquez (1985) indicated that the adult *Z. subfasciatus* lives for about 10 to 12 days, while Barbosa et al. (1999) argue that it lives for about 36 days.

## 3.10 Feeding and Damage

It is the most significant pest of stored common beans and lima beans (*P. lunatus*) (Dobie et al., 1991). It can also feed on other legume seeds, such as cowpeas, peas, lentils, and soybeans (Dell'Orto and Arias-Velásquez, 1985; Rees, 2018). The damage caused by this insect species results from the larvae invading and feeding inside the grains, leading to weight loss, reduced nutritional value, and compromised product hygiene due to the presence of excrement, eggs, and insects. Additionally, the germination capacity of the seeds may be reduced or completely lost (Barbosa et al., 1999).

## 3.11 Cultural Control

A traditional method used to control the population of *Z. subfasciatus* is to store bean seeds inside their own pods (Arnal and Ramos, 2006; Del Obregón and Gómez-Gutiérrez, 2023). This is because females can generally only lay eggs on bare seeds and very rarely on pods unless they are dehiscent (Pimbert and Pierre, 1983).

In many places, a mixture of local plants is used with stored grain. Information about which plants should be used for pest control and which parts of them should be mixed with the grain is passed down from generation to generation in rural areas (Carrera-Rodríguez et al., 2009). Plant-derived substances have been used for pest control since ancient times. However, their use declined with the advent of chemical insecticides, becoming limited to rural areas (Rodríguez Hernández and López Pérez, 2001).

In developing countries, it is common to mix plant-based products with stored beans to protect them during storage. Among the products that have been used are neem leaves (*Azadirachta indica*), *Ocimum canum* leaves, *Capsicum frutescens* fruits, and *Piper nigrum* fruits (Madueke-Onu et al., 2015; Perales-Aguilar et al., 2020; Okafor et al., 2024). Another method involves the use of vegetable oils, generally of local origin. Among the vegetable oils that have been found to be effective are those derived from the seeds of *Anthonomus grandis* (Perales-Aguilar et al., 2020). However, a disadvantage of using oils is that they impart a rancid and sticky appearance to the grains, which could reduce market acceptance (Álvarez Serrano et al., 2021).

The use of mineral powders as a cultural control method for stored grain insects, including *Z. subfasciatus*, has been widely employed (Lopez-Monzon et al., 2016). Mixing sand or ash with the grains is an alternative method for insect control. Sand or ash damages the insect's cuticle by scraping it, causing it to lose moisture. If the grain is dry, there will not be enough moisture for the insect to replenish what it has lost, so it will die from desiccation (Kalpna et al., 2022); ash creates a physical barrier for weevils.

Mixing lime with stored grains is a common practice in northwestern Mexico. Permuy-Abeleira et al. (2008) report that farmers in the region clean the storage area before harvests, removing any debris found, and wash the area with soap; after the grain is harvested, it is mixed with lime to prevent insect attacks.

The use of garlic (*Allium sativum*) extracts as a natural repellent and insecticide against *Zabrotes subfasciatus* in stored beans has also been documented. Studies conducted in El Salvador have shown that aqueous and hydroalcoholic garlic extracts, applied at concentrations between 5 % and 20 %, achieve significant effects on both adult mortality and infestation reduction, without compromising grain quality (Rámos-Archila and Santacruz-Jiménez, 2024).

Another method used is exposing the grains to the sun. The insects abandon the grain when it is exposed to sunlight due to the high temperatures (above 40–44 °C). However, sun exposure does not always kill the eggs and larvae that remain inside the grain (Carrera-Rodríguez et al., 2009). This method only protects the outer layers of the grain, so it can only harm adult insects on the surface or larvae that are moving freely (Cuevas, 2006).

## 3.12 Phytogenetic Control

A wide variety of proteins found in the seeds of wild *P. vulgaris* plants (arcelin and $\alpha$-amylase inhibitors) have been used to control *Z. subfasciatus* in stored beans (Goossens et al., 2000). Although bean seeds possess defense proteins such as enzyme inhibitors and secondary metabolites (alkaloids, saponins), they can still be attacked. This is because insects co-evolve with their food sources, and in the course of evolution, new insect strains emerge that allow them to defend themselves against the seeds' natural chemicals (Rodríguez-Sifuentes et al., 2020).

## 3.13 Physical-Mechanical Control

In the tropical regions of some Central American countries, as well as in Mexico, airtight storage of grains for human consumption is commonly used; under these conditions, insects experience stress due to reduced oxygen levels, creating an unfavorable environment for their survival (Moreno-Martinez et al., 2000). Low levels of $O_2$ and $CO_2$ cause metabolic stress in insects, generally increasing mortality and decreasing fecundity and development rate (Thompson and Suarez, 2009).

Another physical-mechanical treatment involves heat, which consists of heating a container to a specific temperature (50 to 55 °C) for 20 or 30 hours. This duration allows the container materials to expand and adjust to the change. Although storage insects die in less than an hour at these temperatures, such a long duration is necessary because the heat must penetrate to where the insects might be found. However, these control methods are not typically cost-effective, as the containers or heating equipment are often expensive.

## 3.14 Chemical Control

This is the most widely used method in grain warehouses; among the most commonly used are fumigantes (Perales-Aguilar et al., 2020). Phosphamine fumigants and methyl bromide are widely used in the control of stored grain insects (Dierksmeier-Corcuera, 2007). In highly technical warehouses, it is common to use insecticides to control pests that affect stored products. This approach involves the application of chemicals, which can take different forms, such as powder, liquid, or fumigants.

Powdered products are particularly used in warehouses where grain is stored in bulk or in bags, and their application can be both preventive and corrective. The most popular insecticides in this category include malathion, pirimiphos-methyl, and dichlorvos, among others. Although some of these products can also be used as sprays, the use of pyrethroid insecticides is widely preferred, with deltametrina being particularly prominent. Additionally, many warehouses rely on fumigants, with aluminum phosphide being one of the most prominent (García-Lara et al., 2007).

Vázquez-Zamorano (2014) conducted a study to evaluate the effectiveness of permethrin, diazinon, and cypermethrin in controlling adult weevils. Permethrin was found to be the most effective insecticide, with a mortality rate exceeding 60 % when using the highest dose of 500 ppm. In a study conducted in Argentina to evaluate the efficacy of aluminum phosphide in the bag-in-silo storage system, it was observed that although there is some loss of the fumigant, by hermetically sealing the storage system, it is capable of retaining the adequate amount of fumigant to eliminate stored-product insects (Carpaneto et al., 2016).

The use of chemical control methods poses significant problems: risk of toxic residues in food, insect resistance, negative environmental impact, and increasing regulatory restrictions, in addition to the costs associated with their purchase, application, and specialized equipment (Cevallos-Taxi, 2020). From an economic standpoint, chemical control may be more effective in scenarios involving large volumes and mechanized storage facilities, but it is less accessible and viable in rural areas with limited resources (Raygoza-Martínez et al., 2025).

In contrast, cultural control has proven to be highly cost-effective in rural communities, especially when based on traditional knowledge and local resources. This effectiveness stems from the fact that it utilizes locally available inputs, requires little initial investment, does not depend on external commercial products, and can be easily adopted by farming families, thereby reducing risks to human health and the environment.

## 4 Conclusions

The wide geographic distribution of *Zabrotes subfasciatus* and its ability to infest various legumes highlight the need for ongoing research and the implementation of monitoring and control practices adapted to different environmental and cultural contexts. The integrated management approach, which combines cultural, physical-mechanical, chemical, and phytogenetic methods, represents an effective and sustainable strategy for controlling this pest, minimizing dependence on chemical insecticides and their associated risks.

However, challenges remain, such as the limited adoption of sustainable practices, the lack of accessible technologies, and inadequate storage infrastructure. For this reason, it is recommended to deepen research into the development of resistant varieties as a key measure to ensure protein availability and contribute to food security. Similarly, efforts should be made to promote the development of new biological control alternatives and innovation in postharvest management technologies, incorporating participatory approaches that address the needs of smallholder farmers.

It is also crucial that public agricultural policies integrate post-harvest management and strengthen technical assistance programs with a focus on promoting sustainable practices as part of rural development and food security strategies. This involves promoting training programs, incentives for agroecological practices, and improvements in extension systems.

## Declaración de uso de inteligencia artificial

Los autores DECLARAN que, durante la preparación del artículo titulado «Manejo integrado de Zabrotes subfasciatus en el frijol común (*Phaseolus vulgaris*), desafíos y estrategias de control para la seguridad alimentaria», no se utilizaron herramientas de inteligencia artificial generativa ni sistemas automatizados de asistencia para la redacción, análisis, interpretación de datos, generación de contenido, traducción o edición del manuscrito.

Los autores asumen plena responsabilidad por el contenido, la originalidad, la integridad y la versión final del artículo.

## Contribución de los autores

**L.D.J.I.:** Conceptualización, Curación de datos, Investigación, Supervisión, Escritura – revisión y edición. **L.F.C.D.:** Investigación, Curación de datos, Metodología, Escritura – borrador original. **S.A.J.I.:** Conceptualización, Análisis formal, Validación, Escritura – borrador original.

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