



Sawtoothed grain beetle (*Oryzaephilus surinamensis*) in stored dates: biology, damage, and advances in sustainable management

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Received: 12 June 2025 / Accepted: 18 November 2025
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Abstract

The date palm (*Phoenix dactylifera* L.) is a significant crop in arid regions worldwide. However, stored dates are particularly vulnerable to *O. surinamensis*, a major pest that directly compromises fruit quality, accelerates spoilage, and undermines the economic value of date harvests in producing countries. Date palms are cultivated in a wide range of varieties worldwide, with over 300 distinct types recognized. However, these valuable crops are highly vulnerable to significant damage from insect pests, which can threaten both yield and quality. Among the many food products threatened by *O. surinamensis*, stored dates are particularly vulnerable. Dates that have been severely infested by this beetle will eventually rot and become damaged, making fruit unfit for human consumption. This infestation leads to a decline in both the quality and market value of the dates. *O. surinamensis* is common in stored goods and can infest many kinds of date fruits, controlling it with an integrated pest management (IPM) approach is essential. One essential step is cleanliness, which is routinely cleaning storage places to get rid of food leftovers and possible breeding grounds. Although chemical management techniques, such as applying pesticides, have their uses, they should be applied with caution to reduce hazards to the natural world and public health. Plant-based insecticides and repellents have potential as more environmentally friendly substitutes for manmade chemicals. Future research should focus on developing eco-friendly pesticides, improving storage methods, and breeding pest-resistant date palm varieties. Collaboration, monitoring, and extension services are necessary to sustainable pest management and environmental protection.

Keywords Date Fruit · Sawtoothed Grain Beetle · Biology · Damage · IPM · Management practices

1 Introduction

Date palm, also known as *Phoenix dactylifera* L., is a vital crop in the world's arid regions. Around 6,000 years ago, in ancient Mesopotamian region, date palms were first cultivated (Al-Karmadi & Okoh 2024; Johnson et al. 2013). Date palms are extremely important to economics sustainability of producing regions because they can withstand water scarcity, severe weather, and salinity levels as high as 2,000 parts per million. Roughly 60% of world's approximately one hundred million date palms are found in areas where tree has

become deeply embedded in the lives and cultural traditions of local populations.

In many regions, date palm cultivation plays a multifaceted role, serving as a vital food source while also contributing significantly to environmental sustainability, social cohesion, and economic development. Bulk of date palm production worldwide is accounted for by Middle East and North Africa. Date palms have been brought to South America, Mexico, Australia, India, Southern Africa, Pakistan, and United States throughout last thirty years (Al-Khayri et al. 2015). Sixth-largest producer globally in world is Pakistan. Because of their widespread outbreeding, date palms have wide range of genetic variability. Number of date palm hybrids worldwide is estimated to exceed 3,000, while some may be duplicates known by various names (Johnson et al. 2013).

Date palms encompass a diverse range of varieties, each with unique characteristics and vulnerabilities. Some varieties are particularly prized for their quality or resilience, but

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all face challenges from pests and environmental pressures that can impact their productivity and cultural significance. Renowned for its excellence, Aseel variety demonstrates exceptional qualities in both semi-dry and dry variations (Ahmed et al. 2016; Awan et al. 2018). Rich in minerals including calcium, magnesium, iron, and potassium, dates are a great source of critical nutrients. Along with vitamins like niacin, B1, and B2, dietary fibers (varying from 6.4% to 11.5%), fatty acids, proteins, and carbs (with total sugars ranging from 44 to 88%, principally fructose and glucose), they additionally include these substances (Chandrasekaran & Bahkali 2013). In urgent food assistance programs, dates may be essential. Their antibacterial, immune-boosting, anti-fungal, antiulcer, and anticancer qualities have made them highly valued in certain cultures. In addition, certain types of dates have antioxidant properties because of their phenolic components (Brouk & Fishman 2016). Using biological processing to fully utilize potential of raw dates and date seeds could result in creation of wide range of new goods. If food and pharmaceutical companies investigate these technologies on commercial basis, this may be especially rewarding (Chandrasekaran & Bahkali 2013). Date palms, while diverse and culturally significant, remain highly vulnerable to both insect pests and diseases, which can severely impact their productivity and sustainability. Such pest infestations contribute to decline syndrome, leading to a substantial loss of dates, particularly in semi-dry circumstances (Khan et al. 2023; Markhand et al. 2010). Beetle species *Carpophilus hemipterus* and *Oryzaephilus surinamensis* are widely distributed and pose significant threat to agricultural products both pre and post-harvest. In combination with other diseases and pests, these beetles contribute to 30% reduction in overall production of date fruits (Hashem et al. 2012; Swamy & Bitra 2023).

Saw-toothed grain beetle, *O. surinamensis* L. is a common pest and can contaminate goods at several phases of production, storage, and retail. Factors such as food availability, environmental conditions, and processing techniques influence its distribution. Throughout world, this insect can infest a wide range of foods, such as date fruits, dried fruits, dried meats, pastas, cereals, flours, nuts, chocolates, and other packaged products (Trematerra et al. 2016). Date quality is harmed by *O. surinamensis*, which also causes a decrease in both number and weight (Galal 2023). *O. surinamensis* can reach foodstuff that is kept in containers because of their strong chewing jaws. These insects are attracted to smell of goods that have been preserved, and they will persist in trying to enter (Al-Yahyai et al. 2023).

The saw-toothed grain beetle, *O. surinamensis*, is a significant pest in stored agricultural products, including a wide variety of date fruits. Its ability to infest and damage stored goods underscores the need for effective management strategies. This review aims to explore the biology,

ecological impact, and current control measures for *O. surinamensis*, with a focus on integrated pest management (IPM) approaches. By examining both non-chemical and chemical control techniques, as well as the role of sanitation and monitoring, this review seeks to identify sustainable solutions to mitigate the beetle's impact on date palm storage and contribute to global food security. The potential of plant-based insecticides and repellents as environmentally friendly alternatives will also be evaluated.

2 Biology and life cycle of *O. surinamensis*

2.1 Life Cycle of *O. surinamensis*

The life cycle of *O. surinamensis*, from egg to adulthood, typically spans one to ten months, depending on environmental conditions (Fig. 1). Optimal development occurs at temperatures between 17.5 and 37.5 °C, with the fastest growth observed at 32.5 to 35 °C and 90% humidity (Abdel-Banat et al. 2024). *O. surinamensis* breeds year-round in warmer climates, although it can generate up to five generations annually in temperate zones. While dried fruit is primary food source for beetle, its development proceeds somewhat more slowly than in grains (Awadalla et al. 2021).

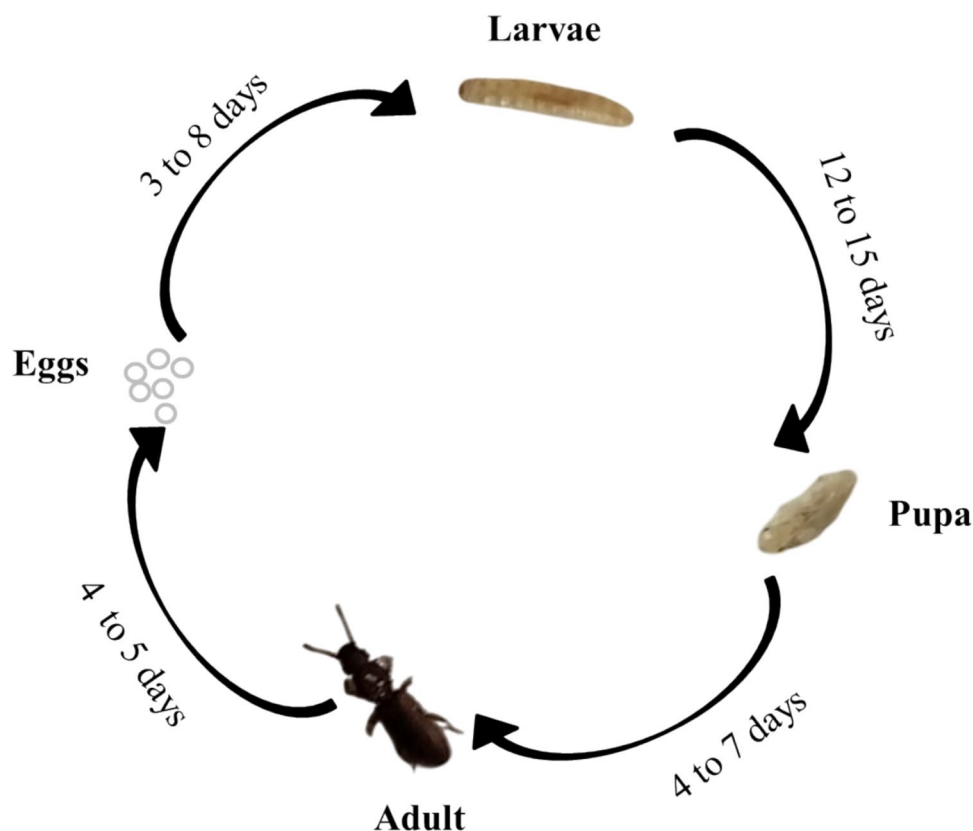
2.2 Biology of *O. surinamensis*

O. surinamensis biology has been examined on wide range of hosts (Nika et al. 2020). *O. surinamensis* commonly infests stored products, including Dadhi and Aseel date fruit varieties, as well as rice, wheat, raisins, groundnut cake, and neem seed kernels. Two date varieties, Aseel and Dadhi, differ greatly from one another in terms of *O. surinamensis* biological factors. For both semi-dry and dried environments, Dadhi variety was recommended for oviposition. Across kinds, egg hatching rates ranged from roughly 72% to 91%, which is a high rate overall. Most studies reported larval death rates below 20%, which is considered comparatively low rate. With significant variance between types and research, pupal stage ranged between 8 and 16 days. Males often live up to 16 days longer than females, with females surviving up to 20 days, depending on date variety (Kousar et al. 2021).

Among several preserved products, *O. surinamensis* life phases show notable variation as shown in Table 1.

3 Morphology of *O. surinamensis*

O. surinamensis females freshly laid eggs that are round and originally white. As these eggs get closer to hatching and are ready to become larvae, they gradually turn to a

Fig. 1 Life cycle of *O. surinamensis***Table 1** Developmental Times of *O. surinamensis* on Different Commodities (in days)

Sr No	Egg stage	Larval stage	Pupal stage	Total development	References
Neem Seed Kernels	4.9–5.5	18.8	4.75	28.45	(Govindaraj et al. 2014)
Dates	4.9–5.5	22.055	5–6	32.70	(Govindaraj et al. 2014)
Groundnut Cake	4.9–5.5	23.3	05–6	~34.30	(Sohaimy & Hafez, 2010)
Groundnut Kernels	4.9–5.5	23.75	5–6	~35.25	(Sohaimy & Hafez, 2010)
Raisins	4.9–5.5	35.9	5–6	47.50	(Curtis 1974)

brownish color (Kousar et al. 2021). Larvae are yellowish during their first stage of development and crawl slowly around food sources. During the second larval stage, the larvae remain predominantly white but begin to develop a more pointed posterior and a brownish coloration at the anterior. They now start to roam around more energetically in an attempt to find food. Larvae have an elongated, yellowish to whitish body in third stage. Jointed appendages show in thoracic area at this stage. In order to survive, larvae at this stage need more food because they have broad posterior and a distinct head with antennae at anterior end. Larvae in their fourth stage are much more active than those in their earlier stages, and they severely infest date fruits. These larvae have eyespots on head, paired antennae, and brownish appearance overall, with significantly deeper brown anterior portion (Kousar et al. 2021).

Pupae have a body that is constricted and dark brown in color, covered in layers of protective cocoon. After few days, anterior end begins to resemble cleft, which indicates emergence of new adult. A dark brown, slender, and energetic adult, it measures about 2 to 3 mm in length. It has large, triangular head, tiny eyes, and teeth-like projections along sides of prothorax (front thorax). Male and female identification is made possible by unique tooth on femur of hind legs. Adults also have paired bead-shaped antennae that help with variety of actions (Kousar et al. 2021).

4 Infestation impact of *O. surinamensis*

O. surinamensis is a significant pest of date palm fruits, among other stored products (Fig. 2). Severe infestations by this beetle lead to fruit decay and extensive damage,



Fig. 2 *O. surinamensis* infestation and damage to stored Date Fruit

rendering the dates unfit for consumption. As a result, both the quality and market value of the fruit are substantially compromised (Mallah et al. 2016).

O. surinamensis is widespread and detrimental insect that also affects wide variety of stored foods, including flours, cereals, pasta, grains, candies, oil seeds, sweets, dried fruits and meats, and nuts. These food products are no longer edible or marketable due to infestation (Zabar & Borowy 2012). Furthermore, beetle's diet reduces phospholipids, different lipids, vital amino acids, and proteins. High relative humidity and moisture content improve pest's capacity to feed (Mallah et al. 2016). Beetle's capacity to adapt different diets enables it to thrive and spread as shown in Table 2, which adds to its widespread presence as a nuisance insect pest (Awadalla et al. 2021).

5 Management practices for *O. surinamensis*

A comprehensive strategy incorporating many control techniques, including storage guidelines, biological, mechanical, physical, and chemical control, is essential for effective

Table 2 *O. surinamensis* cause damage to different hosts of stored grains and fruits

Sr No	Host Types	Host Common Names	Damage	Symptoms of Infestation	Reference
1	Cereals	Wheat	Reduces grain weight and quality by consuming the germ and endosperm	kernels hollowed out, fine powder after eating, <i>O. surinamensis</i> 's adult and larvae present	(Astuti et al. 2018)
2		Rice	Consumes internal organs, resulting in dis-coloration and chalkiness	Grains that are chalky or dis-colored, visible insects	(Astuti et al. 2018; Bunphan et al. 2021)
3		Barley	Creates hollowed-out grains by harming the germ and endosperm	Grain hollows, webbing, and presence of larvae and beetles	(Nika et al. 2020)
4		Oats	Devours inside components, resulting in holes and shriveling	Holes in the dried oats, <i>O. surinamensis</i> adult, larvae, and cast skins	(Nurul & Noor 2019; Sahito et al. 2017)
5		Corn	Causes tiny holes and the formation of mold because it feeds on germ and endosperm	Kernels with mold or tiny holes, as well as <i>O. surinamensis</i> adult and larvae	(Astuti et al. 2018; Bunphan et al. 2021)
6	Stored Fruits	Dates	Feeds on flesh, resulting in mold growth and decomposition	Infested date fruits often show small tunnels or holes, mold growth, a fermented sticky texture, and the presence of adult beetles and larvae	(Bunphan et al. 2021; Mallah et al. 2016)
7		Raisins	Consumes flesh, causing it to shrivel and develop mold	Hollowed-out, rotten raisins with bits of <i>O. surinamensis</i> and larvae inside	(Nurul & Noor 2019)
8		Figs	Ruins flesh, resulting in holes and the formation of fungus	Fruits with holes or hollows in them, a rotten appearance, and adult beetle and larvae present	(Nurul & Noor 2019)
9		Apricots	Consumes flesh, softening it and encouraging the formation of spoilage	Fruits that are soft or rotten, beetle and larval presence	(Nurul & Noor 2019)

control of stored grain pests, particularly *O. surinamensis* (Fig. 3) (Galal 2023).

5.1 Storage guidelines

To ensure effective grain storage and minimize pest infestation, a systematic approach should be followed. Begin with thorough pre-storage preparation: remove all foreign objects, ensure the grain's moisture content is optimal, and verify that storage facilities have adequate drainage and are protected from precipitation leaks. Storage buildings should be strategically located away from doors and ventilators, and modern storage facilities should be utilized whenever possible (Awadalla et al. 2021). During storage, proper stacking is critical bags should be placed on wooden dunnage, positioned at least 0.5 m from walls, and spaced sufficiently to allow for airflow between rows. Maintain rigorous in-storage practices by cleaning and disinfecting bags before use, ensuring proper ventilation, and conducting regular inspections, especially after rainfall, to identify and address any damage promptly. Finally, establish clear emergency procedures for damage control and the safe disposal of infested or compromised grain (Mehta et al. 2021).

5.2 Biological control

The *O. surinamensis* parasitized by *Cephalonomia tarsalis* caused parasitism rate to rise from 19 to 67%. This ectoparasitoid is well recognized for drastically lowering insect populations and is powerful suppressor (Amante et al. 2017). It is commonly known that *O. surinamensis* is biologically controlled, and parasitoid species such as *C. tarsalis* are essential for reducing pest density (Eliopoulos & Kontodimas 2016; Singh et al. 2021). *Cephalonomia tritici* is one of 45 species of Bethyridae that have been found in studies to be efficient against beetles (Eliopoulos 2019). Date fruits that are dry or semi-dry are impacted by this pest (Kousar et al. 2021; Sahito et al. 2017).

For beetle pests of stored products, especially in genus *Oryzaephilus*, *C. tarsalis*, wasp in Bethyridae family, serves as an external parasite (Amante et al. 2017). Although its anatomy, ecology, biology, and behavior have all been studied in considerable detail (Eliopoulos et al. 2017; Eliopoulos & Kontodimas 2016), studies on its potential as a biological control agent have only currently started. It is main natural opponent of *O. surinamensis*, and common pest in agricultural storage situations. Wasp is commonly thought to be ineffectual in managing beetle infestations, even though it

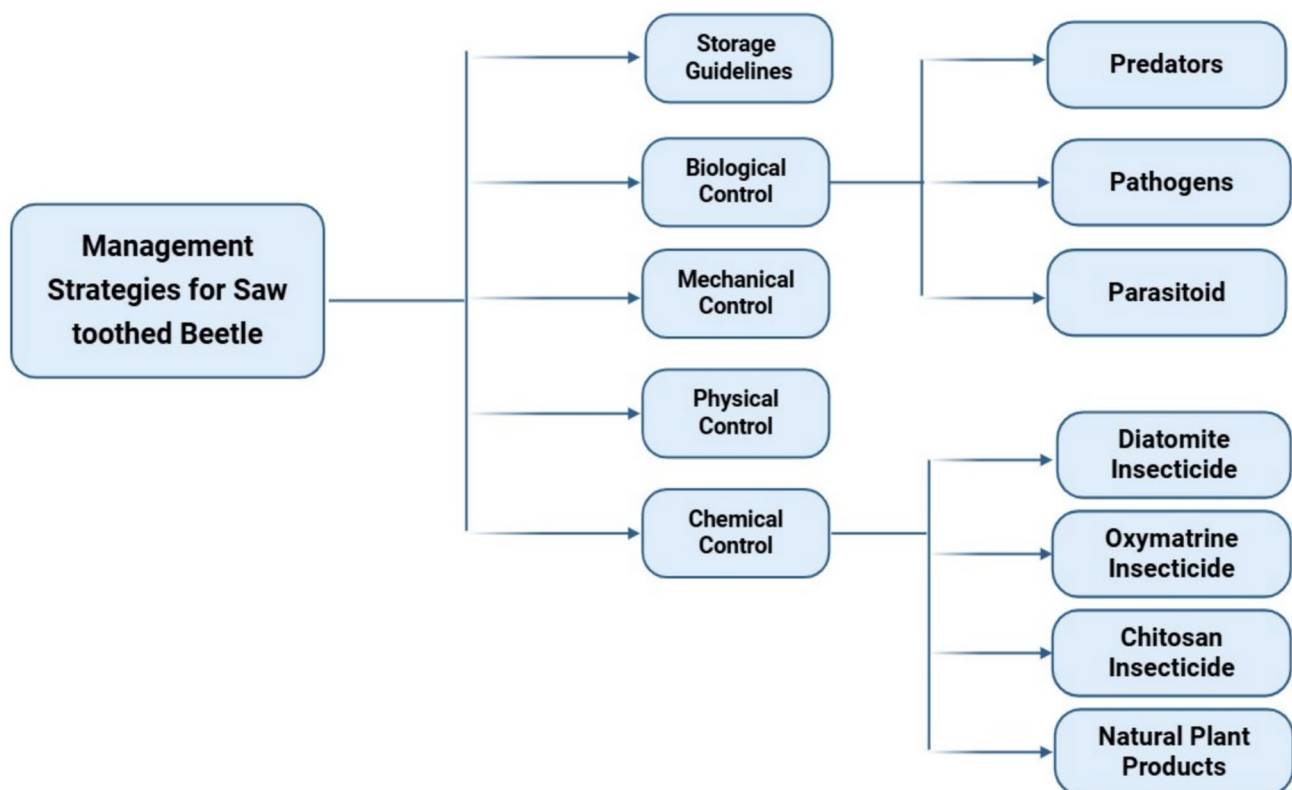


Fig. 3 Different management Strategies used to manage *O. surinamensis*

is common in storage facilities; this is because substantial beetle populations can continue to exist even in the presence of excessive wasp populations (Arco et al. 2024).

5.2.1 Parasitoid and host life table parameters

Life tables are a vital tool for specialists in biological control, helping to optimize mass-rearing techniques and assess the effectiveness of biocontrol agents against pests under different circumstances as shown in Table 3 (Kakde et al. 2014; Portilla et al. 2014; Tuan et al. 2016).

C. tarsalis uses chemical signals, just like a lot of other parasitoids, to locate its hosts. After finding host area, females identify larvae by smelling their excrement and feeling their movements. *C. tarsalis* does not use transient trails created by migrating larvae to locate hosts. Females hide host larvae from other females by rubbing and stinging them with their abdomens, rendering them immobile. Female hides many larvae in shelters after becoming paralyzed and then lays her eggs (del Arco et al. 2024). Since paralyzed larvae do not recover, this tactic increases parasitoid's effectiveness. Low prevalence of parasitism in *C. tarsalis* has led some studies to conclude that it is an economically unimportant biocontrol agent for *O. surinamensis* (Eliopoulos et al. 2017).

5.2.2 Entomopathogenic bacteria against *O. surinamensis*

It is extremely safe to employ entomopathogenic organisms on humans and other animals, including livestock that eat date fruits. Entomopathogenic bacteria can stop *O. surinamensis* from laying eggs. A well-known example is symbiotic bacterium *Xenorhabdus spp.*, which is widely acknowledged as successful biocontrol agent in pest management (Gulcu et al. 2012). Entomopathogenic bacterium *X. nematophila*, which has wide host range and high toxicity against variety of insect pests likewise, *P. temperata* and *X.*

nematophila are extremely potent pathogens that produce proteins and secondary metabolites that are poisonous to a variety of insects (Namsena et al. 2016; Ng'ang'a, 2015). Number of F1 adults that emerged from treated date fruits was much lower than that of control group that received distilled water treatment. Adults in treated fruits were found to be less active, demonstrating bacterial metabolites' deterrent properties. *O. surinamensis*'s fertility significantly decreased as result of these metabolites' disruption of important behaviors like feeding, mating, and reproduction, which also caused F1 adults to emerge in the treated fruits (Alwaneen 2023; Kusakabe et al. 2022).

5.3 Mechanical Control

For post-harvest pest management the first step should be well-designed and maintained facilities. Regular cleaning and consistent is ensured by putting in place thorough sanitation strategy. Various external and internal facility aspects are involved in optimal solutions (Heaps 2012). Minimum of five meters should separate security lights from openings, and buildings should not have direct outside lighting above doorways. Ensure loading, exit, and entry doors are properly sealed at the bottom and do not lead directly to manufacturing facilities. Place pheromone and insect light traps close to doorways and cover any holes in the walls inside (Subramanyam & Hagstrum 2012). Storage areas are particularly vulnerable to pests, necessitating careful observation and management. Reduce the number of windows and make sure those that remain have fine, insect-blocking screens. Avoid artificial ceilings because they can be difficult to clean. Relocate machinery and electrical conduits to make fewer spaces inaccessible, and clean motors on a regular basis to keep pests from eating stored goods (Heaps 2012). In terms of date management, International Center for Agricultural Research in Dry Areas (ICARDA) has provided best practices. Disinfesting dates can be accomplished through

Table 3 Biological parameters of wasp (*C. tarsalis*) and its host *O. surinamensis* under various abiotic conditions

Sr no	Species	Parameter	Value	Temp (°C)	Reference
1	<i>C. tarsalis</i>	Development period (egg to adult)	16.7 days	24	(Eliopoulos et al. 2017)
		Longevity (female)	43–82 days	30–21	
		Fecundity	32–110 eggs	21–27	
		Sex ratio	0.66	24	
		Innate capacity for increase	0.835/week	-	
2	<i>O. surinamensis</i>	Development period (egg to adult)	20.5–37.1 days	25–32.5	(Eliopoulos 2019) (Beckett & Evans 1994; Curtis 1974) (Collins et al. 1989) (Arbogast 1976) (Eliopoulos 2019) (Eliopoulos 2019)
		Innate capacity for increase	0.679–0.848/week	30	
		Innate capacity for increase	0.733/week	30	
		Innate capacity for increase	0.3962/week	-	
		Newly emerged adults	Newly emerged adults	-	

methods including pasteurization, solar heating for drying, or freezing to expedite ripening. It should be obvious how important it is to follow the right storage procedures to keep insects out of stored dates, since post-harvest beetle pests are frequently fungus-feeding opportunists that prey on damaged or contaminated food (Burks et al. 2015).

5.4 Physical Control

Insect pests may be managed through physical control techniques like use of inert dusts like light and sound (Faraone & Hillier 2020), ionizing irradiation (Hallman 2013), diatomaceous earth, thermal regulation, and ozonation (Singh et al. 2011).

Insect pest removal from storage facilities' inaccessible locations using heat treatment is a well-established procedure in the US milling workplace (Fields et al. 2012; Subramanyam & Hagstrum 2012). Heating at pace of 3–5 °C per hour to achieve 50 °C and hold it there for 24–36 h is common procedure. Two primary techniques include either forcing air to disperse heat from external heaters or recirculating warm air within the building (Burks et al. 2015). Although the recirculation method uses less energy, it can be difficult to achieve even heating, particularly when done vertically. On the other hand, the forced air method uses less energy but distributes heat more effectively (Fields et al. 2012).

5.4.1 Physical control—temperature manipulation

Temperature-based pest management, including the use of extreme temperatures and optimized storage conditions, offers a safe and effective chemical-free approach to controlling *O. surinamensis* populations in stored dates, ensuring they remain below economic harm thresholds (Hagstrum & Phillips 2017). Other strategies have also been investigated, such as the use of botanical pesticides and changed atmospheres (Ahmed et al. 2022; Mohammed et al. 2020). The choices for managing storage pests have grown more restricted as methyl bromide fumigation has been discontinued and stored-product insects have become more resistant to phosphine (Gautam et al. 2020; Wakil et al. 2021). Dates that have been preserved are frequently treated with both hot and low temperatures to get rid of insect pests. Insects die within hours at temperatures between −1 and 3 °C because cold temperatures operate more slowly than heat (Abdel-Hady et al. 2021). *Tribolium castaneum*, *O. surinamensis*, and *Ephesia cautella* have all been successfully eradicated at all developmental stages at −18°C using extreme cold, which is frequently employed as a substitute for fumigation (Zinhoum et al. 2025).

It has been demonstrated that low-temperature treatments may successfully target every stage of an insect pest's

growth. The eastern cowpea bruchids (*Callosobruchus chinensis* L.) completely died after 30 min at −20°C (Aker & Tuncer 2022). The effect of temperatures between 0 and −15 °C on several species, including adults of *O. surinamensis* and *Liposcelis bostrychophila* and all stages of *Tribolium confusum*. Whether the insects were put in empty or flour-containing vials, their results demonstrated species-specific reactions to temperature and exposure duration, with 100% mortality of *O. surinamensis* adults occurring after 7 days at −5°C or 8 h at −10°C (Athanassiou et al. 2021). The efficiency of low temperatures in managing pests in dried figs, Complete mortality was achieved at −5°C for seven days, −10°C for two days, and −18°C for one day without sacrificing the figs' quality (Galán et al. 2024).

About 53% adults' *O. surinamensis* were able to live for 8 days at 18 °C without a source of food. At the same temperature, survival rates decreased to 50% after 10 days, 17% after 12 days, and 12% after 16 days. Just 12% of adults lived for up to 10 days without food at 27 °C, compared to 30% who survived for 8 days. However, just 7% of adult beetles survived for eight days without feeding at 0 °C, indicating a considerable drop in survival (Abdel-Banat et al. 2024).

5.5 Chemical control

Chemicals are frequently used in standard pest control techniques. This usually entails spraying grain with residual pesticides at intake when storing grains in bulk. The main strategy for managing pests in stored grains has been application of chemical compounds, especially synthetic pesticides such as carbamates, organochlorides, organophosphates, and synthetic pyrethroids because of their efficiency and user-friendliness (Guru et al. 2022; Mir et al. 2023).

On the other hand, non-polluting storage techniques are better. A lot of work has gone into creating environmental friendly pest management techniques that use materials or substances that are found naturally in order to solve these issues. However, pesticides are still a useful strategy (Sheng et al. 2012).

5.5.1 Diatomite used as natural insecticide

Natural mineral powder diatomite is a great environmental humidity regulator because of its special porous structure and remarkable adsorption powers (Kavallieratos et al. 2015, 2024; Perišić et al. 2018). Diatomite has proven to be a fatal insecticide for common stored grain pests, and it has been used to eradicate them from grain storage areas. The underlying mechanism has been investigated and the settings for its insecticidal process have been optimized (Ogreten et al. 2025).

O. surinamensis, grain beetle, corn weevil, and *Tribolium ferrugineum* are four major stored grain pests that diatomite

has been shown to be effective against as an insecticide. Time took to destroy these pests were shortened by using higher dosages of diatomite. Interestingly, diatomite proved the most successful in reducing weight and sensitivity when used against *O. surinamensis*. Rough diatomite fared better than calcined diatomite in certain areas (Li et al. 2022). Diatomite is a physical insecticide that can be used to control pests of stored grains. It can be removed during milling, which reduces secondary contamination. However, plant-derived or chemical pesticides are already included in commercially available diatomite insecticides, which may have negative effects (Loayza-Huillca et al. 2023).

5.5.2 Insecticides used for surface treatment to control *O. surinamensis*

Growth regulators hydroprene and pyriproxyfen, neonicotinoid chlorfenapyr, and pyrethroid cyfluthrin are among surface treatments used to control insects in United States. When food or other trash is present, their effectiveness is reduced. Utilizing automated methods, many pesticides can be sprayed as 5- to 50- μ m aerosols, offering extensive coverage but not allowing fumigants to penetrate. Two such examples are methoprene and pyrethrins (Arthur 2014). Structural fumigation can disinfest hard-to-reach parts of facilities, similar to heat treatment provides. Integrated circuits and copper are susceptible to phosphorus degradation. In USA, sulfuryl fluoride is now widely used for structural fumigation, whereas methyl bromide was once a common method (Burks et al. 2015; Phillips et al. 2014).

5.5.3 Efficiency of Oxymatrine in Controlling of *O. surinamensis*

Oxymatrine, pesticide with greater efficacy, produced highest mortality rates across all post-treatment periods when applied to *O. surinamensis* stages using plant-derived bioicide. Alkaloids, which are secondary metabolite products of Oxymatrine, are thought to be responsible for its effectiveness (Ali Abo Al-Hab and Al-Zurfi, 2023). Central nervous system is impacted by this bio pesticide, leading to respiratory inhibition, imbalances, and decreased mobility. It causes targeted insects to become paralyzed, experience respiratory failure, and eventually die by speeding up activity of enzymes including phenol oxidase and acetylcholinesterase (Abd El-Mageed & Shalaby 2011).

Second larval stage of *O. surinamensis* was found most vulnerable to different concentrations of Oxymatrine (1.5, 2, and 2.5 ml/L). After only three days of treatment, mortality rates reached 100% at concentrations of 2 and 2.5 ml/L and 95% at 1.5 ml/L. In contrast, adult stage showed lowest

sensitivity, with mortality rates following 70%, 77.5%, and 80% treatment for 14 days at dosages of 1.5, 2, and 2.5 ml/L. Following 14 days of treatment, fifth larval stage death rates at 2.5, 2, and 1.5 ml/L were 95%, 92.50%, and 87.50%, indicating intermediate susceptibility (Ali Abo Al-Hab and Al-Zurfi, 2023).

5.5.4 Chitosan as an effective insecticide against *O. surinamensis*

As pesticide against *O. surinamensis*, chitosan, naturally occurring polymer produced from chitin, has demonstrated encouraging promise. Chitosan has major effect on beetle's rate of oviposition; greater concentrations result in fewer eggs being deposited. Egg-laying rates were greatest in control treatment (314.14 eggs), whereas averages for treatments containing 0.5, 1.0, and 1.5 ppm of chitosan were 209.31, 117.03, and 61.12 eggs, respectively. Chitosan's potential to block acetylcholinesterase enzyme may be cause of this decrease, which would impair insect's general activity and ability to lay eggs (Rajkumar et al. 2020). Chitosan may also include sterilizing agents or interfere with main food source required for egg development, which would further decrease quantity of eggs.

Furthermore, efficiency of chitosan is consistent across *O. surinamensis*'s life stages. As chitosan concentrations grew, it also affected duration of egg incubation period, larval stage, and pupal stage. This could be because of systemic nature of chitosan and its capacity to interfere with hormonal functions, including production of molting hormone, which prolongs larval stage (Campos et al. 2018). Additionally, polymeric components of chitosan create thin coating on eggshell that hinders development of embryos by blocking respiration or facilitating entry of harmful substances. With increasing chitosan concentrations, adult beetle death rate also increased; after 16 days at 1.5 ppm, it reached 98.62%, up from 33.17% in control treatment. This deadly effect could result from chitosan's capacity to pierce insect's cuticle and impact its digestive and neurological systems (Saharan et al. 2015).

Chitosan not only directly affected life cycle of insect but also decreased percentage of weight loss in grains infected by *O. surinamensis*. Treatment with 1.5 ppm chitosan had lowest percentage of weight loss, whereas control treatment had greatest percentages of weight loss. This may be as result of chitosan's effects on larval stages and its capacity to reduce water evaporation from seed surfaces, which lowers weight loss and offers defense against mechanical harm. For controlling infestations of *O. surinamensis*, chitosan shows great promise as natural pesticide (Jamal et al. 2024).

Table 4 Efficacy of various plant species to manage *O. surinamensis*

Sr No	Plant Species	Family	Plant Part Used	Form/Extract	Effect	Reference
1	<i>Agastache foeniculum</i>	Lamiaceae	Aerial parts	Essential oil	Repellent	(Ebadollahi et al. 2010)
2	<i>Ocimum selloi</i> Benth	Lamiaceae	Leaves	Aqueous Extract	Insecticidal	(Moreira et al. 2007)
3	<i>Ailanthus altissima</i>	Simaroubaceae	Bark	Essential oil	Repellent	(Lu & Wu, 2010)
4	<i>Allium cepa</i> Linnaeus	Amaryllidaceae	Bulbs	Essential oil	Repellent	(Gharsan et al. 2018; Moawad & Al-Gamdi, 2018)
5	<i>Allium sativum</i> Linnaeus	Amaryllidaceae	Bulbs	Dried powder	Insecticidal	(Klys & Przystupinska 2015; Moawad & Al-Gamdi, 2018)
6	<i>Ruta graveolens</i> L	Rutaceae	leaves, flowers, and roots	Aqueous Extract	Insecticidal	(Moreira et al. 2007)
7	<i>Anethum graveolens</i> Linnaeus	Apiaceae	Seeds	Essential oil	Repellent	(Jawsuwanwong et al. 2014)
8	<i>Argemone ochroleuca</i>	Papaveraceae	Leaves	Essential oil	Repellent	(Alqurashi & Bakhshwain 2010)
9	<i>Artemisia absinthium</i> Linnaeus	Asteraceae	Whole plant, Leaves	Dried powder, Essential oil	Repellent, Insecticidal	(Bachrouh et al. 2015; Klys & Przystupinska 2015)
10	<i>Artemisia argyi</i>	Asteraceae	Whole plant	Essential oil	Repellent	(Lu et al. 2011)
11	<i>Mentha piperita</i> L	Lamiaceae	Leaves	Aqueous Extract	Repellent, Insecticidal	(Moreira et al. 2007)
12	<i>Artemisia herba-alba</i>	Asteraceae	Leaves	Essential oil	Repellent	(Bachrouh et al. 2015)
13	<i>Azadirachta indica</i>	Meliaceae	Leaves, Seed kernels	Essential oil, Dried powder	Repellent, Insecticidal	(Facknath 2006; Najafabadi et al. 2014)
14	<i>Calotropis procera</i>	Apocynaceae	Leaves	Essential oil	Repellent	(Yousif & Taha 2016)
15	<i>Capparis spinosa</i> Linnaeus	Capparaceae	Leaves	Essential oil	Repellent	(Alqurashi & Bakhshwain 2010)
16	<i>Carum carvi</i> Linnaeus	Apiaceae	Fruits, Seeds	Aqueous extract, Essential oil	Repellent	(Amiri et al. 2016; Gharsan et al. 2018; Moawad & Al-Gamdi, 2018)
17	<i>Cassia occidentalis</i> Linnaeus	Fabaceae	Leaves	Essential oil	Repellent	(Shah et al. 2008)
18	<i>Chenopodium album</i> Linnaeus	Amaranthaceae	Leaves	Essential oil	Repellent	(Kachhwaha et al. 2015)
19	<i>Melia azedarach</i> L	Meliaceae	Whole plant	Ethanollic Extract	Insecticidal	(Manzoor et al. 2011)
20	<i>Citrus aurantium</i> Linnaeus	Rutaceae	Leaves	Essential oil	Repellent	(Abad & Besheli 2016)
21	<i>Crataegus sinaica</i> Boisser	Rosaceae	Leaves	Essential oil	Repellent	(Ismail et al. 2014)
22	<i>Cymbopogon citratus</i> Stapf	Poaceae	Leaves, Whole plant	Essential oil	Repellent	(Hernandez-Lambr��o et al. 2015)
23	<i>Cymbopogon martini</i>	Poaceae	Whole plant	Essential oil	Repellent	(Hernandez-Lambr��o et al. 2015)
24	<i>Cymbopogon citratus</i>	Poaceae	Leaves	Ethanollic Extract	Insecticidal	(Manzoor et al. 2011)
25	<i>Cyperus fuscus</i> Linnaeus	Cyperaceae	Rhizomes	Essential oil	Repellent	(Gharsan et al. 2018)
26	<i>Datura stramonium</i> Linnaeus	Solanaceae	Leaves	Essential oil	Repellent	(Najafabadi et al. 2014; Yousif & Taha 2016)
27	<i>Elettaria cardamomum</i> Linnaeus	Zingiberaceae	Fruits, Seeds	Aqueous extract, Essential oil	Repellent	(Amiri et al. 2016; Moawad & Al-Gamdi, 2018)
28	<i>Eucalyptus dundasii</i>	Myrtaceae	Leaves	Essential oil	Repellent	(Aref et al. 2015)
29	<i>Eucalyptus floribunda</i> F	Myrtaceae	Leaves	Essential oil	Repellent	(Aref et al. 2015)
30	<i>Eucalyptus globulus</i>	Myrtaceae	Leaves	Essential oil	Repellent	(Abd El-Salam et al. 2019)
31	<i>Foeniculum vulgare</i>	Umbelliferae	Seeds, Fruits + Seeds	Essential oil	Repellent	(Moawad & Al-Gamdi, 2018)
32	<i>Fragaria ananassa</i>	Rosaceae	Fruits	Essential oil	Repellent	(Moawad & Al-Gamdi, 2018)

Table 4 (continued)

Sr No	Plant Species	Family	Plant Part Used	Form/Extract	Effect	Reference
33	<i>Illicium verum</i>	Schisandraceae	Flowers	Essential oil	Repellent	(Jawsuwanwong et al. 2014)
34	<i>Datura stramonium</i>	Solanaceae	leaves, seeds flowers	Ethanollic Extract	Insecticidal	(Manzoor et al. 2011)
35	<i>Lantana camara Linnaeus</i>	Verbenaceae	Leaves	Essential oil	Repellent	(Kachhwaha et al. 2015)
36	<i>Lavandula angustifolia</i>	Lamiaceae	Flowers	Essential oil	Repellent	(Gharsan et al. 2018)
37	<i>Leonotis nepetifolia (L.)</i>	Lamiaceae	Leaves	Essential oil	Repellent	(Moreira et al. 2007)
38	<i>Calotropis procera</i>	Apocynaceae	Leaves	Powder	Insecticidal	(Mahmood 2019)
39	<i>Marrubium vulgare Linnaeus</i>	Lamiaceae	Leaves	Essential oil	Repellent	(Alqurashi & Bakhashwain 2010)
40	<i>Matricaria chamomilla Linnaeus</i>	Asteraceae	Flowers	Essential oil	Repellent	(Al-Jabr 2006)
41	<i>Coriandrum sativum L</i>	Apiaceae	Leaves, Seed	Methanolic Extract	Repellent	(Xie et al. 1995)
42	<i>Maytenus emarginata</i>	Celastraceae	Leaves	Essential oil	Repellent	(Kachhwaha et al. 2015)
43	<i>Nigella sativa</i>	Ranunculaceae	Seeds	Powder	Insecticidal	(Mahmood 2019)
44	<i>Mentha longifolia (L.)</i>	Lamiaceae	Leaves	Essential oil	Repellent	(Manzoor et al. 2011)
45	<i>Mentha spp.</i>	Lamiaceae	Leaves	Powder	Insecticidal	(Mahmood 2019)

5.5.5 *O. surinamensis* management by using natural Plant Products

The synthetic pesticides have serious disadvantages, such as decreased grain quality, disagreeable smells, and health risks to people, bio-magnification, and development of pest strains that are resistant. In addition, they can accumulate harmful effects in food and affect non-target creatures, users, and environment (Tapondjou et al. 2002). Plant-derived treatments are becoming more and more popular for managing pests because of these problems and the significant harm that insects do to grains that are stored as shown in Table 4. These are a crucial strategy in insect pest management because they have a number of benefits over synthetic pesticides, including being better for human health, less costly, and more ecologically friendly (Mahmood 2019).

5.6 Conclusion and future prospects

The *O. surinamensis* is a serious hazard to food products that are kept in storage, especially date palm fruits, because of its destructive feeding habits and quick reproduction. Biological, cultural, physical control and improved storage conditions are examples of integrated pest management techniques that must be put into practice. Notably, chitosan-based treatments, temperature manipulation (e.g., cold exposure at -5°C to -18°C), and botanical extracts like neem or clove oil have shown significant promise in reducing infestations. The quality and security of food goods that are preserved depend on the development of

creative solutions to lessen the impact of this pest, which requires ongoing research and cooperation among agricultural stakeholders. Effective management of *O. surinamensis* in date palm fruits requires an integrated approach, including biological, cultural, and physical control methods. For instance, cold treatments and controlled atmosphere storage have proven effective in achieving high mortality rates, while botanical synergisms and nano-formulations of essential oils offer eco-friendly alternatives. Future research should focus on developing environmentally friendly pesticides, such as nano-formulations of plant essential oils or synergistic botanical blends, improving storage techniques, like IoT-based monitoring and refined controlled atmospheres, and identifying pest-resistant date palm varieties. Collaboration among stakeholders, robust monitoring systems, and enhanced extension services are essential for implementing sustainable solutions that protect both crop and environment.

Acknowledgements The authors acknowledge the respected reviewers for the recommendations to improve our manuscript.

Authors contributions Alishbah Mohsin: Writing, Conceptualization, Methodology, Formal analysis. Muhammad Adnan Bodlah: Conceptualization, Writing Supervision, – review & editing. Ayesha Younas: Conceptualization of the original draft. Aleena Kanwal: review & editing.

Funding The authors declare that no funding was received for this study.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Consent to Publish All authors attest to the validity of manuscript contents and agree for submission.

Conflict of interest The authors declare no competing interests.

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