BIOLOGY AND HOST PREFERENCE OF SAWTOOTHED GRAIN BEETLE, *Oryzaephilus surinamensis* L. (COLEOPTERA: SILVANIDAE) ON DATE CULTIVARS AND THEIR MANAGEMENT USING EDIBLE PLANT PRODUCTS

A THESIS

BY

MST. LAMIA JAHAN

REGISTRATION NUMBER: 2205090

THESIS SEMESTER: JULY-DECEMBER, 2023

SESSION: 2022-2023

MASTER OF SCIENCE (MS)

IN

ENTOMOLOGY

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HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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DECEMBER, 2023

Dedicated

To

My Beloved Parents, family, honorable supervisor and teachers

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The Author

BIOLOGY AND HOST PREFERENCE OF SAWTOOTHED GRAIN BEETLE, *Oryzaephilus surinamensis* L. (COLEOPTERA: SILVANIDAE) ON DATE CULTIVARS AND THEIR MANAGEMENT USING EDIBLE PLANT PRODUCTS

ABSTRACT

The sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae) constitutes one of the major pests of date palm in storage conditions throughout the world. The experiments were conducted to find out the biology of *O. surinamensis* while fed on five different date cultivars (Mariyam, Medjul, Dabas, Zahidi and Saad) as well as to evaluate the efficacy of edible plant products against the pest. Both the experiments were conducted at laboratory conditions prevailed 30 ± 5 °C, 80 ± 10 % RH. The study revealed that the highest incubation period of the insect was recorded 3.92 days on Saad but minimum 3.42 days on Mariyam. The larval period ranged from 12.13 (Mariyam) to 14.08 days (Saad) while pupal period 4.56 (Mariyam) to 5.14 days (Saad). The larval to pupal period was 16.69 to 19.22 days. The duration of egg to adult stages of female from 20.1 to 23.14 days. The highest and the lowest pre-oviposition periods were 7.35 (Dabas) and 6.15 days (Mariyam), respectively. The Mariyam date cultivar experienced the highest damage of 22.5 % in October but the lowest 4.5 % in Saad during the month of December. The maximum (91.92 %) egg hatching was found in Mariyam date cultivar while minimum (81.72 %) was noticed in Dabas date cultivar. Survival and mortality percentage of larvae and pupae were recorded and pupal survival rate was found higher than larval survival rate. The highest larval and pupal survival rate was 91.58 and 93.57 %, respectively, in Mariyam date cultivar. Some edible plant products with different concentration (4 %, 2 %, and 0.05 %) were tested against *O. surinamensis* on different dates to determine the mortality percentage. Clove powder showed 100 % mortality at 4 % and 2 % concentrations after 5 and 7 days which were the highest among the edible plant powders.

Key Words: Sawtoothed grain beetle, date cultivars, biological traits, host preference, survival, mortality, edible plant products

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INTRODUCTION

Dates are the fruit of the date palm tree, *Phoenix dactylifera*, is a flowering-plant species in the palm family Arecaceae, cultivated for its edible sweet and nutritious fruit. The species is widely cultivated across the dry and semi-arid parts of northern Africa, the Middle East, and South Asia, and is naturalized in many tropical and subtropical regions where it is used as a staple food (Chandrasekaran and Bahkali, 2013).

Dates are a delicious, nutrient-dense fruit having a good source of antioxidants, vitamins, calories, minerals and protein that provides 2500–3000 calories per kg of fruit and the ripped dates content about 80 % sugar. Many people enjoy eating fruit, and dates are among the most widely consumed fruits worldwide. In Bangladesh, dates have become more popular during the past few years, with many people looking for ways to switch up their diets. The consumption of dates usually goes up in the country during the month of Ramadan. In recent times, both the regular consumers and health-conscious people have been eating the fruit throughout the year. The fruit is now most accessible sources of food in situations of emergency for the distressed people in natural calamities.

As a result the demand for dates has increased significantly in Bangladesh in recent years, and imports of dates have gone up by more than four to five times. About 90,000 metric tons of dates are needed annually in Bangladesh. Based on data from the National Board of Revenue, the demand is satisfied by imports from several countries, such as Egypt, Iraq, Iran, Algeria, Sudan, and Pakistan [Daily star, 2023]. Accordingly, Bangladesh imported dates more than quadrupled in the fiscal year 2021 when compared year-on-year, riding on the ever-growing consumer demand. Data from the National Board of Revenue shows the country imported more than 1, 12,145 tons of dates in the fiscal year

2021, which is significantly higher than 23,491 tons imported in fiscal year 2020. However, with the increasing trend of consumption in the country the date palm damaging pests also increasing specially in the stores where dates were stocked.

Consequently, Buxton (1920) listed 54 arthropod pests of date palm both in the field and stored conditions. Among them, sawtoothed grain beetle, is a common, worldwide stored date pest which also found in Bangladesh. It is typically a packing house and storage insect and is considered an important pest of dates and other dried fruit (Fraenkel and Blewett, 1943; Curtis and Clark, 1974; Simmons and Nelson, 1975; Khairi *et al.*, 2010). Insect infestation in stored food goods is a typical occurrence not only in Bangladesh, but around the world. Pests are currently frequent as a result of the large amount of dry fruit and nut importation; due to this, the damage percentage is also significant in markets and home in store conditions.

Sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae) is one of the most important and common stored date insect pests around the world (Thomas and Shepard, 1940; Champ and Dyte, 1976). Dates are widely attacked both in field condition and stock places. The stored dry fruits (Simmons and Nelson, 1975) and semi-dry or freshly harvested dates (Hussain, 197; Simmons and Nelson, 1975) face a critical problem of insects' infestation mostly from sawtoothed grain beetle reducing their quality day by day as well as quantity and weight loss (Aldryhim and Adam, 1998). If no control measures are implemented, the infestation on stored dry dates may reach up to 75% in just two months (Abdel-Banat *et al.*, 2023). The beetles number increases in the stored dried fruit after long storage period (Turney, 1957). Both the adults and larvae feed on fresh date fruits and dried fruits by making tunnels between the external fruit skin and flesh and produce scars on the surface of the fruit thereby making them rough. In severe infestation, the beetle consumes all date fruit contents leaving the skin or exocarp intact. This is a characteristic damage symptom of sawtoothed grain beetle (Al-Hafidh *et al.,* 1987). The strong chewing mouth parts of the pest allow them to access food which is stored inside boxes and also have the ability to invade the packaged food due to its smell and odor (Mowery *et al.,* 2002).

The larvae of this pest insect reduce the germination strength of the seed as well as lower the date's nutritional value (Kumar *et al.,* 1996). The pests pollute more food than they consume by damaging the fruit cells, leaving insect body parts (antennae, legs, wings, cast skins etc.), frass, webbing, and other excretions. As a result in the reduction of market value of dates as the majority of people consider the infested foodstuffs unsafe for consumption. Dates with low moisture content, with the calyx removed, or that are broken or have mechanical damage are more likely to be infested by the beetle. It is a very small insect which has the ability to hide in many places in stored facilities, making it difficult to control using insecticides and it has built up resistant to several insecticides as well (Greening *et al.*, 1974; Heather and Wilson, 1983).

Biology study of a stored insect done for a variety of purposes. For starters, it sheds light on the insect's life cycle, behavior, and adaptation techniques in various habitats. For showing the age composition of a population, for indicating critical stages in the life cycle at which mortality is high, for showing difference between species, for showing the success of the same species in different biotopes, and in control of pests. From a pest management standpoint, it is very useful to know when a pest population suffers high mortality- this is usually the time when it is most vulnerable.

This information is useful for pest control, agriculture, and understanding ecological equilibrium. Furthermore, stored insects can act as bio indicators, indicating environmental changes and contamination levels. Prevention of losses in stored dates due to the insect pest is of paramount importance.

In Bangladesh, very little work has been done on the damage caused by sawtoothed grain beetle to the different stored date cultivars in relation to their nutritional value. The present study was designed primarily to provide data on the biology of sawtoothed grain beetle,

O. surinamensis on five popular date cultivars consumed in Bangladesh under laboratory conditions.

The need to protect stored dates from pest attack is now an economic and nutritional burning issues of our country. This study also focuses on control of the insect using edible plant powders because chemical pesticides have several serious disadvantages such as the emergence of genetically resistant strains and their deadly effects in non-target organisms, the risk of contamination to users as well as cumulative toxic action on food and environmental pollution (Tapondjou, 2002). Due to the importance of the insect and as a result of the large damage caused to the dates and the fact that the pesticides affect human health and to find alternatives from plant origin that are safer for the environment and less expensive compared to those chemical pesticides, some plant powders have been used.

Objectives of the research

1. To study the biology of sawtoothed grain beetle, *O. surinamensis* on five different date cultivars.
2. To screen the host preference of *O. surinamensis.*
3. To evaluate the efficacy of some edible plant products against *O. surinamensis.*

REVIEW AND LITERATURE

Dates, the fruit of the date palm tree (*Phoenix dactylifera*), offer various health benefits due to their nutritional content. Here are some potential health benefits of consuming dates. Dates are good sources of essential nutrients, including vitamins (such as vitamin B6 and vitamin K), minerals (such as potassium, magnesium, and copper), and fiber. They are naturally sweet and can serve as a healthier alternative to refined sugars. The fruit contains natural sugars like glucose, fructose, and sucrose, providing a quick energy boost. Dates are excellent sources of dietary fiber, which can aid in digestion, promote a feeling of fullness, and help prevent constipation. Dates contain various antioxidants, including flavonoids, carotenoids, and phenolic acid. Antioxidants help neutralize harmful free radicals in the body, which may contribute to aging and various diseases. The potassium content in dates may support heart health by helping to regulate blood pressure. Additionally, the fiber and antioxidants in dates may contribute to overall cardiovascular health. Dates contain minerals such as magnesium, phosphorus, and calcium, which are essential for bone health. Including dates in your diet may contribute to maintaining strong and healthy bones. Due to their natural sweetness, dates can be used as a healthier alternative to refined sugars in various recipes, such as smoothies, energy bars, and desserts. Dates are good source of iron, which is essential for the formation of red blood cells and the prevention of iron deficiency anemia. The fiber in dates can help promote a healthy digestive system by preventing constipation and supporting regular bowel movements. The fiber in dates can contribute to a feeling of fullness, potentially helping with weight management by reducing overall calorie intake. While dates offer several health benefits, it's important to consume them in moderation due to their calorie and sugar content. As with any food, individual dietary needs and health conditions vary, so it's advisable to consult with a healthcare professional or a registered dietitian for personalized advice.

2.1 Identification

The sawtoothed grain beetle is flattened, roughly 2.5–3.5 mm long, and reddish-brown in color (USDA -FGIS, 2015).

Fig. 1: Adult *O. surinamensis*

The adult is 10 mm (1.25 inches) long. Because of its flat body, it is perfectly suited to crawl into cracks and crevices. They can be easily recognized. The thoracic borders have six projections on each side and resemble saws. Despite having well-developed wings, there is no evidence of this insect flying.

Sexual dimorphism: A spine-like projection medially extends from the posterior margin of the hind trochanter and the upper margin of the hind femur in males; this projection is absent in females (Bousquet, 1990).

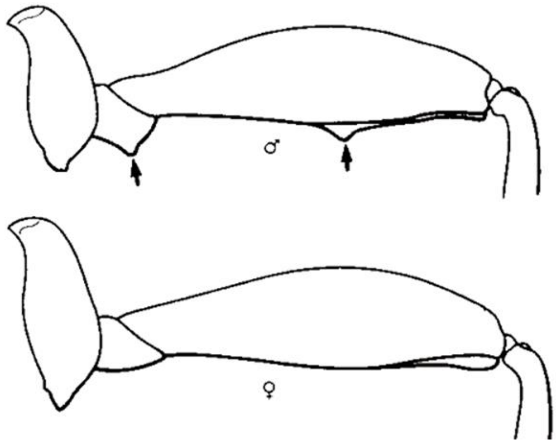


Fig. 2: *O. surinamensis* (♂ male, ♀ female) basal part of hind leg (ventral view) (Bousquet, 1990).

2.2 Regional distribution

O. surinamensis infests 140 commodities, has been detected in 104 countries, and is related with 21 different types of facilities, according to Hagstrum and Subramanyam's (2017) analysis of 1663 insect species linked to stored goods. 26 of the 54 countries in Africa, 27 of the 50 in Asia, 22 of the 51 in Europe, 11 of the 23 in North America, 11 of the 12 in South America, and 7 of the 14 in Oceania are included in this. *O. surinamensis* must have a practically global distribution, in spite of the incompleteness of the data.

Although this beetle is found all across the world, mountainous regions with warm, humid climates are home to large populations of it. India, Pakistan, Sri Lanka, Turkey, Poland, Brazil, Britain, Mediterranean region, East Africa, Argentina, Bulgaria, Switzerland, West Kenya, Indonesia, USA, Canada, Israel, Russia, Australia and Japan, China, Bangladesh, Hawaii, Philippines, Germany, and Saudi Arabia are just a few of the places where *O. surinamensis* has been reported to be present. It can be found in nearly all stored food items, including nuts, dry fruits, flour, biscuits, and other grain products. It is distributed around the world.

Table 1: Distribution of *O. surinamensis* throughout the countries in the world

Continents	Distributed Countries
Africa	Angola, Egypt, Morocco, Kenya, Cote d'Ivoire
Asia	Israel, India, Indonesia, Malaysia, Japan, Russia, Iraq, Taiwan, Hawaii
Europe	Czech Republic, France, Greece, Hungary, Italy, Portugal, Romania, Spain, UK, Germany, Lithuania, Poland, Europe
North America	Canada, Mexico, US, Cuba
South America	Brazil
Oceania	Australia

2.3 Taxonomic position of *Oryzaephilus surinamensis* L.

The sawtoothed gain beetle's systematic position was established by Linnaeus in 1758. The sawtoothed gain beetle has been classified in the following hierarchical order:

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Order: Coleoptera

Family: Silvanidae

Genus: *Oryzaephilus*

Species: *surinamensis*

Binomial name: *Oryzaephilus surinamensis* (Linnaeus, 1758)

Name and synonyms of sawtoothed grain beetle are presented below:

Oryzaephilus surinamensis (Linnaeus, 1758)

Synonyms

Oryzaephilus frumentarius Fabricius, 1775

Oryzaephilus sexdentatus Herbst, 1783

Oryzaephilus cursor Fabricius, 1792

Oryzaephilus sexdentatus Fabricius 1792

Oryzaephilus bicornis Erichson, 1846

Common name

Getreide-Plattkaefer, Getreide-Schmalkaefer (Germany)

Chipushitmschunenthachaze (Israel)

Silvanosurinamense (Italy)

Nokogiri-kokunusuto (Japan)

Rijstkever (Netherlands)

2.4 Host range of sawtoothed grain beetle

The sawtoothed grain beetle (*Oryzaephilus surinamensis*) is a common pantry pest that infests stored food products. The primary hosts of sawtoothed grain beetles are a variety of stored food products. According to Hagstrum and Subramanyam's (2017) they are commonly found infesting 140 commodities. Some of them are:

Cereals: It is common to find sawtoothed grain beetles in cereals that have been preserved, including rice, wheat, oats, and barley.

Flour and Baking Mixes: They can infest flour, baking mixes, and other grain-based products.

Dried Fruits: Raisins, dried apricots, and other dried fruits are susceptible to infestation.

Nuts: Various types of nuts, including almonds, walnuts, and peanuts, can be infested.

Seeds: Seeds such as sunflower seeds, pumpkin seeds, and others are potential hosts.

Chocolate: Sawtoothed grain beetles can also infest chocolate and cocoa products.

Spices: They may infest a variety of spices, including cinnamon, cumin, and others.

Pet Food: Sawtoothed grain beetles can infest dry pet food.

2.5 Life cycle of sawtoothed grain beetle

The sawtoothed grain beetle's life cycle can take anywhere from 27 to 315 days to complete from egg to adult (Simmons and Nelson, 1975). It can complete development between 17.5 to 37.5 °C, with the rapid development occurring around 32.5-35 °C and 90 % RH (Howe, 1956). In temperate regions, the beetle may produce four to five generations a year, while in subtropical and tropical regions, breeding continues (Back and Cotton, 1926). Most developmental research have concentrated on grain, and the sawtoothed grain beetle matures more slowly on dried fruit. (Fraenkel and Blewett, 1943; Curtis and Clark, 1974).

2.6 Biology of sawtoothed grain beetle

2.6.1 Overall biology

Eggs are laid loosely in flour or other food product, or are lodged in crevices in whole grain. The female lays approximately 400 eggs either loosely in flour or other milled grain products or tucked in a crevice of a grain kernel (Mason, 2003). Egg laying begins about 5 days after emergence and reaches a maximum during the 2^{nd} or 3^{rd} week and then declines rapidly after about 10 weeks (Mason, 2003). Eggs hatch in 3-8 days (Anon, 2009; Mason, 2003) and the larvae begin to feed within a few hours of hatching (Mason, 2003). Larvae are typically free-living, mobile and not concealed, usually passing through four instars (range 2-5) during their development. They are unable to develop on undamaged wheat (Surtees, 1965 and Mason, 2003). Under favorable conditions, larvae complete their development in 12-15days.Pupal develop in about 4-7 days and total development time from egg to adult varies from 21 to 51 days, depending on temperature (Calvin, 1990). Infestations will develop between 17 ^{o}C and 37 ^{o}C, 10-90 % RH (Anon., 2009) and are very cold tolerant. Optimum temperature for development is between 30-35 ℃ (Halstead, 1980). Adults normally live 6 to 10 months, or even up to 3 years but quickly die on dust-free fruits (Surtees, 1965 and Calvin, 1990).

2.6.2 Mating

Males and females have more than one mate. Mating occurs within 2-3 days after adult emergence. Males remain responsive to females after previous mating. Females normally mate with 2 males, and males normally mate at least 6 times (Ashworth, 1993; Papadopoulou, 2006). Mating system is polygynandrous.

2.6.3 Reproduction

The female beetle deposits eggs in cracks in food or on ground food, like flour. When the eggs hatch, the larvae feed and grow. When the larvae are ready to change to adult beetles, they make a cocoon from food particles. In warm, humid conditions, the entire life cycle, from egg to mature adult, takes about two months. There can be several generations per year.

2.6.4 Oviposition

Females lay up to about 50-300 eggs. The eggs of *O. surinamensis* are white in color, 0.1 to 0.2 mm long and 0.2 mm wide (Jones, 1913). Each egg weighs approximately 8.4 µg and has a waxy shell which protects the egg from desiccation and hatch in 3 to 10 days in warm weather. The larva eats the egg shell at the time of hatching (Ashworth, 1993). The eggs become dull in color before hatching. Surface of the egg is smooth, without sculpture except at the end portion of egg from which the larva emerges (Runner, 1919). When the shell breaks at the head and the undulating movements carry the young larva gradually clear of it. The dark red eyespots and the ochre spot of mouth parts (mandibles and cibarial sclerite) are visible through the chorion at the anterior end. The chorion appears smooth, but SEM magnification (550-2000 x) reveals imprints of the polygonal follicular cells. No aeropyles or micropyles have been detected. According to Jacob and Fleming (1989) the oviposition period is two to five months long, which is a long period. Pre oviposition period vary from 8 to 207 days depending on the surrounding environmental condition.

2.6.5 Egg

A female is reported to lay 50-300 eggs in 3-60 days after emergence. The eggs are dropped loosely among the food grains or tucked in crevices in the grains. Eggs are small, 0.1-0.2 mm in size; slender and white in color. Eggs hatch within 3 to 5 days. The egg is white, shiny, and elongate-oval in form, becoming ochre-yellow as they age, symmetrically oblong with the anterior and posterior ends of almost identical shape, regularly rounded, or with the anterior end slightly narrower. Freshly laid eggs are glossy, smooth, and non-opalescent, with both ends pellucid. During embryo development, eggs lose their gloss. An oblong depression is usually formed on the ventral side. The young embryo when fully developed nearly fills the eggshell, which becomes wrinkled and undulates with the movements of the embryo. When ready to break from the shell, the embryo sets in motion a series of undulations from carded forward, the head and prothorax seeming to swell up at the end of each undulation, stretching the shell of the egg to the bursting point.

2.6.6 Larva

Length of larval stage: First hatched larvae and its movements are slow and uncertain. It soon gains strength and becomes active, however and begins to attack the available food. Its body acquires a pale yellowish color, with darker bands on the dorsal surface of the thoracic and abdominal segments. The head capsule is a pale yellowish brown. When first hatched the larva is about 0.80 to 0.90 mm. in length, and the width of the head capsule is 0.24 mm. When fully grown the larva attains a length of from 2.5 to 2.8 mm., and the width of the head capsule is from 0.46 mm. to 0.54 mm thrives on practically all foodstuffs of store products as corn, nuts, wheat, barley, and rice, both ground and unground and in all their varied forms, such as flour, meal, and breakfast food, dried foods, nut meats, copra, etc. It is free-living and active, and does not always confine its feeding to one spot, but nibbles here and there as fancy dictates. It is apparently unable to feed on wholegrain unless the grain is quite soft. The length of the larval stage as determined at Washington, D. C, varied considerably, and was affected chiefly by the temperature. Data bearing on larval life will be found in during the spring the period from hatching to pupation ranged from about4 to 7 weeks, whereas in midsummer this period was about 2 weeks, 12 days being the shortest larval period recorded. With the approach of cooler weather in the fall, the period again lengthened until during the winter months, when the laboratory was heated only during the day, the period was about 8 to 10 weeks. The number of molts varied. A majority of the larvae observed molted three times, a few molted four times and quite a number molted but twice. Those individuals that molted four times were all reared during the fall and winter, when development was slow and the larval period quite long.

Ashworth (1993) stated that the first instar is less than 1 mm long and covered with fine hairs. The larvae go through four larval instars before pupation, and the weight ranges from 2.5 to 5.0 mg. Runner (1919) reported that the first instar is 0.55 to 1.4 mm long and yellowish white in color. The second instar is about 3 mm long and yellowish white, and the last instar is 4 mm long, and body is yellowish white, set entirely with long, yellowish brown hairs. Newly hatched larvae move away from light and are extremely active (Ashworth, 1993). These tiny larvae are able to infest packaged food by entering through small holes (Runner, 1919). The older larvae are less active but are still capable of considerable wandering and remain negatively phototropic. Larvae are scarabaei form in shape, i.e., when at rest, bodies curl into a "c" shape. The larvae stop feeding and build cell when they are fully grown, and the formation of this cell is influenced by the food substrate. Disturbance may cause old larvae to give up a partly-made cell and build new cells or even cause them to form naked pupae (Howe, 1957). They tend to penetrate deeply into loosely packed commodities. Insect activity ceases when the temperature falls below 19.5 ºC (Runner, 1919) and the beetle overwinters in the larval stage (Ashworth, 1993). Development of larvae stops when the temperature falls below 17 ºC or above 42 ºC (Howe, 1957).

2.6.7 Pupa

Last instar larvae usually construct cocoon-like casings from grain fragments cemented together with a sticky oral secretion in which to pupate, while sometimes no pupal cell is made. The larva attaches itself by the anal end to a solid object (Anon., 2009; Back and Cotton, 1926). Pupa is uniformly white when first formed, and is 3.5 mm long and 1.7 mm wide. Pupal period is 7-21 days. Tips of elytra reach the fourth segment of the abdomen. Metathoracic legs are formed under the elytra. The head is curved beneath pronotum. The ultimate portion of the abdomen is paired with lateral protuberances (Runner, 1919). The pupae have many projections about 0.1 mm long arising from the lateral aspect of the pronotal and abdominal tergites. At the eclosion of the pupa, the projections lie close to the body but become erect soon after. A slightly viscous secretion is apparent within 20 hours of eclosion, remaining throughout the pupal stage if untouched, and may protect the vulnerable pupae against predation (Klein and Burkholder, 1983).

2.6.8 Adult

Adult: The adult *O. surinamensis* is a very active, slender, flattish, brown beetle, about one-tenth of an inch (2 to 3 mm) long and has six tooth like projections along each side of the margin of the body in front of the wings (hence the name 'Sawtoothed'). It is a general feeder and in raisins stored this insect can become very abundant. It has well developed wings, but rarely if ever flies. Males, but not females have the posterior margin of the hind trochanter and the upper margin of the hind femur medially with a spine-like projection (Bousquet, 1990; Mason, 2003 and Olsen, 1977). Wings are well developed in both sexes (Mason, 2003). The adult is nearly omnivorous. It is cosmopolitan and gregarious; living in nearly all stored human dried fruits & nuts. Its flattened body is well adapted for crawling into cracks and crevices. The elytra are longitudinally grooved. Additionally, there are three longitudinal ridges along the top surface of the thorax (Mason, 2003).

2.7 Symptoms and damage

Both adults and larvae cause damage to stored products but the damage done by larvae is more serious (Bousquet, 1990). In Australian conditions adults are short-lived and feed little if at all (Rees, 2004). Damage is caused by *O. surinamensis* usually results in loss of weight and decrease in quality. A single insect only causes a few milligrams of weight loss, whereas populations measured by millions of *O. surinamensis* individuals can bring considerable weight loss. Stored products are holed and contaminated with cocoons and frass when infested by *O. surinamensis*. In nuts & dry fruits the holes destroy the product, and holes spoil the sack or package. Infestation of cereal grains and of seeds of beans and other plants could adversely affect germination as the germ is attacked (Howe, 1957). Malhotra (2007) reported that about 17 to 25 percent losses are caused by insects, moulds, rodents etc. to different spices during storage. These losses are caused by converting fruits into powder form.

2.8 Effect of environment on pest survival

Larval activity of the Sawtoothed grain beetle ceases when the temperature falls below 15 °C (59°F) and these larvae can remain dormant for many months and may over-winter in this stage in cool climates. Howe (1956) stated that the developmental period is affected by humidity and temperature as well as type and availability of food. Lefkovitch and Currie (1963) reported that food shortages prolong development and reduces survival of the immature stages and also reduces the weight of the resulting adults. Larvae will eat eggs and pupae in the absence of other food sources. Ashworth (1993) concluded that the minimal temperature for development was about 18 °C, but oviposition has been recorded at 15 °C. All stages are killed at 2.2 °C for16 days or -3.8 °C for 7 days but eggs may survive shorter periods of exposure.

2.9 Nature and extent of damage

Both adults and larvae cause damage to stored products but the damage done by larvae is more serious (Bousquet, 1990). In Australian conditions adults are short-lived and feed little if at all (Rees, 2004). Damage is caused by *O. surinamensis* usually results in loss of weight and decrease in quality. A single insect only causes a few milligrams of weight loss, whereas populations measured by millions of *O. surinamensis* individuals can bring considerable weight loss. Stored products are holed and contaminated with cocoons and frass when infested by *O. surinamensis*. In nuts & dry fruits the holes destroy the product, and holes spoil the sack or package. Infestation of cereal grains and of seeds of beans and other plants could adversely affect germination as the germ is attacked (Howe, 1956). The extent of damage inflicted by stored-pests on dates is influenced by many factors including date variety, whether dates are stored loose or pressed together, and the storage conditions, particularly temperature and relative humidity. Pressed dates are more likely to withstand stored- product insect pests than loose dates, due to the absence of free space in the former, which appears to hinder the free movement of insects, their behavior and finally their population build-up.

2.10 Factors regulating loss in storage

2.10.1 Ecology

Ecology deals with interaction of abiotic and biotic environment of dried nut and fruits in storage of *O. surinamensis* L.

2.10.2 Biotic environment

Biotic environment includes living associations of storage insects among themselves as well as with other organisms. Both biotic and abiotic factors are responsible for the loss of stored seeds in storage. Baloch *et al.* (1994) revealed that the major biotic factors influencing seeds loss during storage are insects, moulds, birds and rats. Storage insects are usually confined in a specially limited ecosystem and interact among themselves and also with storage fungi, mites and nematodes etc. living together in this complex ecosystem.

2.10.3 Abiotic or physical environment

This environment includes factors like atmospheric humidity, moisture content of the grain, temperature, light; season and food etc. are revised as follows. High temperature causes deterioration, while low temperature is good for storage. High temperature accelerates the respiration of fruits, which produces carbon dioxide, heat and water, conditions favorable for spoilage, while decreasing humidity is good for storage any fruits. Generally the colder and drier the surrounding environment is better for storage fruits. The conditions to aim for are 30 % relative humidity or as low as possible and temperature bellow 59 °F (15 °C). Darkness is a third rule of optimal fruit storage. Light stimulate and support the germination process in the fruits and storage in darkness helps keeping the pre-germination process in the fruit at a low level. Atmospheric humidity and moisture: Both these factors are closely related. It has been reported in case of *O. surinamensis* that its larval development, pupation and transformation into normal sized adults could take place even in a medium containing practically no free water (Schwardt, 1938). Thomas and Shepard (1940) reported a rapid development of this beetle at higher humidity. *O. surinamensis*, however, failed to develop below 10 percent moisture content at 31 °C to 34 °C in nuts (Howe, 1956). Rate of population growth increased rapidly at humidity range between 42-56 percent, but remained constant at 74 % RH. This beetle generally showed a pronounced avoidance of high humidity and a lesser avoidance of low ones (Arbogast and Carthon, 1972). No development was recorded at 46 % RH. at a constant temperature of 30 °C (Arbogast, 1976). Studies conducted at CRRI, Cuttack concluded that this beetle was unable to develop in sound nuts even at high atmospheric humidity, but developed after infestation of major pests in long term storage (Prakash *et al*., 1987).

2.10.3.1 Temperature

This is one of the most important factors governing the rate of metabolism, growth, development, reproduction, general behaviour and distribution of storage insects. No development of *O. surinamensis* took place at 15 °C and at 40 °C, but at 20 °C and 25 °C the life cycle was completed in 69.06 and 30.31 days respectively (Thomas and Shepard, 1940). In rural storage structures, which are not usually, air tight, insects are continuously subjected to variations of temperature, because temperature fluctuates with outer environment. The optimum temperature varied from 26 °C to 37 °C for total development (Back and Cotton, 1926) of *O. surinamensis*. But at 60-76 % R.H. the optimum temperature was 35 °C. The optimum temperature varied from 30 °C to 35 °C for larval development (Nigam et al., 1969). At 78 to 82 % R.H. the optimum temperature varied from 33 °C-35 °C for larval and pupal development (Prakash and Rao, 1989). At 17.5 °C, eggs of large and intermediates trains of this beetle were hatched, but the larvae and pupae died with 70 % RH. (Jacob and Fleming, 1989). Fatal high temperature is of great significance, wherein grains are being sterilized to kill latent stages of insects. Total mortality of all stages of *O. surinamensis* is observed in bags at 60 °C-69 °C. However, its adults died at 50 °C in 3 minutes exposure in laboratory test.

2.10.3.2 Light

According to Pajni and Gill (1974), *O. surinamensis* responded positively to photos when adults moved. Elvin and Schroeder (1961) also noted that adult movements of *O.*

surinamensis showed photopositive responses to UV light in 50 % of cases at one or more levels of 3660 A0 light.

2.11 Management

Local storage structures which are commonly used in rural India and Bangladesh fail to maintain the optimum health and also fail to provide complete protection from insects. In general, these structures are not moisture proof. The moisture content is high in stored nuts which facilitates insect multiplication. The longer the storage period, higher is the insect infestation.

The type of storage plays a fundamental role in storage efficiency. Nuts and dates should be kept in tightly sealed container. Climate conditions, seeds conditions at storage, seeds and pest control practices all contribute to the rate of loss caused by insects. As these factors interact, it is difficult to isolate them or identify one factor, which has a direct influence on loss. Average statistics for loss, whether for store types, areas, or quantities of seeds stored are inconclusive. An average figure for loss for a region or a country holds no significance unless a decision regarding a new system of storage, or new pest control techniques is required. Nevertheless average loss figures are always sought.

MATERIALS AND METHODS

3.1 Experimental site

The research work was carried out in the Entomology laboratory (25.64 °N, 88.64 °E) of Hajee Mohammad Danesh Science and Technology University, during the period of July to December 2023 at 30 ± 5 °C and 80 ± 10 % temperature and relative humidity, respectively. Two sets of experiments were conducted to fulfill the objectives of the present study. The materials and methods used in the two experiments are described in detail here:

3.2 Mass rearing of *O. surinamensis*

To initiate the stock culture, *Oryzaephilus surinamensis* was collected from the fruit market of Dinajpur town. The stock culture (Plate 1) was then maintained using all stages of *Oryzaephilus surinamensis* on Mariyam date cultivar in the laboratory.

3.3 Experiment 1: Biology and host preference of sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae) on five date cultivars

3.3.1 Tested date cultivars

The biological performances of *O. surinamensis* were evaluated on five date cultivars. Date cultivars were collected from the local market of Dinajpur city. The tested date (*Phoenix dactylifera*) (Plate 5) cultivars were –

1. Mariyam
2. Medjul
3. Dabas
4. Saad/Saad
5. Zahedi/Rama

3.3.2 Biology of *O. surinamensis* on five date cultivars

Development and adult performance of *O. surinamensis* was tested on five cultivars of date (Mariyam, Medjul, Dabas, Saad/Saad, and Zahedi/Rama) at the same laboratory. Rearing units were kept in the laboratory at 31 ± 2 °C and 80 ± 10 % relative humidity. Six gravid females for each treatment were taken randomly from mass culture and transferred them to fresh selected dates in petridishes. Females were allowed to lay eggs for 12 hrs. After that females were removed from petri dishes. The *O. surinamensis* larvae that had hatched without exuviae were the only ones placed in petridishes with dates. Various phases of *O. surinamensis* growth and development, including the egg, larval, and pupal phases, were documented during the investigation. The time between egg laying and larval hatching was used to calculate the incubation period. The observations was made at 12 hrs. interval using the trinocular zoom stereo microscope (Model: SM-2TZ LED, AmScope Microscope, Irvine, CA 92606, USA) (Plate 3). Thirty replications were observed for each date cultivars. For the determination of pre-oviposition period of *Oryzaephilus surinamensis*, 10 newly emerged females were taken for each cultivars in petridishes. Male insect from the mass culture were introduced in those petridishes for matting. Data were recorded from the day of female emergence to 1st day of egg laying.

3.3.3 Host preference of *O. surinamensis*

3.3.3.1 Survival and mortality percentage of immature stages of *O. surinamensis* on five date cultivars

For the estimation of egg hatching percentage, survival, and mortality percentage of larvae and pupae, newly emerged 10 females were taken in 10 petridishes, and 10 males from mass culture were introduced in each petridishes for mating. The females were allowed to lay eggs for up to five days. This procedure was done for each type of date cultivars. Daily observation was made until adult emergence. The number of hatched larvae were counted to calculate hatchability percentage. The number of living and dead individual was calculated to determine the rate of mortality and survival percentage and the population ratio of the sawtoothed grain beetles by using the following formula:

$$\text{Rate of mortality} = \frac{\text{No. of dead individuals}}{\text{Total no. of individuals}} \times 100$$

$$\text{Survival rate} = \frac{\text{No. of survival individuals}}{\text{Total no. of individuals}} \times 100$$

3.3.3.2 Damage status of date cultivars by *O. surinamensis*

For observing the feeding behavior to find out the host preference, 50 grams of each date cultivar which were free from insect infestation those were weighed by electronic balance machine and kept in plastic boxes along with 10 pairs of beetles of same age. This whole process was carried out in three different months and then data were recorded and analyzed to calculate the percentage of damage and monitor the varietal susceptibility of different stored date palm varieties against saw tooth grain beetle. The boxes were covered tightly to prevent movement of beetles from inside to outside and then kept at room temperature. After each month the weight of date fruit of each box was calculated according to the given formula:

$$\text{Damaged weight ratio} = \frac{\text{Damaged weight}}{\text{Total weight}} \times 100$$ (Mallah *et al*., 2016)

3.4 Experiment 2: Evaluation of edible plant products as protectant of stored dates against sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae)

The research work was carried out in the laboratory of the Department of Entomology (25.64 °N, 88.64 °E), Hajee Mohammad Danesh Science and Technology University, at 30 ± 5 °C temperature and 80 ± 10 % relative humidity.

3.4.1 Source and collection of date fruits

Date fruits, *Phoenix dactylifera* were used as host of sawtoothed grain beetle, *Oryzaephilus surinamensis* in this experiment. Clean and healthy date fruits were purchased from the local market of Dinajpur town. The collected dates were sun dried and maintained at 12 ± 1 % moisture levels and preserved in plastic jars in the laboratory for experimental use. *O. surinamensis* were reared under open laboratory conditions (30 ± 5 °C and 80 ± 10 % RH). Adult insects of 2 weeks old were collected and used for the experiment.

3.4.2 Tested plant products used against sawtoothed grain beetle

The biologically active parts of tested plants such as leaves, fruits, seeds and rhizome (Plate 8) were collected from the local sources. The botanicals viz., powders of clove, ginger, bay leaf, fennel (Plate 9) were tested for the management of date fruits (Table 2).

3.4.3 Collection and preparation of plant powders

The tested plant parts which were used in the present study were purchased from the local market. The collected botanicals viz., dried flowers of clove (*Syzygium aromatic*), bay leaf (*Laurus nobilis*), rhizome of ginger (*Zingiber officinale*) and seeds of fennel (*Foeniculum vulgare*) were washed with running clean tap water and then oven dried at 40^{o}C in the laboratory for 1.5 hrs. After that, they were ground thoroughly in an electric 1.5HP kitchen grinder and sieved through a 40 holes/ mm^2 mesh screen to get fine powder. Each of the plant powder was kept in a separate plastic container with a tightly fitted lid. The names of these plants, its sources and active ingredient are shown in Table 2.

3.4.4 Experimental design

To determine the effect of tested plant powders on the adult mortality of *O. surinamensis*, powders of four different plant were used. About 20gm of Zahidi date were used as diet for each replication. The tested concentrations were 0.5, 2, and 4 % w /w. In a plastic box 20gm of dates with the admixtures were taken and vibrated well to mixing the dates with the powder. As for the control treatment, it was without adding any powder to it. Three replications were done. Each replicate was infested with 12 adults of sawtoothed grain beetle of same age were taken and left to move freely and feed from the treated diet for up to 10 days under open laboratory conditions. The adult mortality was recorded after 1, 3, 5, 7 and 10 days. Percentage of mortality was calculated using the following formula:

Mortality % = [(Number of dead insects ÷ Total number of insects] × 100. (Eldeghidy *et al.* 2023)

3.5 Statistical analysis

All the obtained data were analyzed by following the analysis of variance (ANOVA) technique with the help of Statistix 10 program and the mean differences were adjusted by List Significant Difference (LSD) method. All graphical works were done through Microsoft excel program. Means and standard errors (SE) of data was calculated using SPSS statistical analysis version 25. Mortality percentage was analyzed by using Statistics 10 software.

Table 2: List of plant products evaluated against sawtoothed grain beetle on date fruits

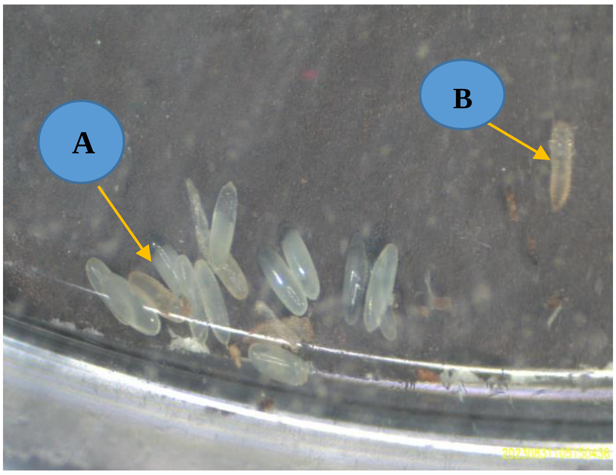
Common name	Scientific name	Family	Plant parts	Active ingredient
Clove	*Syzygium aromatic*	Myrtaceae	Dry flowers	Eugenol
Ginger	*Zingiber officinale*	Zingiberaceae	Rhizome	Gingerols
Bay leaf	*Laurus nobilis*	Lauraceae	Leaf	Cineole
Fennel	*Foeniculum vulgare*	Apiaceae	Seed	Anethole

Plate 1. Mass rearing of *O. surinamensis*

Plate 2. Camel hair brush for picking larvae

Plate 3. Trinocular Zoom Stereo Microscope (Model: SM-2TZ LED, AmScope Microscope, Irvine, CA 92606, USA) observing and counting egg and first instar larva

Egg of *O. surinamensis*



A. Eggs in mass form, B. Newly hatched larvae of *O. surinamensis*

Larva of *O. surinamensis*

Pupa of *O. surinamensis*

Adult *O. surinamensis*

Plate 4. Different life stages of *O. surinamensis*

Saad date

Medjul date

Mariyam date

Dabas date

Zahidi date

Plate 5. Tested five date (*Phoenix dactylifera*) cultivars used for the experiment

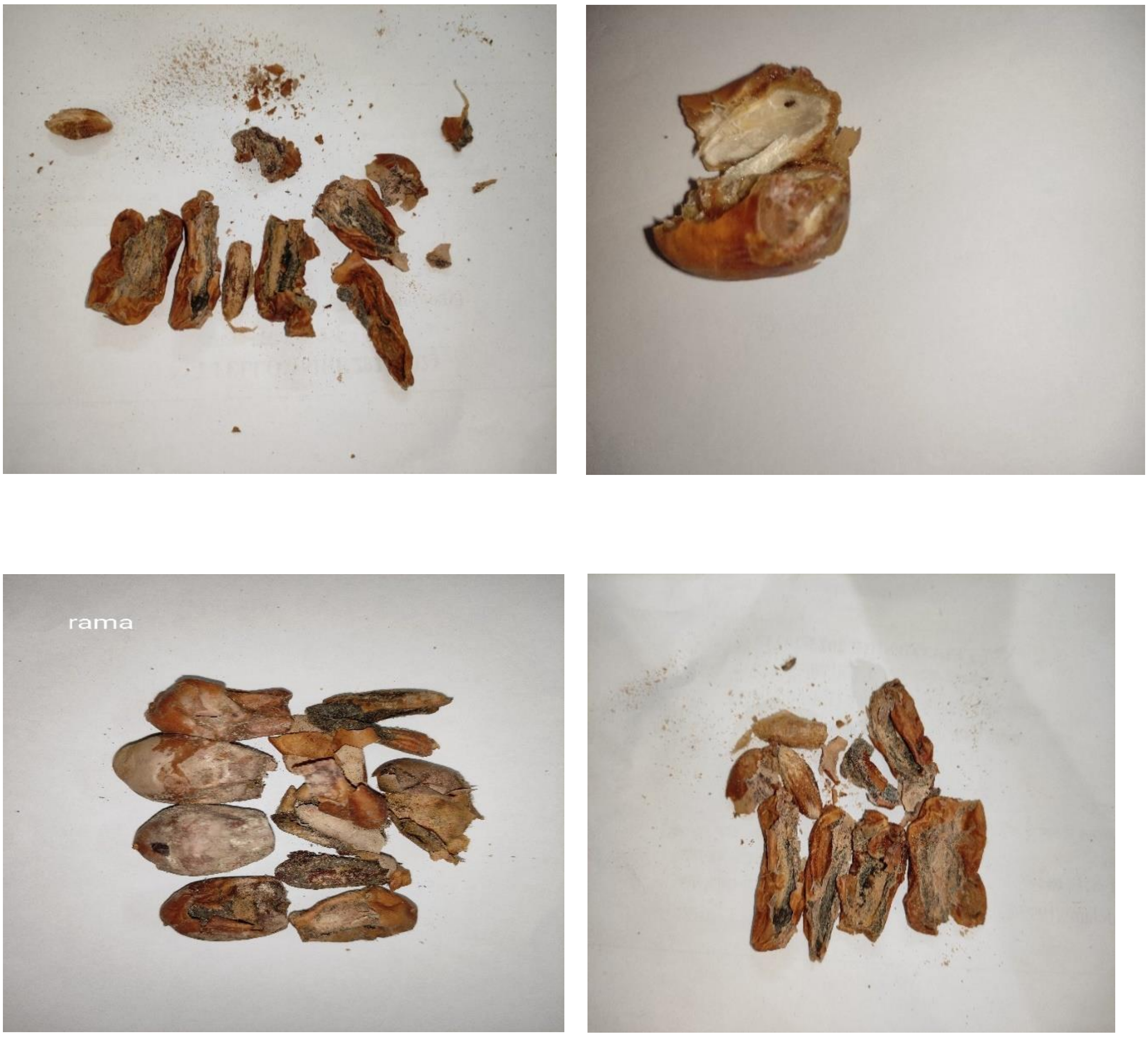


Plate 6. Damaged dates attacked by *O. surinamensis*

Plate 7. Experimental arenas used for the research

Clove

Ginger

Bay leaf

Fennel

Plate 8. Edible plant products used against *O. surinamensis*

Clove powder

Ginger powder

Bay leaf powder

Fennel powder

Plate 9. Powder form of edible plant products used against *O. surinamensis*

RESULTS AND DISCUSSION

4.1 Experiment 1: Biology and host preference of sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae) on five date cultivars

4.1.1 Biology of *O. surinamensis* on five date cultivars

The results presented in Table 3 showed the performance of five date cultivars impacted on the development of saw-toothed grain beetle, *O. surinamensis*, under laboratory conditions of 30 ± 5 °C and 80 ± 10 s% relative humidity. The development time of different life stages of males and females of *O. surinamensis* on five date cultivars are presented below. There were significant differences (P<0.5) observed among the biological parameters such as egg, larval, pupal period on different date cultivars.

4.1.1.1 Incubation period

Incubation period was the duration between the dates of egg laying and hatching. The duration of incubation period of *O. surinamensis* range from 3.41 to 3.92 days in females and 3.2 to 3.83 days for males when fed on five date cultivars as food (Table 3). The periods were showed statistically variations (female: df = 4, 82; F = 15.05; P < 0.05; male: df = 4, 39; F = 4.74; P < 0.05) (Appendix Table 1 and Appendix Table 2) at 30 ± 5°C and 80 ± 10 % RH. The incubation period of female was the highest (3.92 days) in the Saad cultivar while the lowest (3.42 days) in the Mariyam cultivar. There was no significant difference in the incubation period between the Mariyam and Dabas cultivars and Medjul and Zahidi cultivars, but a significant difference was observed among the Mariyam, Medjul, and Saad cultivars. The incubation period of male was highest (3.83 ± 0.17 days) in the Saad date cultivar and lowest (3.2 ± 0.081 days) in the Mariyam cultivar. There was no significant difference in the incubation period among Medjul, Dabas, and Zahidi cultivars, but there was a significant difference between Mariyam and Saad cultivars. The female incubation period was longer than the male incubation period when developed on five different cultivars. Similar results were observed in research conducted by Jacob and Fleming (1990), who found that, at 35 °C and 50 % RH, the incubation period was 3.4 ± 0.07 days. Eldeghidy *et al.* (2022) found in their study that the incubation period lasted longer on whole white sesame seeds (4.04 days) and a standard diet (4.00 days), while it was shorter on semi-dry date (3.00 days). On the dry date, the incubation period was 3.71 days at 29 ± 1 °C and 65 ± 5 % RH, which is similar to the results of this study. The same authors (Eldeghidy *et al*., 2021) also conducted research on different date varieties at 29 ± 1 °C and 65 ± 5 % RH, and found that the egg period varies between 4.83 and 5.04 days. However, different results were obtained for different commodities under different environmental conditions. According to Awadalla *et al.* (2023), the incubation period was found same for different graminaceous grains as 6.2 ± 0.52 days, with no significant differences at 28 ± 1 ºC and 60 ± 5 RH %. Astuti *et al*. (2018) stated from their study that the results of egg and stadium on did not indicate a significant difference among the varieties, and the egg period was 4.16 ± .08 days at 27 ± 2 ºC, 60 ± 5 % RH. The results of Govindaraj *et al.* (2014) revealed that the duration of egg stage on all stored products, viz., neem seed kernel, groundnut kernel, groundnut cake, rice, wheat, dates, and raisin, was almost uniform and ranged from 4.90 to 5.50 days. Fouad *et al.* (2021) get the result from their study that incubation period of sawtoothed grain beetle varies with temperature. The incubation periods were 11.75, 8.5, 5.75 and 4.25 days at 20 °C, 25 °C, 30 °C, and 35 °C respectively. Kousar *et al.* (2021) stated in their research that incubation periods were different on two different dry and semi-dry dates (Aseel and Dadhi) varieties between 3.04 and 5.25 days at 25 ± 2 °C and 60 -70 % RH. Back (1927) stated in his study in mid-summer that with mean average temperatures ranging from about 80 °F to 85 °F, the eggs hatch within 3 to 5 days after deposition. In cool spring and fall weather, with mean average temperatures ranging from 73 °F to 68 °F, the eggs hatched in 8 to 17 days.

4.1.1.2 Larval period

The date cultivars influenced the larval periods of *O. surinamensis* and showed significant differences among the cultivars (Table 3). The larval periods of female insects were ranged from 12.13 to 14.08 days (df = 4, 82; F = 56; P<0.05) (Appendix Table 1) and that of male insects it was between 12.05 to 13.58 days (df = 4, 39; F = 22.41; P<0.05) (Appendix Table 2) at 30 ± 5 °C and 80 ± 10 % RH. The female larval period was longer than the male larval period when it was developed on five different date cultivars. There was no significant difference among Dabas and Zahidi cultivars in female insects, but a significant difference was observed among Saad, Dabas, Mariyam, and Medjul cultivars. The longest larval period was 14.08 days in Saad cultivars, and the lowest was 12.13 days in Mariyam cultivars. There was no significant difference in the larval period between Mariyam and Medjul cultivars or Dabas and Zahidi cultivars for male insects. Significant differences were observed between the Saad, Mariyam, and Dabas cultivars. A similar result was found by Eldeghidy *et al.* (2022) on semi-dry dates where the larval period was 13.90 days, and on dry dates, it was 14.45 days at 29 ± 0 °C and 65 ± 5 % RH. Astuti *et al.* (2018) found that the average larval period on floured black rice was faster (13.38 days) than on floured red rice (13.68 days). In contrast, the average larval lifespan on whole grain red rice was longer (17.42 days) than on floured white rice (17.06 and 16.74 days, respectively). Eldeghidy *et al.* (2021) stated that significant differences appeared among the tested varieties with respect to the larval period at a probability of 0.05. The shortest larval developmental period (14.20 days) was recorded at 29 °C and 65 % RH when the larvae fed on the Malkabi variety but the longest period (18.00 day) detected on the Gondella variety, which proved to be the least preferred food for this insect. A difference in larval developmental period was observed at different temperatures and relative humidity. According to Nika *et al.* (2020), the developmental time of larvae was significantly longer when *O. surinamensis* fed on whole oat flakes (20.3 days) and whole barley flour (19.2 days) as compared with maize flour (16.6 days) or cracked maize (17.2 days). The developmental duration of larvae fed cracked barley was 18.3 days at 30 °C and 65 % RH. Awadalla *et al.* (2023) noticed in their study that at 28 ± 1 °C and 60 ± 5 % RH, the larval stages for *O. surinamensis* were ranged between 19.2 ± 1.26 days on rice grains and 25.6 ± 0.98 days on white corn grains, with highly significant differences. It can be noticed that the longest larval duration was recorded on white corn grains, followed by yellow corn grains and wheat grains, and represented by 25.6 ± 0.98, 25.4 ± 1.01, and 24.5 ± 0.81 days, respectively. Meanwhile, the shortest larval stage was recorded on rice grains as 19.2 ± 1.26 days. Fouad *et al.* (2021) experienced in their research that the larval period decreased as the temperature increased, where the average durations were 35, 26.3, 21.5, and 18 days at 20 °C , 25 °C, 30 °C, and 35 °C, respectively.

4.1.1.3 Pupal period

The pupal periods of *O. surinamensis* are presented in Table 3. The male and female pupal periods were ranged from 4.5 to 4.56 days (df =4, 82; F = 6.83; P<0.05) (Appendix Table 2) and 4.5 to 5.14 (df = 4, 39; F = 2.09; P<0.05) (Appendix Table 1) days, respectively. The pupal period of sawtoothed grain beetle was found statistically different among the date cultivars. There were no significant differences among the three date cultivars (Dabas, Zahidi, and Saad) and between the other two cultivars (Mariyam and Medjul). These groups of three date cultivars and the two date cultivars also did not show any significant differences in pupal developmental period for female insects, but there were significant differences between the two groups of date cultivars (Dabas, Zahidi, and Saad) and (Mariyam and Saad). In the case of male insects, the significant difference in pupal period was the same as that in female insects in terms of date cultivars. There were no significant differences between the male and female pupal periods. Jacob and Fleming (1990) found out in their experiment that at 30 °C and 70 % RH, the pupal developmental period was 5.2 days, and at 35 °C and 70 % RH, it was 4.4 days, which is similar to the results of this study. Astuti *et al.* (2018) stated from their research that at 27 ± 2 ºC and 60 ± 5 % RH, the pupal phase was 4.75 - 6.6 days on various stored products. According to Nika *et al.* (2020), there were no statistically significant differences between tested commodities at 30 °C and 65 % RH. The developmental periods of the pupae were ranged from 4.6 to 4.7 days. Eldeghidy *et al.* (2022) found that the maximum pupal period was between 5.05 and 4.90 days on whole semi-dry dates and whole white sesame seeds, while the minimum was 4.70 days on dry dates. Eldeghidy *et al.* (2021) found that the pupal period ranged from 4.40 days in Skooty to 4.80 days in Malkabi. This result clearly indicated that the different varieties of dry dates had no obvious influence on the pupal period. According to Awadalla *et al.* (2023), the pupal periods ranged between 12.9 ± 0.59 days on rice grains and 13.8 ± 0.74 days on yellow corn grains, with no significant differences. The results of Govindaraj *et al.* (2014) revealed that the pupal period ranged from 4.75 to 6.60 days for different food materials. The pupal stage was the shortest when reared on the neem seed kernel (4.75 days). In other stored products, the pupal stage ranged from 5.0 to 6.0 days, indicating that these (groundnut kernel, groundnut cake, dates, resin, wheat, and rice) stored products had a significant impact on pupal development. Studies conducted by Curtis and Clark (1974) also indicated no significant variations in the pupal stages of different stored products. Kousar *et al.* (2021) stated in their research that pupal periods were different (13.45 to 8.30) and (15.83 to 11.36) days, respectively on dry and semi-dry dates (Aseel and Dadhi) varieties at 25 ± 2 °C and 60-70 % RH.

4.1.1.4 Larval to pupal period

The male and female larval-pupal periods were statistically different while *O. surinamensis* reared on five date cultivars (Table 3). The period ranged from 16.69 to 19.22 days (df = 4, 82; F = 51.64; P<0.05) (Appendix Table 1) in female insects and about 16.55 to 18.50 days (df = 4, 39; F = 19.54; P<0.05) (Appendix Table 2) in male insects, respectively. The highest larval - pupal period was observed in the Saad date cultivar (19. 22 days), while the lowest was observed (16.69 days) in the Mariyam date cultivar in the case of female insects. The larval-to-pupal period in male insects was lower than that in female insects. Similarities found in a recent study conducted by Eldeghidy *et al.* (2022), they explored that the developmental period of larva to pupa under different environmental conditions. The specimens were exposed to a controlled temperature of 29 ± 1 °C and a relative humidity of 65 ± 5 %. Notably, semi-dry dates showed a developmental duration of 18.95 days, while dry dates took slightly longer at 19.15 days for the larval to pupal transition. A significant finding emerged when examining various substrates. Whole reddish-yellow sesame seeds proved the most conducive for the larval-pupal period, requiring an extended duration of 25.80 days. In contrast, the standard diet resulted in the shortest developmental span, with only 15.85 days needed for larval to pupal period. The study also investigated the impact of specific substrates on the larval to pupal period. Crushed groundnut exhibited the longest duration as 31.05 days, highlighting the influence of substrate composition on the developmental timeline. Conversely, the standard diet once again emerged as the optimal substrate, showcasing the shortest larval-pupal period at 15.85 days. In the study by Eldeghidy *et al.* (2021), an investigation was undertaken to examine the impact of environmental conditions, specifically at a temperature of 29 ± 1 °C and a relative humidity of 65 ± 5 % on various date varieties. Notably, the Malkabi date variety exhibited a larval - pupal developmental duration of 19.00 days, while the Gondella date variety demonstrated a slightly extended duration of 22.53 days for the same developmental process.

4.1.1.5 Total developmental period

Table 3 represents the total developmental period of male and female *O. surinamensis*. This period significantly differed in males (*df* = 4, 39; *F* = 60.15; *P*<0.05) (Appendix Table 2) and females (*df* = 4, 82; *F* = 24.25; *P*<0.05) (Appendix Table 1) during *O. surinamensis* rearing on five date cultivars. The period was ranged from 20.1 to 23.14 days for female insects and 19.75 to 22.33 days for male insects. The shortest (20.1 days) total development period were found in females found on Mariyam but the longest period (23.14 days) on Saad date cultivars, which was significantly different from the developmental period of those reared on other cultivars. This highlighted cultivar-specific influences on the developmental time for both sexes. Findings of this research showed similarities with Jarosˇık and Honek (2007). They mentioned in their research that male insects of Silvanidae family of Coleoptera order take shorter time to be fully developed from egg to adult than that of females.

Eldeghidy *et al.* (2022) stated that the insects took 21.95 days and 22.83 days for full development on semi-dry and dry date varieties, respectively, at a temperature of 29 °C and relative humidity of 65 ± 5 %. The longest developmental periods were 29.14 and 29.18 days on whole white and reddish yellow sesame seeds, respectively, while the shortest 19.85 days on standard diet. Eldeghidy *et al.* (2021) mentioned in their study that the shortest mean developmental period (22.96 days) was noticed on the Malkabi date variety, which was similar to the total developmental period of the Zahidi cultivar of this research, while the longest (26.53 days) mean was detected on the Gondella date variety. Skooty and Pertomoda date varieties took 23.36 and 23.63 days, respectively, which shows similarity with current research where the Saad variety took 23.14 days for development. However, other studies on different food substances showed different results in different environmental conditions. The time required for the developmental period from egg to adult varied among different hosts, with neem seed kernel exhibiting the shortest duration as 28.45 days and raisins having the longest duration as 47.50 days. Dates showed an intermediate total development period of 32.70 days, closely to neem seed kernel. Wheat and rice had similar total development periods, with 39.05 days and 37.50 days, respectively. Notably, Komson (1967), Curtis and Clark (1974) observed a significant difference in the total developmental period on various hosts. Awadalla *et al.* (2023) found that *O. surinamensis* exhibited the lengthiest total development period on yellow grains, with a duration of 45.4 ± 1.08 days, followed by white corn grains at 45.0 ± 1.02 days, and oats at 43.8 ± 0.91 days. In contrast, the shortest total development period was observed on rice, lasted 38.3 ± 0.83 days. The study was conducted under conditions of 28 ± 1 °C temperature and 60 ± 5 % relative humidity.

4.1.1.6 Pre-oviposition period

In the lifecycle of insects, the pre-oviposition period plays a crucial role in determining their reproductive behavior and population dynamics. This period refers to the duration between the emergence of adult insects and the initiation of egg-laying activities. Here, this research explores the pre-oviposition periods of insects on five date cultivars, namely Mariyam, Medjul, Dabas, Zahidi, and Saad dates (Fig. 3). Pre-oviposition periods were statistically varied among five cultivars ($df = 4, 45$; $F = 9.49$; $P<0.05$) (Appendix Table 3) at 31 ± 2 °C and 80 ± 10 % RH. Pre-oviposition period found the highest (7.35 days) in Dabas dates while the lowest (6.15 days) in Mariyam dates. Pre-oviposition period for

Medjul, Saad/Saad and Zahidi dates were 6.45, 6.85 and 6.60 days, respectively. The variations observed in the pre-oviposition periods among different date varieties suggested potential differences in the suitability of these dates for insect reproduction. Astuti *et al.* (2018) discovered through their study that there was a remarkable variation in the pre-oviposition period among female *O. surinamensis* imagoes when exposed to various feed types. Notably, the pre-oviposition period was notably quicker on whole grain black rice, averaging at 7.55 days. However, this duration didn't significantly differ from that observed with whole grain white, whole grain red, floured red, and floured black rice, which ranged from 7.60 to 11.60 days. In contrast, the pre-oviposition period with floured white rice was significantly longer, averaging at 24.30 days, distinguishing it notably from the other food types. However, this result may vary due to different environmental condition and quality of food.

4.1.2 Host preference of *O. surinamensis*

4.1.2.1 Survival and mortality percentage of immature stages of *O. surinamensis* on five date cultivars

The maximum eggs were laid (in first 5 days) on Medjul date cultivar as compared to other four date cultivars. Egg hatching ranged from 91.91 to 81.72 % (Table 4) and showed statistically difference among cultivars *(df = 4, 45; F = 10.31; P<.05)* (Appendix Table 5). Mariyam date cultivar showed maximum hatching percentage (91.91 %) and Dabas date cultivar showed the lowest (81.72 %). From this result it can be concluded that Mariyam cultivar is preferred by sawtoothed grain beetle because hatching percentage was high, and number of unhatched eggs was low. A study by Eldeghidy *et al.* (2021) revealed that the highest eggs hatchability (86.67 %) was found in two varieties named Malkabi and Shamia. On the other hand, the lowest hatching (66.67 %) was observed in Gondella variety. Another study was conducted by Kousar *et al.* (2021)

in both semi- dry and dried conditions, where saw-toothed grain beetle laid more egg on Dadhi variety than the Aseel kind. Overall egg hatching percentages on the Dadhi variety (90.57 to 72.37) and Aseel variety (88.47 to 76.91) were recorded.

From Table 5, it can be seen survival percentage of larval stage *(df = 4, 45; F = 10.78; P<.05)* (Appendix Table 5) and pupal stage *(df = 4, 45; F = 10.3.39; P<.05)* (Appendix Table 5) and mortality percentage of larval stage and pupal stage were statistically different among the cultivars. Mariyam date cultivar showed maximum survival percentage at pupal stage (93.58 %) while larval survival was 91.46 %. Mortality was recorded on larval stage as 8.54 % but pupal mortality was 6.42 %. The survival percentage for Medjul date cultivar was 88.57 % of larval stage but 90.32 % at the pupal stage, with mortality at the larval stage of 11.43 % and at the pupal stage of 9.36 %, respectively. The Zahidi cultivar showed 83.63 % survival at the larval stage and 88.76 % at the pupal stage, with mortality rates of 16.37 % at the larval stage and 11.24 % at the pupal stage. On the fruit Dabas cultivar, the survival at the larval stage was 81.36 %, and at the pupal stage it was 86.64 %, with mortality at the larval stage of 18.64 % and at the pupal stage of 13.36 %. On the fruit Saad cultivar, 77.04 % and 83.67 % survival percentages were noticed at the larval and pupal stages, respectively, with mortality at the larval stage of 22.96 % and at the pupal stage of 16.33 %. The findings showed that Mariyam is exceptionally attractive to sawtoothed grain beetles because of the cultivar's extremely soft, delicate, and foam-like fruit, which made it more vulnerable to the beetles' impact and injury. It also summaries that the larval stage is more vulnerable than pupal stage. Results from other studies by Sahito *et al.* (2017) and Kousar *et al.* (2021) agreed with this study and they also revealed that larval stage is more vulnerable than pupal stage.

4.1.2.2 Damage status of date cultivars by *O. surinamensis*

To determine which date palm cultivar was susceptible to sawtoothed grain beetle infestation and the eating habits of the insect on five distinct date cultivars (Mariyam, Medjul, Zahidi, Dabas, and Saad) were studied. The eating habit of the beetle was observed monthly from October to December. The results also included a record of the amount of damage caused to each cultivar and the month when the beetle caused the most destructive. From Table 6, it can be concluded that when it comes to Mariyam date cultivar, the highest damage of 22.5 % was reported in October, while the lowest damage of 4.5 % was recorded in Saad date cultivar in the month of December. Weight loss among the cultivars were statistically different (Table 6). During the month of October all the five date cultivars showed high consumption than that of November and December. This data also revealed the overall highest consumption was noticed in Mariyam date cultivar (17.77 ± 4.39) and lowest (7.17 ± 2.52) consumption was observed in Saad date cultivar.

The findings indicated that the highest rate of infested and damaged dates were recorded in October due to an increase in temperature, while the lowest rate was recorded in December due to a reduction in temperature during this months. Numerous studies have addressed this issue, including those by Mallah *et al.* (2016) and Jacob (1981). They found that *O. surinamensis* beetles are typically active in the 25-35 ℃ temperature range, and the rate of infected date fruits and rate of the beetle growth decrease at temperatures outside of that range.

Table 3. Mean (±SE) developmental time of *O. surinamensis* on five different date cultivars

Date Cultivars	Sexes*	N**	Incubation period	Larval period	Pupal period	Larval to pupal period	Total developmental period
Mariyam	F	16	3.416 ± 0.05 C	12.13 ± 0.10 D	4.56 ± 0.11 B	16.69 ± 0.11 D	20.1 ± 0.12 E
	M	10	3.2 ± 0.081 c	12.05 ± 0.13 c	4.50 ± 0.17 b	16.55 ± 0.17 c	19.75 ± 0.20 c
Medjul	F	17	3.59 ± 0.04 B	12.47 ± 0.12 C	4.74 ± 0.08 B	17.21 ± 0.18 C	20.8 ± 0.18 D
	M	10	3.35 ± 0.08 bc	12.25 ± 0.08 c	4.50 ± 0.13b	16.75 ± 0.18 c	20.10 ± 0.22 c
Dabas	F	17	3.42 ± 0.04 C	13.03 ± 0.09 B	5.09 ± 0.09 A	18.18 ± 0.12 B	21.53 ± 0.12 C
	M	09	3.33 ± 0.08 bc	12.83 ± 0.14 b	4.90 ± 0.14 a	17.72 ± 0.19 b	21.07 ± 0.15 b
Zahidi	F	18	3.75 ± 0.06 B	13.28 ± 0.09 B	5.08 ± 0.10 A	18.36 ± 0.13 B	22.11 ± 0.17 B
	M	10	3.56 ± 0.13 ab	13.05 ± 0.15 b	4.89 ± 0.13 a	17.94 ± 0.15 ab	21.5 ± 0.19 b
Saad/Saad	F	18	3.92 ± 0.07 A	14.08 ± 0.09 A	5.14 ± 0.09 A	19.22 ± 0.12 A	23.14 ± 0.13 A
	M	06	3.83 ± 0.17 a	13.58 ± 0.08 a	4.90 ± 0.21 a	18.50 ± 0.18 a	22.33 ± 0.19 a

*F = females, M = males

** Number of individuals tested

Means (±SE) of the same sex within a column followed by different letters (capital letters for female and small latter for male) are significantly different at 0.05 % LSD

Table 4. Egg hatching percentage of *O. surinamensis* on five date cultivars

Dates cultivars	No. of female observed	Eggs laid by female	Egg laying rate per female/day	Egg fertility		
				No. of hatched eggs	No. of unhatched eggs	Hatching
Mariyam	10	408	8.16	375	33	91.91 ± 0.58 a
Medjul	10	436	8.72	385	51	88.30 ± 1.28 b
Zahidi	10	387	7.74	330	57	85.27 ± .78 bc
Dabas	10	394	7.88	322	72	81.72 ± 2.04 c
Saad/Saad	10	381	7.62	318	63	83.46 ± .96 c

Means (±SE) of hatching % within a column followed by different letters are significantly different at 0.05 % LSD

Table 5. Survival and mortality percentage of larvae and pupae of *O. surinamensis* on five date cultivars

Date cultivars	Life stages	No. of tested individual	Survival	Mortality
Mariyam	Larva	375	91.58 ± 1.44 A	8.42 ± 1.43 D
	Pupa	343	93.57 ± 0.85 a	6.42 ± 0.80 c
	Adult	321	-	-
Medjul	Larva	385	88.68 ± 0.83 AB	11.32 ± .85 CD
	Pupa	341	90.24 ± 2.82 ab	9.75 ± 2.76 bc
	Adult	308	-	-
Zahidi	Larva	330	83.72 ± 1.32 BC	16.27 ± 1.36 BC
	Pupa	276	88.80 ± 1.22 abc	11.20 ± 1.25 abc
	Adult	245	-	-
Dabas	Larva	322	81.27 ± 1.30 CD	18.72 ± 1.38 AB
	Pupa	262	87.07 ± 2.38 bc	12.92 ± 2.30 ab
	Adult	227	-	-
Saad	Larva	318	77.23 ± 3.00 D	22.76 ± 3.2 A
	Pupa	245	83.65 ± 1.23 c	16.35 ± 1.31 a
	Adult	205	-	-

Means (±SE) within a column followed by different letters (capital letters for larval survival and mortality %; small latter for pupal survival and mortality %) are significantly different at 0.05 % by LSD

Table 6: Month wise damage percentage in grams of different date fruit cultivars by *O. surinamensis*

Months	**Date cultivars**				
	Mariyam	**Medjul**	**Zahidi**	**Dabas**	**Saad**
October	22.5 a	13.5 b	11.5 c	10.83 c	9.5 d
November	17 a	11.75 b	9.5 c	9.16 c	7.5 d
December	13.83 a	7.5 b	6.5 b	4.83 c	4.5 c
Mean ± SD	17.77 ± 4.39	10.92 ± 3.08	9.17 ± 2.52	8.27 ± 2.17	7.17 ± 2.52

Damage % within a row followed by different letters are significantly different at 0.05 % by LSD

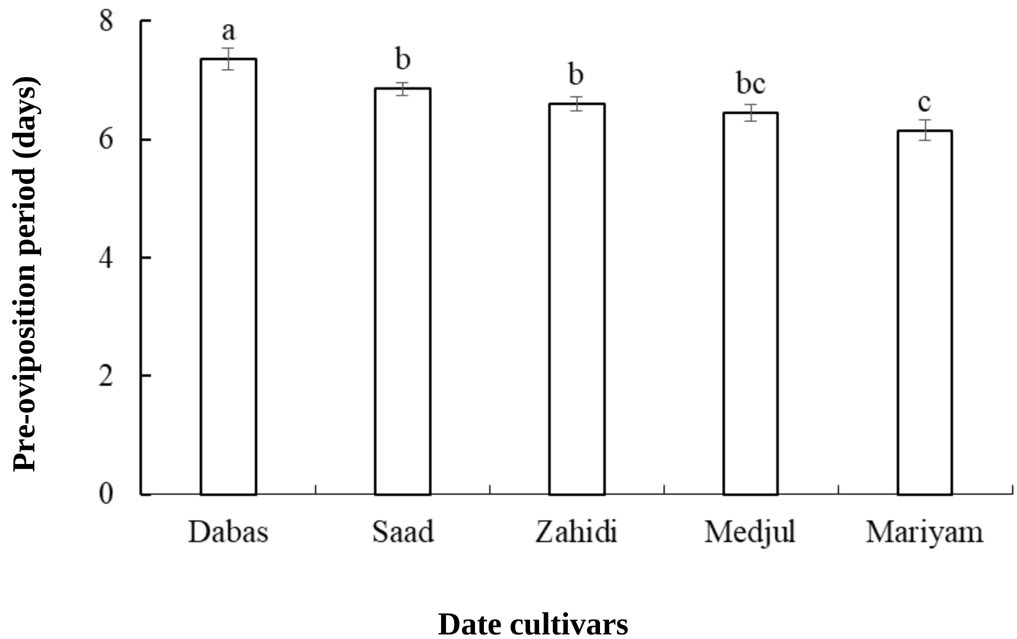


Fig. 3: Graphical representation of pre-oviposition period of *O. surinamensis*

4.2 Experiment 2: Evaluation of edible plant products as protectant of stored dates against sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae)

The experiment aimed to investigate the effects of different concentrations of clove, ginger, bay leaf, and fennel powder on mortality rate of sawtoothed grain beetles over a span of 10 days. The results obtained present intriguing insights into the potential bioactivity of these plant extracts.

None of the powdered plant parts used at the concentration of .05 %, induced sawtoothed grain beetle mortality throughout the experimental period (Figs.: 4, 5, 6, 7) and the result was similar to those in the admixture-free untreated control culture.

After the first day of the experiment, clove powder used at the concentration of 2 %, induced 13.89 % sawtoothed grain beetle mortality. The other three powder didn't cause any mortality on day one and the result was similar to those in the admixture-free control culture (Figs.: 4, 5, 6, 7). After the third day of testing, clove caused a 61.11 % and ginger induced an 11.11 % beetle mortality. In other testing periods, i.e., the 5^{th} and 7^{th} days, this plant powder at low concentration caused the highest beetle mortality in the cases of clove (88.87-100 %) and ginger (22.22-36.11 %) (Figs.: 4 and 5).

A pronounced increase in the sawtoothed grain beetle mortality rate occurred when the concentrations of powdered clove, garlic, bay leaf, and fennel reached 4 %. Clove powder caused 27.78 % mortality after one day. Neither ginger, bay leaf, nor fennel affected the beetle at 4 % concentration after 24 hours. Clove followed by ginger, bay leaf and fennel powder caused 91.67 %, 13.89 %, 8.34 % and 13.89 % mortality of the sawtoothed grain beetle after 3rd day of exposure (Figs.: 4, 5, 6, 7). The highest mortality of 100 % on 5th day was induced by clove powder at the same concentration, a slightly lower mortality of 27.78 % and 19.45 % were noted in the dates with an admixture of powdered ginger and bay leaf, respectively, after the same period of time (Figs.: 3, 5, 6). In other testing periods, i.e., the 7th and 10th days, ginger caused 41.67 % and 63.89 % mortality respectively (Fig. 5). Bay leaf induced 30.56 % mortality after 7th day (Fig. 6).

From these results, it can be concluded that the longer the exposure period, the higher the mortality percentage. In addition, concentrated plant powders play an important role in the mortality percentage, with higher concentrations resulting in higher mortality.

Eldeghidy *et al.* (2023), discovered that clove powder exhibited remarkable effectiveness against *O. surinamensis*. Similarly, our study corroborates these findings, indicating that clove powder emerged as the most effective substance against the beetle.

This study, in concordance with Omran *et al.* (2020), the impact of leaf powders derived from *C. dioscoridis*, *C. nardus-spreng*, and *M. oliefera* on the mortality rate of *O. surinamensis* adults. The results revealed significant variations among the different powders. *M. oliefera* powder exhibited the highest efficacy, resulting in a mortality of 78.89 %. This was followed by *C. nardus-spreng* with a mortality of 60 %, while *C. dioscoridis* showed the lowest effectiveness with a mortality of 35.18 %. Furthermore, the study also explored the influence of exposure duration on mortality. It was observed that longer exposure periods correlated with higher mortality percentages. Additionally, the concentration of the extracts played a crucial role in determining mortality rates. Higher concentrations of the extracts were associated with increased mortality percentages. Overall, these findings underscore the potential of these leaf powders as effective agents against *O. surinamensis* adults, with *M. oliefera* showing the highest potency among the tested substances.

Malgorzata and Anna (2015), found that powdered plants of various species including *Mentha piperita* L., *Artemisia abinthium* L., *Salvia officinalis* L., and *Allium sativum* L. exhibited significant effectiveness at higher concentrations, resulting in increased mortality rates of the sawtoothed grain beetle. Additionally, Karso's (2018) stated, that dry powder derived from *Mentha piper* L. demonstrated the highest mortality percentage among tested substances against *Oryzaephilus surinamensis*, reaching an impressive 78.55 %.

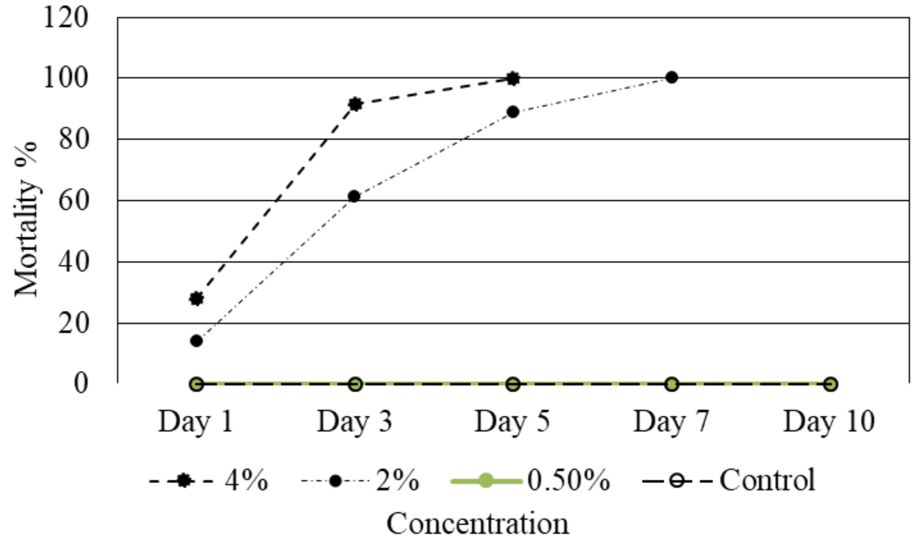


Fig. 4: Mortality of *O. surinamensis* induced by powdered clove

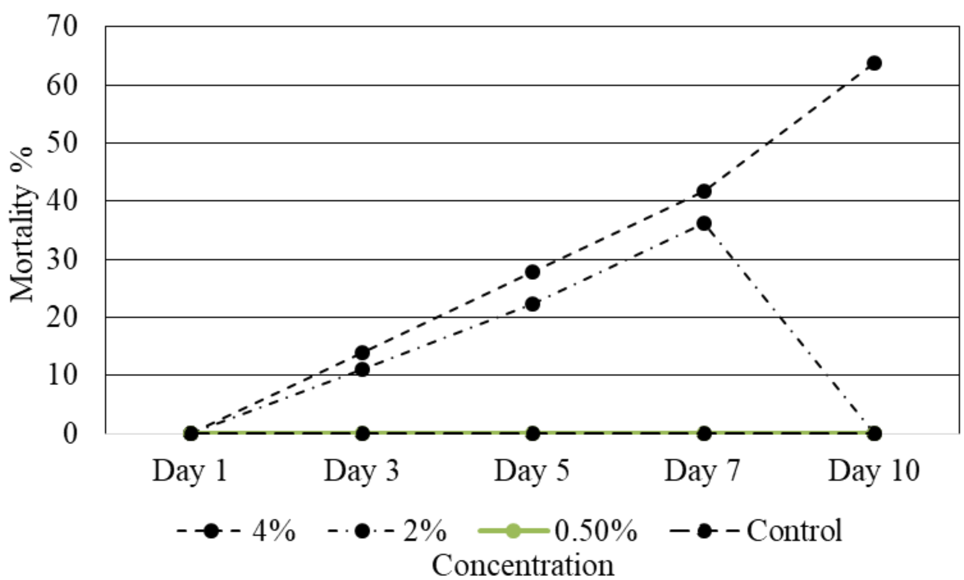


Fig. 5: Mortality of *O. surinamensis* induced by powdered ginger

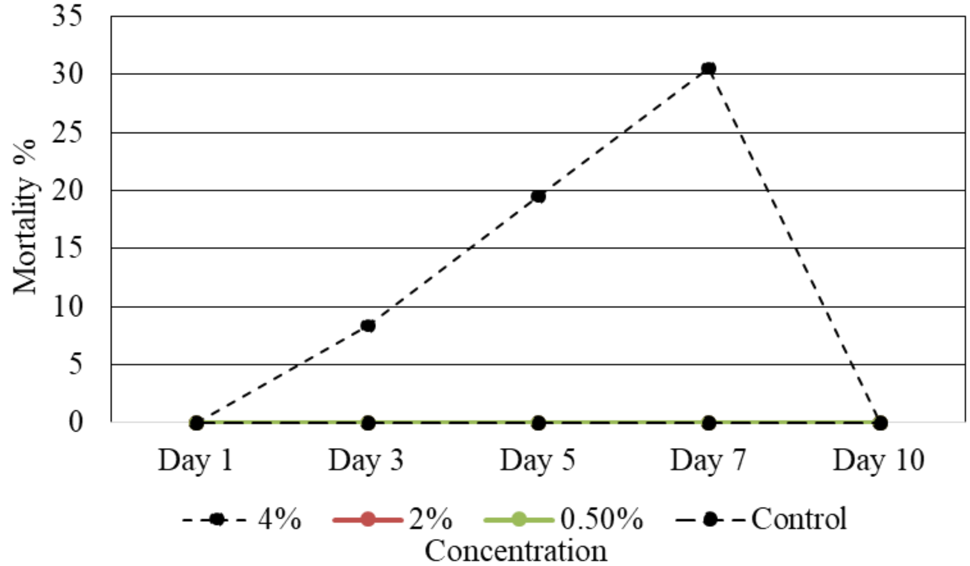


Fig. 6: Mortality of *O. surinamensis* induced by powdered bay leaf

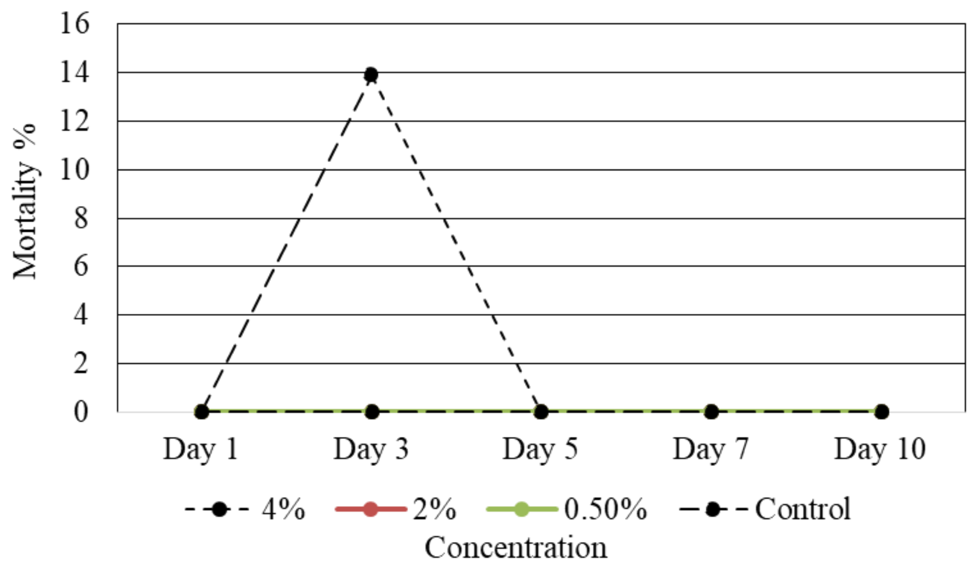


Fig. 7: Mortality of *O. surinamensis* induced by powdered fennel

SUMMARY AND CONCLUSION

The sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae) constitutes one of the major insect pests of stored dates (*Phoenix dactylifera*) in Bangladesh. The present study was conducted in the laboratory of the Department of Entomology, Hajee Mohammad Danesh Science and Technology University (HSTU), during the period from July to December 2023. All experiments were carried out under laboratory condition at 30 ± 5 ˚C, 80 ± 10 % RH. The objectives of this study were to study the biology of the *Oryzaephilus surinamensis* fed on five different date cultivars (Mariyam, Medjul, Zahidi, Dabas and Saad); to find out which cultivar is more susceptible to *Oryzaephilus surinamensis* and effect of some edible plant products against *Oryzaephilus surinamensis*; to find out the best edible plant product as protectant of date in storage against the beetle.

The study revealed that the maximum incubation period of female was recorded 3.92 days on Saad dates while minimum 3.42 days on Mriyam date. Incubation period of male insect ranged from 3.2 to 3.83 days. Maximum (91.92 %) egg hatching was noticed in Mariyam date cultivar but minimum (81.72 %) in Dabas date cultivar. The larval stages ranged from 12.13 to 14.08 days for female insects while 12.05 to 13.58 days for male insects. The pupal period of female varied from 4.56 to 5.14 days, in male insects, it was 4.50 to 4.90 days. The duration of egg to adult stage of female lasted from 20.1 to 23.14 days and for male it was highest and lowest pre-oviposition periods were 7.35 days (Dabas) and 6.15 days (Mariyam), respectively. Shorter pre-adult duration, short pre-oviposition period and high hatching percentage all reflect that a given date (Mariyam) cultivar is more susceptible to an insect attack. The difference in growth rate of insects on different cultivars may be caused by different nutritional value and softness of the cultivars.

Survival and mortality percentage of larvae and pupae were recorded and it was noticed that pupal survival rate was higher than larval survival rate. The highest larval survival rate was 91.58 % and pupal survival rate was 93.57 % in Mariyam date cultivar.

The Mariyam date cultivar experienced the highest damage of 22.5 % in October but the lowest in 4.5 % in Saad during the month of December. All five date cultivars consumed more during October, with the highest rate of damaged dates due to high temperature. High consumption was noticed in Mariyam date cultivars in every month during the experiment.

Some edible plant products with different concentrations (4 %, 2 %, and 0.05 %) were tested against *Oryzaephilus surinamensis* on different dates to determine the mortality rate. Clove power showed 100 % mortality at 4 % and 2 % concentration after day five and seven which were highest among the edible plant powders. Moderate mortality was observed by ginger powder (63.89 %) at 4 % concentration after day ten at 2 % concentration by ginger powder was 36.11 %. Lowest mortality was found in fennel powder (13.89 %). The death rate increased with the length of the exposure period. Additionally, plant powders with higher concentrations leading to higher mortality.

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APPENDICES

Appendix Table 1. Analysis of variance for developmental time of female *O. surinamensis* on five different date cultivars

Sex	Immature to adult stage	Source of variation (SV)	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	F-value	P-value	Coefficient of variation (CV) (%)
Female	Egg	Treatment	4	3.39	0.85	15.06	0.00	6.54
		Error	82	4.60	0.056			
		Total	86	7.98				
	Larva	Treatment	4	39.49	9.87	56	0.00	3.22
		Error	82	14.46	0.18			
		Total	86	53.95				
	Pupa	Treatment	4	4.60	1.15	6.83	0.0001	8.31
		Error	82	13.80	0.17			
		Total	86	18.40				
	Larva to Pupa	Treatment	4	67.73	16.93	51.64	0.00	3.19
		Error	82	26.88	0.33			
		Total	86	94.61				
	Adult	Treatment	4	94.67	23.67	60.15	0.00	2.91
		Error	82	32.26	0.39			
		Total	86	126.937				

Appendix Table 2. Analysis of variance for developmental time of male *O. surinamensis* on five different date cultivars

Sex	Immature to adult stage	Source of variation (SV)	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	F-value	P-value	Coefficient of variation (CV) (%)
Male	Egg	Treatment	4	1.79	0.45	4.74	0.0032	8.98
		Error	39	3.68	0.094			
		Total	43	5.47				
	Larva	Treatment	4	12.19	0.43	22.51	0.1005	2.90
		Error	39	5.28	0.204			
		Total	43	17.47				
	Pupa	Treatment	4	1.71	5.57	2.09	0.00	9.60
		Error	39	7.98	0.29			
		Total	43	9.70				
	Larva to pupa	Treatment	4	22.304	5.57	19.54	0.00	3.07
		Error	39	11.13	0.28			
		Total	43	33.43				
	Adult	Treatment	4	35.03	8.76	24.25	0.00	2.89
		Error	39	14.08	0.36			
		Total	43	49.11				

Appendix Table 3. Analysis of variance for test pre-oviposition period of *O. surinamensis* on five different date cultivars

Pre-oviposition period	Source of variation (SV)	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	F- value	P-Value	Coefficient of variation (CV) (%)
	Treatment	4	8.18	2.05	9.49	0.00	6.95
	Error	45	9.70	.215			
	Total	49	17.88				

Appendix Table 4. LSD all-pairwise comparisons test of pre oviposition period by treatment

Treatments	Mean ± SE
Saad	7.35 ± 0.11 a
Dabas	6.85 ± 0.18 b
Zahidi	6.60 ± 0.12 b
Medjul	6.45 ± 0.14 bc
Mariyam	6.15 ± 0.17 c

Means (± SE) within a column followed by different letters are significantly different at 0.05 % by LSD

Appendix Table 5: Analysis of variance for egg hatching, survival percentage of immature stages of *O. surinamensis* on five different date cultivars

Immature to adult stage	Source of variation (SV)	Degrees of freedom (df)	Sum of squares (SS)	Mean square (MS)	F-value	P-value	Coefficient of variation (CV) (%)
Hatching %	Treatment	4	634.32	158.58	10.31	0.00	4.55
	Error	45	692.37	15.39			
	Total	49	1326.69				
Survival % of larvae	Treatment	4	1313.27	328.32	10.78	0.00	6.53
	Error	45	1370.04	30.445			
	Total	49	2683.31				
Survival % of pupae	Treatment	4	543.05	135.76	3.92	0.0082	6.64
	Error	45	1559.08	34.65			
	Total	49	2102.12				

Appendix Table 6: Mortality (%) of adult fed on *O. surinamensis* mixed with edible plant products at 4 %, 2 % and 0.5 % (W/W) concentration

Treatment	Concentration	Mortality (%)				
		Day 1	**Day 3**	**Day 5**	**Day 7**	**Day 10**
Clove	4 %	27.78A (5.31)	63.89A (8.02)	8.34AB (2.61)	0B (0.71)	0B (0.71)
Ginger		0B (0.71)	13.89B (3.75)	13.89A (3.75)	13.89A (3.75)	22.22A (4.74)
Bay leaf		0B (0.71)	8.34B (2.97)	11.11A (3.36)	11.11A (3.36)	0B (0.71)
Fennel		0B (0.71)	13.89B (3.75)	0B (0.71)	0B (0.71)	0B (0.71)
	CV	11.92	9.90	32.82	20.47	15.24
Clove	2 %	13.89A (3.75)	47.22A (6.90)	27.78A (5.31)	11.11A (3.36)	0 (0.71)
Ginger		0B (0.71)	11.11B (3.36)	11.11B (3.36)	13.89A (3.75)	0 (0.71)
Bay leaf		0B (0.71)	0C (0.71)	0C (0.71)	0B (0.71)	0 (0.71)
Fennel		0B (0.71)	0C (0.71)	0C (0.71)	0B (0.71)	0 (0.71)
	CV	23.02	12.14	17.21	20.47	
Clove	0.50 %	0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)
Ginger		0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)
Bay leaf		0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)
Fennel		0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)	0 (0.71)
	CV					

Means within a column followed by different letters are significantly different at 0.05 % by LSD. Figures in the parentheses are $\sqrt{(x+0.5)}$ transformed value