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Sitophilus oryzae: A comprehensive review of its biology, infestation dynamics and management strategies

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Abstract

The rice weevil, *Sitophilus oryzae* is among the most damaging stored cereal pests globally, causing severe post-harvest losses and significantly impacting grain quality. A member of the superfamily *Curculionoidea*, it has a sophisticated life cycle and exceptional adaptability to varied environmental conditions, enabling infestations to develop well in stores. Its feeding damages grain weight, drains nutrients, decreases germination, and reduces market value. Although chemical pesticides will control the pest efficiently, excessive use has raised issues of pesticide resistance, toxicity, and environmental contamination. These issues have prompted research into safer, environmentally friendly alternatives. Integrated pest management (IPM) strategies integrating botanical pesticides, biological control, physical treatments, and advanced molecular tools are yielding encouraging results in sustainable control. Recent studies further highlight the importance of genetic research, novel biocontrol products, and precision agriculture in optimizing the efficiency of pest management. This review synthesizes existing information on the rice weevil's taxonomy, life history, feeding habits, and management, with the ultimate goal of enabling more effective and environmentally sustainable management.

Keywords: *Sitophilus oryzae*, botanical pesticides, Integrated Pest Management (IPM), stored grain pests and precision agriculture

Introduction

Weevils are small to medium-sized beetles belonging to the superfamily *Curculionoidea*. They are one of the most diverse and widespread groups of insects, with over 60,000 known species. Weevils (Curculionoidea) are among the most diverse insect groups, with around 5,800 described genera and 62,000 valid species, most belonging to the family Curculionidae. Although some sources cite 100,000 described species, this figure reflects all available names listed in the WTaxa database not the number of valid species. As of June 2013, WTaxa recorded 131,012 species names and 11,599 genus names, indicating significant synonymy, especially in subfamilies like Platypodinae and Scolytinae. The estimated total number of existing weevil species is about 220,000 but may be higher with further exploration of tropical regions [1].

The rice weevil (*Sitophilus oryzae*) is a major stored grain pest worldwide. Females lay eggs inside grain kernels, where larvae feed and develop. The feeding damage caused by both larvae and adults can reduce grain weight by up to 75%, affecting nutritional value, germination, and market price. Synthetic pesticides are commonly used for stored grain protection, but they pose problems like insect resistance, toxicity, and environmental contamination. As a result, there's a growing interest in natural pesticides with low mammalian toxicity. Botanical pesticides, derived from plants, offer a promising alternative. They're biodegradable, eco-friendly, and cost-effective, making them a valuable component of integrated pest management (IPM) strategies. *Sitophilus oryzae* is a significant pest that can infest cereal-based food products during production, distribution, transportation, or storage. Due to their ability to penetrate packaging materials, it's crucial to repel and prevent S. oryzae invasion to maintain food quality and freshness. Effective measures are necessary to protect packaged food from this pest [2-3].

Fig 1: *Sitophilus oryzae*

Life cycle and reproductive biology

Sitophilus oryzae life table study on milled rice in the coastal climatic conditions of Odisha indicated that the total life cycle varied between 59-70 days for males and 64-80 days for females during summer (4 instars), and 87-102 days for males and 98-109 days for females during winter (3 instars). The sex ratio was 0.94 males for every 1.00 female, with a generation survival rate of 56.9%. Age-specific fecundity analysis yielded a net reproductive rate (R_0) of 16.35, a mean generation time (T) of 36.65 days, and an intrinsic rate of increase (r_m) of 0.0764. The growth period of *Sitophilus oryzae* is about 25 days under ideal conditions of 30°C and 70% relative humidity. It is shortened, nonetheless, at higher temperatures, reduced humidity, and poor-quality food. Females deposit eggs during the adult stage by boring into grains and capping each with a waxy secretion each being bored with a single egg. A female may deposit 150-300 eggs, hatching in approximately six days at 25°C. The larva burrows into the grain, devouring the interior. It goes through four instars within duration of 25 to 100 days, depending on environmental factors. Pupation takes place within the grain, and the adult that emerges carves a serrated exit hole, a tell-tale indication of infestation. Adults live for 3 to 6 months, depending on environmental circumstances [4].

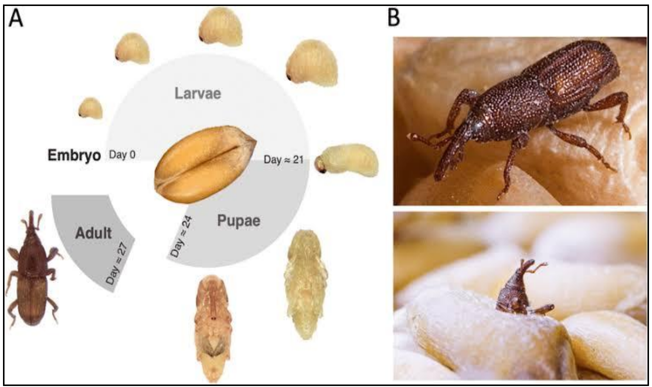

Fig 2: A Life Cycle of *Sitophilus oryzae*

The rice weevil *Sitophilus oryzae* is a major pest of stored cereals worldwide. A study conducted in Benin examined how climate and environmental factors affect its distribution and infestation sources. Researchers surveyed 138 rice stocks across 52 sites, recording pest presence in storage facilities, rice fields, and natural habitats using visual inspections, panicle monitoring, and pheromone traps, along with temperature, humidity, and grain moisture measurements. Results showed higher pest densities in the southern and central regions, where temperatures averaged 30.4-31.2°C and humidity ranged from 76.8% to 85.2%, while infestations were lower in the drier northern region. The Angoumois grain moth was detected in both paddy fields and storage, initiating infestation at rice maturation, whereas *S. oryzae* was mainly confined to storage.

The weevil's total life cycle from egg to adult lasted 34-49 days (average 42 days) under temperatures of 15-34°C and relative humidity of 58-89%, consistent with previous findings. The pre-mating period was 5-8 days (average 6.5 days), mating occurred during daylight especially in bright sunlight lasting 35-70 minutes (average 56 minutes). Pre-oviposition lasted 8-11 days (average 8.65 days), and oviposition continued for 9-29 days (average 25 days) on maize, with females laying mostly one egg per grain, sometimes two, sealing them with a gelatinous material. Fecundity ranged from 12 to 84 eggs (average 56.5), predominantly in the first week. Without food, females survived 8-16 days (average 10.5 days) and males 6-11 days (average 8.44 days), while with food, longevity increased to 86-122 days for females (average 116.33 days) and 72-117 days for males (average 97.86 days). The insect's development includes egg, larva, pupa, and adult stages, with life cycle duration influenced by environmental factors and grain type. Mixed grain diets prolonged development compared to single cultivars like HPW-2361, and certain rice varieties showed greater susceptibility, with fissured grains being more prone to infestation. [5- 1, 5].

Taxonomy and morphology

The rice weevil *Sitophilus oryzae* shows noticeable physical differences between males and females. These differences can be seen in various body parts, including overall shape, rostrum and sensory structures on the antennae, eyes, thoracic segments, abdomen, and reproductive organs. When viewed from the side, females have a straight ventral surface, while males show a slight backward curve. The male's rostrum is shorter, thicker, less curved, duller in appearance, and more densely pitted, whereas the female's is longer, slimmer, shinier, and more sparsely pitted. Even the eyes differ, with males having slightly more visual units (about 167 ommatidia) compared to females (around 154), which may be linked to differences in behavior and activity [1, 6].

Table 1: Taxonomy of *Sitophilus oryzae*

Rank	Classification
Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta
Order	Coleoptera
Family	Curculionidae
Genus	Sitophilus
Species	Oryzae(linnaeus)

Adult *Sitophilus oryzae* are small, slender insects, typically measuring 2.0-3.5 mm in length, with an elongated cylindrical body ranging from reddish-brown to dark brown in color. Their most distinctive feature is the curved rostrum, which they use to bore into grains, with elbowed, clubbed antennae positioned midway along it. The pronotum is finely punctured, while the elytra (wing covers) bear four reddish or yellowish spots and extend to cover the entire abdomen. Equipped with well-developed legs, these weevils can walk efficiently and burrow into grain kernels.

They also have fully formed wings, enabling them to fly and disperse to new food sources [1, 7].

Host preferences and infestation behaviour [1, 8-2, 4]

Sitophilus oryzae is a major pest of stored grains, with adults consuming the endosperm and larvae attacking the germ, which together reduce seed germination potential and degrade nutritional value. In one study, its impact was tested on five grain types polished rice, rough (unpolished) rice (*Oryza sativa*), and others using ten replicates under free choice conditions. Researchers measured grain damage, weight loss, and F1 adult emergence. Polished rice proved to be the most susceptible, with 18.75% damage, 14.11% weight loss, and an average of 138.8 F1 adults, while rough rice was least preferred.

Another experiment explored whether Natal Habitat Preference Induction (NHPI) the tendency to prefer the grain type an insect was reared on affected host selection. Virgin males and females raised on maize, wheat, or barley were tested for feeding and oviposition preferences. Results showed no NHPI effect; maize consistently ranked highest in grain damage, weight loss, and progeny production, regardless of rearing history. Oviposition studies on wheat (*Triticum aestivum*) revealed that females preferred larger kernels (≥20 mg), accepting them faster and laying more eggs there. While they created oviposition holes in shriveled grains, actual egg deposition was rare. Progeny emerging from larger kernels were bigger, though survival rates did not differ. Higher egg counts in large seeds were due to more frequent visits, not more eggs per visit. Laboratory trials at the University of Agriculture, Faisalabad (2015-16) tested the pest's life cycle under temperatures of 25°C, 30°C, and 35°C, and relative humidities of 55%, 60%, and 65%. Development was slowest at 25°C and fastest at 35°C, with 65% RH producing the most adult emergence and 55% RH the least. Both temperature and humidity significantly shaped weevil growth.

In Ethiopia, post-harvest grain losses pose a significant threat to food security, with stored product pests like the rice weevil contributing heavily to reductions in both quantity and quality of staple grains with S. oryzae among the most damaging pests. Control approaches include cultural practices, botanical treatments, pest-resistant varieties, improved storage designs, and biological controls such as entomopathogenic fungi. While direct comparisons are limited, adapting existing methods like modifying underground pits to reduce moisture can improve storage outcomes. Integrated pest management (IPM) offers the most sustainable long-term solution.

Globally, rice is a staple and a vital source of carbohydrates, B vitamins, and trace elements like selenium. Yet, poor storage and pest infestations cause significant losses about 9% in developed countries and over 20% in developing ones. These pests reduce rice quality by depleting proteins, amino acids, starch, and vitamins, while contamination makes grain unfit for consumption. Growing concerns over pesticide residues and resistance have boosted interest in eco-friendly solutions such as resistant varieties, transgenic cultivars, and other sustainable methods. In Australia and worldwide, phosphine fumigation is critical for stored grain pest control, but resistance in S. oryzae is a growing threat. National monitoring data analyzed with Bayesian hurdle models showed that fumigation in unsealed storage and frequent weak resistance cases drive the development of strong resistance. Evidence suggests resistance arises independently in multiple locations rather than spreading via migration. Targeted management in high-risk areas is key to slowing resistance spread [1, 8-2, 4].

Management strategies [2, 5-2, 7]

1. Chemical Control

Chemical control remains a primary approach for managing *Sitophilus oryzae* in stored rice, with synthetic pyrethroids such as deltamethrin widely used. However, overuse has led to significant resistance most notably the T929I "super kdr" mutation reported in India, which increases deltamethrin resistance by 134-fold. To address this challenge, alternative strategies are being explored, including: Alternative insecticides Synergists to enhance pesticide efficacy Botanical oils, e.g., from Simmondsia chinensis and Rosmarinus officinalis, for integration into resistance management programs.

2. Biological Control

Biological methods offer sustainable, residue-free pest management options. The parasitoid Anisopteromalus calandrae can reduce weevil populations by approximately 60% in stored rice. Combined use of the predator Xylocoris flavipes and parasitoid Theocolax elegans further enhances control efficiency. Entomopathogenic fungi such as Metarhizium anisopliae have shown strong insecticidal potential, with higher concentrations significantly increasing mortality.

3. Physical Control

Physical strategies focus on environmental manipulation and non-chemical interventions: Temperature and humidity reduction slows development and reproduction. Controlled atmosphere storage, including CO_2 fumigation, provides chemical-free suppression and can be combined with other methods. Hot air sterilization of grains effectively prevents infestation unsterilized rice developed weevil infestations within six months, whereas sterilized grains (imported, parboiled, raw milled) remained pest-free.

4. Emerging Eco-Friendly Approaches

- **Rock powder and ZnO nanoparticles:** Laboratory experiments on Oryza sativa L. var. Giza 171 demonstrated that rock powder and ZnO nanoparticles exhibit strong insecticidal activity against S. oryzae, show low toxicity to rats, and contain bioactive compounds within the rock powder.
- **Repellent sachets with allyl mercaptan (2%):** Demonstrated strong repellency against S. oryzae in brown rice, with potential application in active food packaging systems.
- **Diatomaceous Earth (DE):** At 13 mg/100 g wheat, DE achieved complete mortality within 6-7 days, enhanced seed germination to 99% (vs. 53% in controls), increased seedling length to 59.41 cm, and improved vigor index to 5881.59, making it an eco-friendly dual-purpose solution.
- **Botanical Extracts:** Methanolic extracts derived from *Lantana camara* (leaves), *Carica papaya* (seeds), *Ricinus communis* (leaves), *Calotropis gigantea* (flowers), and *Gliricidia sepium* (leaves) have shown notable insecticidal potential against *Sitophilus oryzae*.

Recent advances and future directions [2, 8]

1. Advances in Genetic and Molecular Research

Recent genetic analyses have pinpointed critical resistance-associated mutations, notably the T929I mutation in the vgsc gene, which is linked to deltamethrin resistance emphasizing the importance of molecular diagnostics in resistance surveillance. Genome sequencing has also revealed high transposable element activity, potentially enhancing adaptability and offering new targets for genetic-based pest control strategies.

2. Development of Novel Biocontrol Agents

Targeting the rice weevil's symbiotic bacterium, Sodalis pierantonius, presents a promising avenue for disrupting its development and survival. Genetic profiling and population level studies make it possible to design strain-specific biocontrol agents for more effective interventions.

3. Potential of Precision Agriculture

Molecular tools such as microsatellite markers allow precise monitoring of pest population structure and genetic diversity. When integrated into precision agriculture systems, these data enable targeted pest management, reduced pesticide reliance, and optimized use of biological controls**.**

4. Policy and International Collaboration

Sitophilus oryzae broad genetic diversity and minimal regional population structuring, global coordination is crucial. Policies should promote integrated pest management (IPM) that blends genetic, biological, and technological approaches. International partnerships can facilitate data exchange, harmonized resistance management strategies, and global dissemination of biocontrol solutions for long-term sustainability.

Conclusion

Sitophilus oryzae is an extremely cosmopolitan and damaging insect of stored cereals with enormous economic and nutritional losses globally. Its quick breeding, penetration capacity through packages, and broad host range render it challenging to manage with traditional chemical insecticides, which have also contributed to resistance, environmental risks, and health issues. Sustainable management thus depends upon integrated pest management (IPM) approaches that incorporate botanical pesticides, biological control agents, physical control measures, enhanced storage strategies, and genetic technologies. Breakthroughs in molecular science, precision agriculture, and targeted biocontrol provide hopeful, environmentally friendly alternatives, but long-term success will be contingent upon international cooperation, awareness among farmers, and the practice of sustainable, science-based practices for the protection of grain quality and minimizing post-harvest losses.

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