Review Article

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Plants as Potential Repellent Against *Oryzaephilus* Species

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ABSTRACT
Stored food pests are a perennial problem in storage facilities and retail stores where they infest and contaminate on a variety of products including grain products, dried fruits, nuts, seeds, dried meats, and in fact, almost all plant products that were used as human foods. The utilization of synthetic pesticides as the main strategy to control food pests has long attracted major concern due to the residue problems and adverse effects to consumers. In view of the above, there is an increasing extensive search for plant species that are showing insecticidal and repellent properties to eradicate these pests that feed on the stored products. These harmful pests include *Oryzaephilus surinamensis* Linnaeus which is the subject of this review. This review describes the biology of *O. surinamensis* L. and summarizes on the current state of the alternative methods using plant as a repellent to control this species and other stored product pests within the same niche.

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Introduction

The insect infestation affects the food manufacturing and other industries greatly. Recently, many controls have been developed in order to avoid this pest attack from happening. The methods used include chemical, biological, and cultural control (i.e Integrated Pest Management). However, in spite of the use of all available controls, the pest infestation still occurred especially in household. The main insect pests that can cause a huge threat to stored-product are khapra beetle (*Trogoderma granarium* Everts), rice weevil (*Sitophilus oryzae* Linnaeus), red flour beetle (*Tribolium castaneum* Herbst), drug store beetle (*Stegobium paniceum* Linnaeus), cigarette beetle (*Lasioderma serricorne* Fabricius), lesser grain borer (*Rhyzopertha dominaca* Fabricius), long headed flour beetle (*Latheticus oryzae* Waterhouse), saw-toothed grain beetle (*Oryzaephilus surinamensis* Linnaeus), rice moth (*Corcyra cephalonica* Stainton), cowpea weevil (*Callosobruchus maculatus* Fabricius) and angoumois grain

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moth (*Sitotroga cerealella* Olivier) [1]. Some pests prefer storage containers, grain silos and warehouses as their home. These pests will damage the raw materials and stored-product through their feces, web and cast skin.

Among the insects mentioned, *Oryzaephilus* (Coleoptera: Silvanidae) species is a very common pest that feed of a variety of foodstuffs [2]. They are secondary pests in stored grain due to their habit to eat only some part from whole grain. However, this species can cause a mechanical damage to the grains in storage facilities, where this pest population will gradually increase and cause a huge infestation problems [3]. *Oryzaephilus mercator* Fauvel (merchant grain beetle), *Oryzaephilus acuminatus* Halstead (grain beetle) and the sawtoothed grain beetle, *Oryzaephilus surinamensis* Linnaeus are the most common species from this genus. Morphologically, these species were similar with each other. They might be differed based on the width of the temple. Both *O. mercator* Fauvel and *O. acuminatus* Halstead have relatively big eyes and short temples, while *O. surinamensis* L. posses small eyes and long temples [4, 5]. The temple of sawtoothed grain beetle is at least one-half length of the eyes. While, the temple of mercant grain beetle is only one-third length of the eye.

These species are abundant and widespread. They can be found in various foodstuffs and habitats, particularly in fodder storages, retail stores, mills, and restaurants [6, 7]. However, because they live in the bottom layers of infested food products, they are difficult to be detected. Frequently, the merchant grain beetle can be detected in higher oil contents products such as nuts and olive. Other than that, this species also feed on seed-borne fungi [7]. Meanwhile, the sawtoothed grain beetle is a polyphagous species that infested mostly on the foods that have high content of carbohydrates such as oats, barley, sugar, dried meat, cereal, rice, dried fruit, seeds, and less often on processed foods such as confectioneries and bread [8].

The needs to control the infestation of *Oryzaephilus* sp. has become a major issue because up to 6% of the raw materials can be damaged due to this problem especially during harvest, transport and storage [9]. While, Matthews [10] added that insect damage might cause for 10-40 % of loss worldwide. In the Kenyan highlands, total loss due to pest in maize were estimated at 57% with insect pest being more important than diseases [11]. According to Pinto [12], the damage caused by overall insect activity range from 0.2 % to 30 % of the grain production particularly due to the poor storage condition in Brazil. In terms of monetary value, Indian agriculture industry suffered a loss of US$ 36 billion annually due to insects and pests damage [13]. Meanwhile in Malaysia, post-harvest loss of rice at commercial level caused by these insects was reported around 20-44% [14]. Based on a study conducted by Syarifah Zulaikha [15], *O. surinamensis* L. showed the highest abundance in three rice storage facility (Tenggara, Jasa, Target Lane) in Klang with total 47403 individuals recorded during the study period. These data have shown that insect pest of stored food products prevalent in many countries and caused variable losses. Therefore, it is important to have safe methods (i.e using semiochemicals derived from plants) of preservations and control for this pest to avoid major economic loss.

Description and life cycle of Oryzaephilus surinamensis L.

Among all stored product pests, the sawtoothed grain beetle *O. surinamensis* L. is one of the most widespread species, and their infestation can originate at the manufacturing, storage or retail levels. The distribution of the beetle is influenced by many factors such as processing techniques, food availability, environmental conditions and interaction between pest species. Foods that may be infested include cereals, flours, pastas, dried fruits, nuts, dries meats, candies, and other similar packaged goods [16].

As accurate identification is key to a successful pest management, here in this part we provided brief description about morphology and life cycle of target pest; sawtoothed grain beetle *O. surinamensis* L. Adults beetle usually are less than 3 mm long, with long, narrow and flattened chocolate brown bodies. Figure 1 showed the morphometric characterizations of *O. surinamensis* L. reared in oat grout under laboratory conditions (27℃ and 64% RH) at Kulliyyah of Science, International Islamic University Malaysia. Females and males are almost similar but males are slightly more elongated in shape than females. According to Barnes [17], in their culture, males range in length from 3.4 to 3.7 mm and females from 3.3 to 3.5 mm. Other than that, the head of the males is broader, while in females, the head slightly narrower. Males also have the posterior margin of the hind trochanter and the upper margin of the hind femur with a spine-like projection. Wings are well developed in both sexes. Along each side of the thorax are six distinctive tooth-like projections [18]. Eggs are elongated, capsuled-shape, about 0.4 mm long, and deposited singly or in small clusters. The larvae are elongated yellowish-white with a brown head has numerous setae (hairs) and three pairs of legs.

They are about 0.8 mm when newly hatched and 3-4 mm when fully developed. The mature larvae are quite active. Adults are relatively long-lived. They can survive for 19 weeks. Adults are also active and they can climb most of vertical surfaces. They do not penetrate packaging materials well but they are fast at gaining access through small holes or gaps in packaging seals. Due to their flattish form, they can pass through holes as small as 0.7 mm in diameter [8].

Oviposition begins shortly after adult emergence (30-35°C and 56–74% relative humidity). Average number of eggs per female is about 280 with maximum numbers of 432. The eggs hatch within 3-8 days [19]. Depending on temperature, the life cycle ranges from 20-80 days. While, depending on the environmental conditions, the adults usually live around 6 to 10 months. Humidity greatly influenced oviposition and development with both decreasing as humidity decreases below 50%. Above 96% relative humidity, the growth for this species is not possible [20]. However, Mallis [21] previously give an opposing view by stated that low humidity only has little effect on the egg period and did not affect the length of the developmental stages.

Fig 1 *Oyzaephilus surinamensis* L. morphometric characterization; a) Length of antenna, b) Head width, c) Length of thorax, d) Body length, e) Body width at the widest point, f) Length of hind femur.

Control of Oryzaephilus species

The control of pests includes the management and regulation of pest which effectively resist further growth of insects and damage done on products. The chemical control is the most popular and effective method. Several publications have shown the efficacy of pesticides such as pirimiphos methyl, phosphine, deltamethrin and chlorpyriphos to control the pest in stored grains i.e Rejesus [22], Arthur [23] and Sgarbiero [24]. The findings showed that these chemical control agents produced effective effects. Phosphine (PH_3) was first introduced in the late 1700s and has been utilized as a grain fumigant since the 1930s [25]. It is by far the most common pest insect control in stored grain. Phosphine has high toxicity to aerobic organisms, but harmless to anaerobic or metabolically dormant organisms. Thus, it can be utilized to kill insect pests in grain, without affecting grain viability. However, in other report, due to its high toxicity, fumigation with phosphine is now seldom used [26]. According to Nath [25], the three hydrides (NH_3 and AsH_3) can disturb of the sympathetic nervous system, suppressed energy metabolism and toxic changes to the redox state of the cell.

The chemical method is probably the commonest and main means in pest management especially in foods and crops such as fruit, vegetables and grains but it has some disadvantages [27]. First, the materials used are usually poisonous to human beings and leave residues on food; and secondly, it caused a development of high degrees of resistance in many insect pests due to continuous use of commercially available synthetic pesticides, thus making controls more difficult. These chemicals also resulted in resurgence and outbreak of new pests which previously regarded as non-insect pests (due to their low population in nature). Furthermore, pesticide contamination is disrupting the ecosystem sustainability by severely affecting beneficial insects, microbes, plants, fishes, birds and other animals [28]. Although effective, they can have a disastrous effect on a habitat's food web. As our knowledge of the side effects of modern broad-spectrum pesticides and fumigants has increased, scientists have started to find new ways to control pest infestation. It appears to be advisable, therefore, to implement the other means rather than the chemical method.

Apart from that, biological control also can be used in order to save the product from *O. surinamensis* L. attack. There is one potential natural enemies of *O. surinamensis* L. which is the parasitoid wasp, *Cephalonomia tarsalis* Ashmead (Hymenoptera:

Bethylidae) reported from Iran [29]. Entomogenous fungus *Beauveria bassiana* (Bals.) Vuill also was identified to have potential to reduce breeding success of *O. surinamensis* L. [30]. However, biological control is not commonly use and mostly still in experimental stage.

Other control methods including physical control using inert dust such as diatomaceous earth [31, 32], ionizing irradiation [33], light and sound [34], thermal regulation and ozonation [35] and semiochemical control or chemical derived from plants to control insect pests by behavioural manipulation (i.e insecticides, repellents or antifeedants) [36, 37]. This review focuses on potential plant as semiochemical of *Oryzaephilus* species and other control methods are not discussed in details.

Plant as semiochemical control; biopesticides, natural repellents and antifeedants

Biopesticides or 'biological pesticides' are naturally occuring substances that are extracted or derived from such natural materials as plants, animals, bacteria, and certain minerals. Biopesticides have gained a great attention in recent years because they offer a safe, friendly, and integrated environmental development. At present, biopesticides are successfully implemented in food industry to manage (either to prevent or delay) the development of pests in food products. Another benefit of biopesticides is they appear to be safe during accidental contacts with higher animals such as human and other mammals [38]. Plant-derived insecticides (targeted only on insects) can replace synthetic chemical insecticides as alternatives to control pest in food products. This is because plants and herbs usually posses only little health risk to human. Moreover, the production and processing costs are low. Biopesticides are in the form of powder, essential oil or solvent extract such as pyrethrum extracted from *Tanacetum cinerariifolium* (Trevir.) Sch. Bip. (Asteraceae) or neem from *Azadirachta indica* A. Juss (Meliaceae) are popular in the market [39, 40].

Meanwhile, repellents are the substances that cause insects to direct their movement away from the food source [41]. Insects will detect the repellent from a short distances and causing them to move away [42]. Plant extracts are safe, non-poisonous, less toxic (not true in all cases) and biodegradable. Traditionally, plant-based repellents have been used as a personal protection method against pests [43, 44]. Through ethnobotanical studies, knowledge on traditional repellent plants obtained is beneficial for the development of new natural products [45]. Plant-based repellent can protect against the pest with minimal impact on the ecosystem, as they keep the insect pest away from the food products by stimulating olfactory or other receptors. Plant derived repellents are safe in pest control and able to minimize pesticide residue. The safety of the people, food, and environment are also guaranted [43].

As antifeedant, allelochemicals from plants target on specific sensory cells (i.e antifeedant receptors) in the pest or insect. The neurons associated with these antifeedant receptors either prevent insect feeding (feeding deterrent effect) or cause cessation or slowing of further feeding (feeding suppressant effect) [46]. In other words, the chemicals interupt insect feeding by rendering the treated materials unattractive or unpalatable. Another mode of action of some antifeedants is by blocking the function of pest feeding-stimulant receptors, or an ability to bind directly to its normal feeding cues, such as sugars and amino acids therefore disrupting the sensitivity of sugar-sensing cells in insect pest and thus causing the insects to incorrectly assess nutritional adequacy of treated host [37]. For example, study of antifeedant property in *Vernonia oocephala* Baker (Asteraceae) has highlighted the potential of this plant in reducing feeding activity of stored product pests particularly *Tribolium castaneum* Herbst as this could be due to saponins, glycosides, and alkaloids found in the plant extract [47].

Diversity in plant forms as semiochemical against stored product pests

Plant repellent can be formed from plant extracts, raw/powders and essential oil [48] which are extracted from many parts of the plant such as roots, leaves, seed and bark. İt is reported that these plant parts also able to reduce oviposition rate and suppress adult emergence of stored product insects, and also reduce seed damage rates [49]. Several studies also have shown that plant families namely Annonaceae, Asteraceae, Canellaceae, Lamiaceae Meliaceae, and Rutaceae are the most promising natural repellents [50, 51, 52].

Essential oils repel insect with their effect lasting from several minutes to several hours. Essential oils are formed by plants as secondary metabolites [53]. They are volatile and has a strong odour (concentrated extract that retain the natural smell and flavour of the source). Essential oils that have insect repellent activity usually contain allelochemicals like the monoterpenes such as cineole, pinene, eugenol, limonene, citronellol, terpinolene, citronellal, camphor and thymol [54]. The most common essential oil is extracted from Neem. Neem plant *Azadirachta indica* A. Juss (Meliaceae) is a bitter tonic that has parasiticidal, insecticidal, spermicidal properties and hence destroys a wide range of organism. Ahmed [55] and Talukder [56] reported that 1 to 2% of the neem oil shown to be effective against stored grain insect pests like *Oryzaephilus* sp., *Sitophilus oryzae* Linnaeus, *Tribolium castaneum* Herbst, *Rhyzopertha dominica* Fabricius, and *Callosobruchus chinensis* Linnaeus. According to these researchers, the neem oil bind to the grains and protect against storage pests for 180 to 330 days.

Other than Neem, the essential oil of *Artemisia annua* Linnaeus (sweet wormwood) from Family Asteraceae also has been utilized as a repellent against *Tribolium castaneum* Herbst and *Callosobruchus maculatus* Fabricius [57]. In northern Cameroon, the essential oils of *Xylopia aethiopica* (Dunal) A. Rich. (Annonaceae), *Vepris heterophylla* (Engl.) Letouzey (Rutaceae) and *Lippia rugosa* A. Chev (Verbenaceae) were also applied to protect from the infestatation of stored grain insect pests [58]. In other study by Zia [59], the essential oil from citrus peels was used as grain protectants against *Callosobruchus chinensis* L., *Trogoderma granarium* Everts and *Tribolium castaneum* Herbst. They observed that depending on concentrations and exposure durations, the essential oil showed variable toxicity to insects. Due to similarity in behavior and niche, similar results also can be expected occurred on *O. surinamensis* L.

Meanwhile, Al-Jabr [19] in his study evaluated the application of several essential oils such as *Cinnamomum camphora* (L.) H. Karst (Lauraceae), *Cymbopogon winterianus* Jowitt (Poaceae), *Matricaria chamomilla* Linnaeus (Asteraceae), *Mentha viridis* Linnaeus (Lamiaceae) , *Prunus amygdalus* var. *amara* (DC.) Buchheim (Rosaceae), *Rosmarinus afficinalis* Linnaeus (Lamiaceae) and *Simmondsia chinensis* (Link) CK. Schneid (Simmondsiaceae). The toxicity and repellent effectiveness against adults of *O. surinamensis* L. and *Tribolium castaneum* Herbst were tested using these plants extracts. Their results showed that essential oil of *Mentha viridis* Linnaeus, *Matricaria chamomilla* Linnaeus and *Cinnamomum camphora* (L.) H. Karst. showed a high mortality of *O. Surinamensis*. Similar results regarding repellant activity of *Cinnamomum camphora* (L.) H. Karst. on other insect pests also have been reported by many authors such as Liu [60], Cansian [61] and Guo [62]. Other plant oil that has been found effective against stored product pest is coconut oil [63].

Rajashekar [52] on the other hand, highlighted that dried leaves (raw form) of *Azadirachta indica* A. Juss (Meliaceae) was effective against insects when mixed with stored grains. In term of availability, raw form (without extraction) is the best form to be studied their potential as repellent against stored product pests as it readily available for household use compared to essential oil and solvent extract. A study by Klys [64] has investigated effectiveness of the plant powders of peppermint *Mentha piperita* Linnaeus (Lamiaceae), wormwood *Arthemisia absinthium* Linnaeus (Asteraceae), common sage *Salvia officinalis* Linnaeus (Lamiaceae), allspice *Pimenta dioica* (L.) Merrill (Myrtaceae) and common garlic *Allium sativum* Linnaeus (Amaryllidaceae) used in different concentrations on the mortality rates of the *O. surinamensis* L. The result showed that at the concentration of 1.23%, all spice seeds powder demonstrated the highest mortality among *O. surinamensis* L. Meanwhile, the powder of sage, peppermint and wormwood caused the highest statistically significant mortality of *O. surinamensis* L when the concentrations of 3.61 and 5.88% were used.

Rajashekar [52] also reported that a significant finding was shown when the root powder of *Decalepis hamiltonii* Wight & Arn. (Apocynaceae) was tested against various stored grain insect pests. Other than that, extraction from powder (using distilled water) of ginger *Zingiber officinale* Roscoe (Zingiberaceae) and caraway *Carum carvi* Linnaeus (Apiaceae) and cardamom *Elettaria cardamomum* Linnaeus (Zingiberaceae) by Amiri [65] demonstrated that high repellency was detected in ginger and caraway on larvae and adult of *O. surinamensis* L. and *O. mercator* Fauvel than cardamom. In their study, a high repellent effect was detected for all plant extracts with the increased concentrations and time of exposure. While, in an experiment set up by Devi [66] the powders of 17 spices such as mace, pepper, nutmeg, cloves, cinnamon, star anise, fennel, ajowan, cumin, caraway, turmeric, ginger, bay leaves, red chilies, cappers, coriander, and fenugreek were evaluated for their insecticidal, antifeedant and antiovipositional potential against *Sitophilus oryzae* Linnaeus infesting wheat. The results showed that these spices powder showed an effective protection to wheat up to 9 months without affecting seed germination thereby showing promise as grain protectants. On the other hand, Tiwari [67] reported that the powders of *Rauvolfia serpentina* (L.) Benth. ex Kurz., *Acorus calamus* Linnaeus (Apocynaceae) and *Mesua ferrea* Linnaeus (Calophyllaceae) showed a positive finding as grain protectants against *Rhyzoperta dominica* Fabricius.

Meanwhile, solvent extracts of many plants have shown varying levels of insect-repellent properties. Commonly used solvents are ethyl acetate, diethyl ether and dichloromethane. The repellent effects of solvent extracts of indigenous plants were tested against *O. surinamensis* L. by Shah [68]. According to the authors, *Typhonium trilobatum* (L.) Schott (Araceae), *Cleome viscosa* Linnaeus (Capparidaceae), *Cassia occidentalis* Linnaeus (Fabaceae), *Pongamia pinnata* (L.) Pierre (Fabaceae), *Mensua ferrea* Linnaeus (Calophyllaceae) and *Trewia nudiflora* Linnaeus (Euphorbiaceae) showed the highest repellency rate at 10.0% dose level. Manzoor [69] reported that *O. surinamensis* L. were repeled by the ethanolic extract of five plant leaves; bakain *Melia azedarach* Linnaeus (Meliaceae), datura *Datura stramonium* Linnaeus (Solanaceae), lemongrass *Cymbopogon citratus* Stapf. (Poaceae), mint *Mentha longifolia* (L.) Huds. (Lamiaceae) and habulas *Myrtus communis* Linnaeus (Myrtaceae). The result demonstrated that lemongrass showed the maximum number of repellent (based on number of alive insects) after 48 hour. In addition, Dwivedi [70] observed that *Cassia occidentalis* Linnaeus (Fabaceae) and other aboriginal plant species showed possible repellent action of against a stored product pest insect under laboratory conditions. From their observation, the acetone extracts showed good repellent effect towards the tested insect.

Other than studies that have been reviewed above, many other research have been done on plants in order to find method which does not burden producers, retailers and consumers financially, safer for environment and quite effective to control stored product pests. Table 1 listed some of the studies on potential plants species as repellent against *O. surinamensis* together with other stored product insects. From an economical point of view, synthetic chemicals are still more popular as repellents than plant-based. However, for a safer repellents for humans and the environment, these natural products should be considered as an alternative to the synthetic chemicals.

Table 1 List of plant species reported to show insecticidal or repellent activity on *O. surinamensis* and other stored product insects from the same study

No.	Plant species	Family	Plant parts	Stored product pests	References
1.	*Agastache foeniculum* (Pursh) Kuntze	Lamiaceae	Aerial parts	*Oryzaephilus surinamensis* L. *Lasioderma*	[71]

				serricorne Fabricius	
2.	*Ageratum conyzoides* Linnaeus	Asteraceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[72]
3.	*Ailantus altissima* (Mill.) Swingle	Simaroubaceae	Bark	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Sitophilus oryzae* L. *Liposcelis paeta* Pearman	[73]
4.	*Allium cepa* Linnaeus	Amaryllidaceae	Bulbs* Bulbs	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Oryzaephilus surinamensis* L.	[74] [75]
5.	*Allium sativum* Linnaeus	Amaryllidaceae	Bulbs	*Oryzaephilus surinamensis* L.	[64], [75]
6.	*Anethum graveolens* Linnaeus	Apiaceae	Seeds	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[76]
7.	*Argemone ochroleuca* Sweet	Papaveraceae	Leaves	*Oryzaephilus surinamensis* L.	[77]
8.	*Artemisia absinthium* Linnaeus	Asteraceae	Whole plant Leaves	*Oryzaephilus surinamensis* L. *Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[64] [78]
9.	*Artemisia argyi* Levl. et	Asteraceae	Whole plant	*Oryzaephilus surinamensis* L.	[79]

	Vant.				
10.	*Artemisia herba-alba* Asso.	Asteraceae	Leaves	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[78]
11.	*Azadirachta indica* A. Juss	Meliaceae	Leaves Leaves, Seed kernels	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Oryzaephilus surinamensis* L. *Acanthoscelides obtectus* Say *Sitophilus oryzae* L. *Cryptolestes ferrugineus* Stephens	[80] [81]
12.	*Calotropis procera* (Ait.) Ait.	Apocynaceae	Leaves	*Oryzaephilus surinamensis* L.	[82]
13.	*Cananga odorata* Hook. f. et Thomson	Annonaceae	Flowers	*Oryzaephilus surinamensis* L.	[83]
14.	*Capparis spinosa* Linnaeus	Capparaceae	Leaves	*Oryzaephilus surinamensis* L.	[77]
15.	*Caralluma tuberculata* N.E. Brown	Apocynaceae	Leaves	*Oryzaephilus surinamensis* L.	[77]
16.	*Carum carvi* Linnaeus	Apiaceae	Fruits Seeds* Seeds	*Oryzaephilus surinamensis* L. *Oryzaephilus mercator* Fauvel *Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Oryzaephilus surinamensis* L.	[65] [74] [75]

17.	*Cassia occidentalis* Linnaeus	Fabaceae	Leaves	*Oryzaephilus surinamensis* L.	[68]
18.	*Chenopodium album* Linnaeus	Amaranthaceae	Leaves	*Oryzaephilus surinamensis* L.	[41]
19.	*Cinnamomum camphora* (L.) H. Karst	Lauraceae	Wood*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
20.	*Citrus aurantium* Linnaeus	Rutaceae	Leaves	*Oryzaephilus surinamensis* L. *Lasioderma serricorne* Fabricius	[84]
21.	*Cleome viscosa* Linnaeus	Cleomaceae	Leaves	*Oryzaephilus surinamensis* L.	[68]
22.	*Cordia verbenacea* A. DC.	Boraginaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[672]
23.	*Crataegus sinaica* Boisser	Rosaceae	Leaves	*Oryzaephilus surinamensis* L. *Carpophilus hemipterus* L.	[85]
24.	*Cymbopogon citratus* Stapf	Poaceae	Leaves	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Callosobruchus chinensis* L.	[69]
			Whole plant	*Oryzaephilus surinamensis* L. *Sitophilus zeamais* Motschulsky	[86]
25.	*Cymbopogon martini*	Poaceae	Whole plant	*Oryzaephilus surinamensis* L.	[86]

	(Roxb.) W.Watson			*Sitophilus zeamais* Motschulsky	
26.	*Cymbopogon nardus* (L.) Rendle	Poaceae	Whole plant	*Oryzaephilus surinamensis* L. *Sitophilus zeamais* Motschulsky	[86]
27.	*Cymbopogon winterianus* Jowitt	Poaceae	Aerial parts*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
28.	*Cyperus fuscus* Linnaeus	Cyperaceae	Rhizomes*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[74]
29.	*Datura stramonium* Linnaeus	Solanaceae	Leaves	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Callosobruchus chinensis* L. *Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Oryzaephilus surinamensis* L. *Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[69] [80] [82] [72]
30.	*Elettaria cardamomum* Linnaeus	Zingiberaceae	Fruits Seeds	*Oryzaephilus surinamensis* L. *Oryzaephilus mercator* Fauvel *Oryzaephilus surinamensis* L.	[65] [75]

			Fruits + Seeds	*Oryzaephilus surinamensis* L.	[87]
31.	*Eucalyptus dundasii* Maiden	Myrtaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius	[88]
32.	*Eucalyptus floribunda* F. Muell.	Myrtaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius	[89]
33.	*Eucalyptus globulus* Labill.	Myrtaceae	Leaves*	*Oryzaephilus surinamensis* L.	[90]
34.	*Foeniculum valgare* Miller	Umbelliferae	Seeds Fruits + Seeds	*Oryzaephilus surinamensis* L. *Oryzaephilus surinamensis* L.	[75] [87]
35.	*Fragaria ananassa* Duch.	Rosaceae	Fruits	*Oryzaephilus surinamensis* L.	[75]
36.	*Illicium verum* Hook. F.	Schisandraceae	Flowers	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[76]
37.	*Lantana camara* Linnaeus	Verbenaceae	Leaves	*Oryzaephilus surinamensis* L.	[41]
38.	*Lavandula augustifolia* Miller	Lamiaceae	Flowers*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Oryzaephilus surinamensis* L.	[74] [83]
39.	*Leonotis nepetifolia* (L.) R. Brown	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius	[72]

				Sitophilus oryzae L.	
40.	*Lepidoploa aurea* (Mart. ex DC.) H. Robinson	Asteraceae	Leaves	*Oryzaephilus surinamensis* L. *Sitophilus zeamais* Motschulsky *Tribolium castaneum* Herbst	[91]
41.	*Linum usitatissimum* Linnaeus	Linaceae	Seeds*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[74]
42.	*Marrubium vulgare* Linnaeus	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L.	[77]
43.	*Matricaria chamomilla* Linnaeus	Asteraceae	Flower*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
44.	*Maytenus emarginata* (Willd.) Ding Hou	Celastraceae	Leaves	*Oryzaephilus surinamensis* L.	[41]
45.	*Melia azedarach* Linnaeus	Meliaceae	Leaves	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Callosobruchus chinensis* L.	[69]
46.	*Memora nodosa* Miers	Bignoniaceae	Flowers	*Oryzaephilus surinamensis* L. *Sitophilus zeamais* Motschulsky *Tribolium castaneum* Herbst	[91]
47.	*Mentha longifolia* (L.) Hudson	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L. *Tribolium*	[69]

				castaneum Herbst *Callosobruchus chinensis* L. *Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[80]
48.	*Mentha piperita* Linnaeus	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L. *Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[64] [72]
49.	*Mentha viridis* Linnaeus	Lamiaceae	Leaves*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
50.	*Mesua ferrea* Linnaeus	Calophyllaceae	Leaves	*Oryzaephilus surinamensis* L.	[68]
51.	*Mormodica charantia* Linnaeus	Cucurbitaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[72]
52.	*Myrtus communis* Linnaeus	Myrtaceae	Leaves	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst *Callosobruchus chinensis* L.	[69]
53.	*Nigella sativa* Linnaeus	Ranunculaceae	Seeds	*Oryzaephilus surinamensis* L.	[75]
54.	*Ocimum basilicum* Linnaeus	Lamiaceae	Leaves*	*Oryzaephilus surinamensis* L.	[90]

55.	*Ocimum gratissimum* Linnaeus	Lamiaceae	Whole plant	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Tribolium castaneum* Herbst *Callosobruchus chinensis* L. *Sitophilus oryzae* L.	[92]
56.	*Ocimum selloi* Benth.	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[72]
57.	*Pimenta dioica* (L.) Merrill	Myrtaceae	Seeds	*Oryzaephilus surinamensis* L.	[64]
58.	*Pongamia pinnata* (L.) Pierre	Fabaceae	Leaves	*Oryzaephilus surinamensis* L.	[68]
59.	*Prunus amygdalus* var. *amara* (DC.) Buchheim	Rosaceae	Seed kernels*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
60.	*Prunus laurocerasus* Linnaeus	Rosaceae	Leaves	*Oryzaephilus surinamensis* L. *Carpophilus hemipterus* L.	[85]
61.	*Punica granatum* Linnaeus	Lythraceae	Leaves	*Oryzaephilus surinamensis* L.	[41]
62.	*Pyracantha coccinea* Roemer	Rosaceae	Leaves	*Oryzaephilus surinamensis* L. *Carpophilus hemipterus* L.	[85]
63.	*Rhazya stricta* Decne.	Apocynaceae	Leaves	*Oryzaephilus surinamensis* L.	[77]

64.	*Rosmarinus officinalis* Linnaeus	Lamiaceae	Leaves + young stems*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
65.	*Ruta graveolens* Linnaeus	Rutaceae	Leaves	*Oryzaephilus surinamensis* L. *Rhyzopertha dominica* Fabricius *Sitophilus oryzae* L.	[72]
66.	*Salvia officinalis* Linnaeus	Lamiaceae	Whole plant Leaves + Flowers	*Oryzaephilus surinamensis* L. *Oryzaephilus surinamensis* L.	[64] [75]
67.	*Simmondsia chinensis* (Link) C.K. Schneid	Simmonsiaceae	Seeds*	*Oryzaephilus surinamensis* L. *Tribolium castaneum* Herbst	[19]
68.	*Solenostemma argel* (Del.) Hayne	Apocynaceae	Leaves	*Oryzaephilus surinamensis* L.	[782]
69.	*Sorbus aucuparia* Linnaeus	Rosaceae	Leaves	*Oryzaephilus surinamensis* L. *Carpophilus hemipterus* L.	[85]
70.	*Syzygium aromaticum* (L.) Merr. et L.M. Perry	Myrtaceae	Seeds	*Oryzaephilus surinamensis* L.	[75]
71.	*Thymus vulgaris* Linnaeus	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L.	[75]
72.	*Trewia nudiflora* Linnaeus	Euphorbiaceae	Leaves	*Oryzaephilus surinamensis* L.	[68]
73.	*Triticum aestivum* Linnaeus	Poaceae	Seeds	*Oryzaephilus surinamensis* L.	[75]

74.	*Typhonium trilobatum* (L.) Schott	Araceae	Leaves	*Oryzaephilus surinamensis* L.	[68]
75.	*Vitex negundo* Linnaeus	Lamiaceae	Leaves	*Oryzaephilus surinamensis* L.	[41]
76.	*Zingiber officinale* Roscoe	Zingiberaceae	Fruits	*Oryzaephilus surinamensis* L. *Oryzaephilus mercator* Fauvel	[65]
			Rhizomes	*Oryzaephilus surinamensis* L.	[87]

* Commercially available essential oils.

Conclusion

Biological and Chemical studies of protective allelochemicals in plants especially those disrupting pest functional activity is important for future efforts to control the damage in crops due to pest infestation. Due to this fact, many researchers have evaluated the insecticidal properties of plant-based repellents on various species of stored product insect pests. The results clearly showed that the application of plant-based products as alternative to synthetic chemicals is proven to be more effective, sustainable and safe with low toxicity effect on non-target organisms. Some of plant products can work not only on *Oryzaephilus surinamensis* Linnaeus but simultaneously against many other pest species like *Tribolium castaneum* Herbst and *Sitophilus oryzae* Linnaeus. In addition to that, the pest management will be more efficient and impactful if some measures were taken such as early detection, effective monitoring and knowledge of the way of life and habits of pest species.

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