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Utilization Of Plant Extractives And Compounds For Sitophilus Oryzae (Rice Weevil) Management

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Abstract
In stored crops, Sitophilus oryzae (rice weevil) can cause damage of up to 80%, depending on the circumstances of storage. A vast variety of grains and seeds, including sorghum, wheat, corn, oats, rye, barley, rice, and beans, are all highly palatable to the bug. The most practical and effective technique to control insect pests in stored food products is to use synthetic insecticides. These substances do, however, have adverse effects on the ecosystem. It has been established that plants contain important compounds that are poisonous to insects. Because they are renewable, do not persist in the environment, and are generally safe for use by humans, non-target creatures, and natural enemies, botanicals are the preferred method of controlling pests and diseases. A lot of research has been done to determine the efficacy of plant extracts in management of rice weevil. However, the information is scattered in different publishes articles. This paper provides a review on insecticidal activity of plant extracts against Sitophilus oryzae. From the results, the most studied plant species belong to the Lamiaceae family (20) followed by Asteraceae (16), Fabaceae (9), Labiatae (9), Rutaceae (9), Myrtaceae (7) and Zingiberaceae (6). The efficacy of plant extracts against the insects depend on the type of plant, extract concentration, growth conditions, exposure duration, and plant part used. The study's findings confirm that certain plant extracts are highly poisonous, repellant, antifeedant, and have the ability to suppress growth and oviposition in Sitophilus oryzae (L.) and may offer an alternate method of preventing weevil damage to stored crops. However, very little is known about plant-derived insecticidal chemicals against the weevil. Further study to find such insecticidal ingredients and formulations is recommended.

Keywords: *Rice weevil; Sitophilus oryzae; stored grains; Insecticide; plant extracts; plant compounds*

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I. Introduction

Worldwide, stored insect pests are a serious issue since they drastically lower food yields and quality. One of the worst insect pests is the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), which can inflict damage of 10 to 65 percent in moderate storage circumstances and up to 80 percent in long storage conditions[1]. This pest, which has a global spread, is particularly harmful in warm and humid environments. Both the adult insects and their larvae exhibit a ravenous appetite for a wide range of grains and seeds, such as sorghum, wheat, corn, oats, rye, barley, rice, and dry beans[2]. According to Huang and Subramanyam, synthetic insecticides are the most practical and efficient way to manage insect pests in stored goods[3]. Due to their sluggish rate of environmental biodegradation and the presence of some hazardous residues that are harmful to the health of mammals, these compounds are linked to unfavorable environmental impacts[4-11]. The need for efficient and biodegradable pesticides has increased due to the negative impacts of synthetic pesticides.

Natural products are a great way to lessen harmful effects on the environment and human health when compared to synthetic pesticides[12-19]. Botanical powders and extracts are among the many types of natural materials that have drawn special attention as natural treatments for pest management. It has been determined that plants are a source of significant chemicals that are poisonous to harmful pests and microorganisms[20-22]. The use of botanical for pests and disease control is preferred because they are renewable, non-persistent in the environment and relatively safe to natural enemies, non-target organisms and human beings[23-30]. In addition, chances of pests and pathogens developing resistance to botanical pesticides are highly unlikely. Furthermore, plant extracts have been widely used as anti-parasitical, bactericidal, fungicidal, antiviral and insecticidal materials[31-37]. There are numerous investigations on the insecticidal activity of plant extracts against the rice weevil *S. oryzae*. Search for insecticidal compound from plants has yielded important compounds including alkaloids, terpenoids, flavonoids, steroids and quinones[38-43]. Such compounds represent an important source of drugs in the process of developing new pharmacologically active compounds. This paper provides a review on insecticidal activity of plant extracts with emphasis on plant extracts exhibiting toxicity, repellent, antifeedant, oviposition deterrent and growth inhibition activities against *Sitophilus oryzae* (L.).

II. Rice Weevil Insecticidal Plant Extracts

The insecticidal activities of several plant species against *Sitophilus oryzae* have been evaluated using various bioassay techniques[44, 45]. Out of the 131 plant species identified, the most studied plant species belong to the Lamiaceae family (20) followed by Asteraceae (16), Fabaceae (9), Labiatae (9), Rutaceae (9), Myrtaceae (7) and Zingiberaceae (6) (Figure 1 & Table 1). The efficacy of plant extracts was found to vary depending on the type of plant, extract concentration, growth location, exposure duration, and plant part used[46-48]

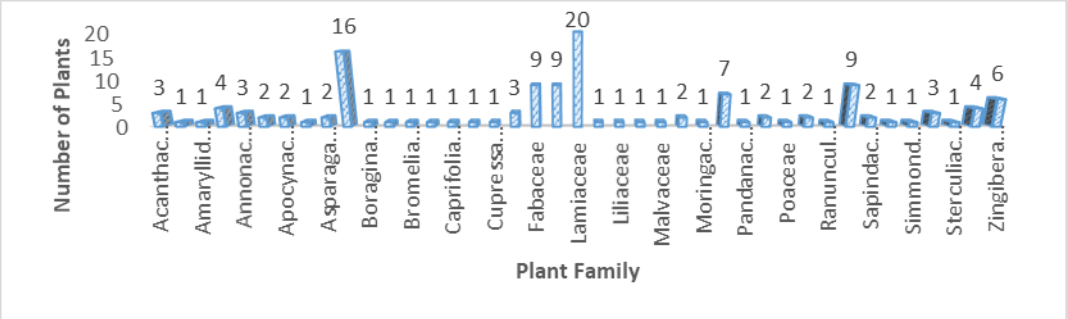

Figure 1. Distribution of the tested insecticidal plants by plant family

Zingiber officinale (ginger), *Azadirachta indica* (neem), *Syzygium aromaticum* (clove) and *Nicotiana tabacum* (tobacco) extracts were tested mortality, grain damage prevention and repellency efficacy against *S. oryzae* infesting stored wheat. The highest mortality of *S. oryzae* (99.17%) was recorded in *Z. officinale extract*, while the lowest mortality (67.50%) was observed in *N. tabacum* extract. The highest grain damage due to *S. oryzae* (0.19%) was observed in *N. tabacum* treated crude extract, while the least grain damage (0.04%) was observed in *Z. officinale* treated grains. *Z. officinale* exhibited the highest repellent effect on *S. oryzae* (95.77%) [49]. *Thymus vulgaris*, *Schinus molle* and *Melia azedarach* extracts showed mortality, prevention of grain damage and growth inhibition effects against rice weevils at different concentrations. *M. azedarach* and *T. vulgaris* extracts gave the highest efficacy[50]. Mohammad and co-workers tested methanolic extracts of *Lantana camara* (leaves), *Carica papaya* (seeds), *Ricinus communis* (leaves), *Calotropis gigantea* (flowers), and *Gliciridia sepium* (leaves) for toxiciy effect against rice weevil. Insecticidal effect of the plant extracts was in the following order: *Gliciridia sepium* > *Lantana camera* > *Galotropis gigantea* > *Ricinus communis* > *Carica papaya*[51]. *Cannabis sative* L., *Dodonaea visicosa* L., and *Parthenium hysterophorus* L. extracts were tested for insecticidal and synergism effect against rice weevil at different concentrations. *D. visicosa*, *P. hysterophorus*, and *C. sativa* caused 97, 90, and 83 percent mortalities respectively at 3% concentration[52]. When used in combination, the effects of *D. visicosa*, *P. hysterophorus*, and *C. sative* produce 100% mortalities[52].

Essential oil - based nanoemulsions from *Carlina acaulis* L., *Mentha longifolia* (L.) and *Hazomalania voy*ronii were evaluated as insecticides against *Sitophilus oryzae* (L.) on barley, oats, and maize kernels [53]. All the tested nanoemulsions showed elevated efficacy when applied on barley, while mortalities were lower on oats and maize. *C. acaulis* was the most effective, followed by *H. voyronii* and *M. Longifolia*[53]. Neem, clove, lavender, karanj, eucalyptus, lemon grass, and tea tree oils obtained from local market in India were tested for insecticidal effect against rice weevil[54]. Neem oil cause the highest number of deaths (83.33%), followed by karanj oil (77.77%), clove oil (67.77%), eucalyptus oil (57.77%), lemon grass oil (54.44%), tea tree oil (51.10%) and lavender oil (31.11%). Neem oil was the most effective in weight loss prevention (7.32%), followed by karanj oil (11.99%) [54]. Makai *et al* found out that peppermint (*Mentha piperita*), sage (*Salvia officinalis*) and feverfew (*Tanacetum parthenium*) had repellent and fatal effects against the insect as compared to control[55]. *Mentha piperita* was the most effective treatment with mortality rate of 38.33%. *Tanacetum parthenium* exhibited high repellency of 5.95 % against Sitophilus oryzae. In a study by Arafah *et al.*, *Pandanus amaryllifolius* and *Garcinia atroviridis* extracts exhibited repellent, antifeedant and anti-progeny effect against rice weevils. *Pandanus amaryllifolius* extract was the most effective, with a repellency of 46.67% and anti-progeny effect of 2.175%. *Garcinia atroviridis* showed an anti-progeny effect of 6.525% [56]. When *Mentha spicata* L. (spearmint), *Mentha piperita* L. (peppermint), *Mentha arvensis* L. (corn mint) and *Mentha citrate* L. (bergamot mint) were tested for repellence activity against the insect, *Mentha spicata* essential oil gave the highest repellency of 66.66% at 12 nL/cm^2 followed by *M. piperita*, which had 53.33% repellency at 40 nL/cm^2 concentration. *M. arvensis* and *M. citrata* gave 66.66 and 53.33% repellency at 173 nL/cm^2 concentration[57]. *Azadirachta indica* (neem) and *Piper nigrum (*black pepper) exhibited mortality and grain damage protection against rice weevil[58].

Kły´s *et al* determined the effect of *Carum carvi* L. (caraway) essential oil and L-carvone on the emigration, repellence and mortality of *Sitophilus oryzae*[59]. Caraway essential oil recorded a repellency of (60–98%) while L-carvone at 0.1% caused 16–100% repellence. The highest mortality of *S. oryzae* was caused by

0.5% caraway essential oil and 1% L-carvone. Khanal *et al* tested extracts from *Azadirachta indica* A. Juss, *Nicotiana tabacum* L., *Zingiber officinale* Roscoe, *Allium sativum* L, *Zanthoxylum armatum* Roxb and *Acorus calamus* L. for insecticidal effect of rice weevil on wheat seed[60]. *Acorus calamus* recorded had the highest mortality (98.33%), followed by *N. tabacum* (85.67%), *A. sativum* (73.34%), *A. indica* (70.67%), *Z. armatum* (70.34%) and *Z. officinale* (58.34%). In onothe study, *Acorus calamus, vitex negundo, Adhatoda vasica* and *Calotropis gigentae* showed insecticidal activity against rice weevil in stored wheat seeds[61]. *A. calamus* was most effective in preventing the number of adult emergence, weight loss and seed damage followed by *A.vasica, C. gigantean* and *V. negundo*[61, 62]. *Eucalyptus globulus, Lantana camara, Murraya koenigii, Ricinis communis, Vitex negundo, Tagetes erecta, Citrus aurantium, Curcuma longa, Ocimum sanctum* and *Mentha spicata* exhibited fumigant toxicity and repellent effects against rice weevil. *Mentha spicata* exhibited 83.33% toxicity with maximum repellency of 76.11%. *Ocimum sanctum* had 80% toxicity and 76.11% repellency. *Vitex negundo* caused 83.33% toxicity and repellency of 72.78%. *Curcuma longa* caused 75.56% repellence[63]. *Azadirachta indica, Curcuma longa* and *Mentha longifolia* showed mortality, adult emergence, grain damage prevention against *S. oryzae* in unhusked and husked rice. The highest mortality rate was recorded in turmeric powder at 93.3% followed by neem at 80% [64]. *Ocimum basilicum, Nigella sativa* and *Lavandula angustifolia* essential oils showed repellent and toxicity effects against *Sitophilus oryzae*. *O. basilicum and L. angustifolia* essential oils explicated 100% mortality at 6 mg/cm^2 after 48 hours exposure[65]. *Eucalyptus camaldulensis* and *Eucalyptus viminalis* leaf essential oils showed promising fumigant toxicity against *S. oryzae*, which was positively dependent on concentrations and exposure times. *E. viminalis* essential oil, which was found to be rich in monoterpenes was more toxic to insect[66]. In another study, leaf powder of *Ageratum conyzoides* was the most effective treatment against the weevil with highest mortality (96.67%), lowest population increase (18.33), the least grain damage (12.61%) and weight loss (1.75%), followed by *Melia azedarach, Vitex negundo* and *Ocimum sanctum*[67].

Jayakumar *et al*. reported the toxicity and repellent effects of wintergreen, rosemary, lemon, lavender, geranium, eucalyptus, citronella, aniseed, camphor and vetiver extracts against *S. oryzae*[68]. In another study, powders of *Annona squamosal, Justicia adhatda, A. indica, Carica papaya* and *Ocimum tenuiflorum* showed insecticidal effects against *S. oryzae* [69]. *Farsetia aegyptia* (gerba), *Mentha pulegium* (Egyptian mint) and *Moltkiopsis ciliate* (halama) extracts showed repellent and toxicity effects against the weevil[70]. *Melia azadarach, Perthenium hysterophorus, Phlogocanthus thyrsiflorus, Vitex trifolia, Zanthoxylum acanthopodium* and *Azadirachta indica* exhibited mortality, growth inhibition and grain damage reduction effect against the insect on rice grain[71]. *Melia azadarach* had the highest mortality rate (80.54%) at 35 days after treatment, followed by *Z. acanthopodium, A. indica* (70.74%), *P. hysterophorus* and *P. thyrsiflorus* (56.11) and *Vitex trifolia* (36.66%). A. *indica* was the most effective in prohibiting the adult emergence and reduction in grain damage[71]. In another study, *Psidium guajava, Citrus reticulata, Citrus limon, Citrus sinensus* and *Azadirachta indica* extracts showed repellent affects against the weevil. *Psidium guajava* was most effective while *A. indica w*as the least effective. *C. reticulata, C. limon* and *C. sinensus* showed moderate repellent effect[72]. *Curcuma longa* rhizome, *Dennettia tripetala* fruits, *Piper guineense* seed and *Zingiber officinale* rhizome extracts increased adult mortality and suppressed the adult emergence of the rice weevils. *P. guineense* and *D. tripetala* gave the highest mean mortality of 18.8 and 16.5 respectively at 35 days after treatment[73]. Khani *et al.* reported the insecticidal activity of *Piper nigrum* and *Jatropha curcas* extracts. Petroleum ether and chloroform extracts of *P. nigrum* recorded LC_{50} values of 1.61 and 1.70 µl/g respectively while petroleum ether extract of *J. curcas* had LC_{50} value of 6.82 µl/g [74]. *Hyptis suaveolens, Mentha cordifolia* and *Citrus hystrix* showed repellency, mortality, grains weight loss protection and growth inhibition effects[75]. *Clerodendrum inerme, Withania somnifera, Gliricidia sepia, Cassia tora* and *Eupatorium odoratum* extracts showed mortality and progeny production efficacy against rice weevil. *C. inerme* and *W. somnifera* extracts were more effective than *G. sepia, C. tora* and *E. doratum* against adult insects[76].

Govindan and Jeyarajan[77] reported mortality, adult emergence and grain damage protection efficacy of twenty plant powders. Five days after treatment, the highest mortality was observed in *V. negundo* followed by *A. officinarum, N. speciosum, C. longa* and *A. indica*. The lowest grain weight loss was recorded in *A. indica* at 8.55% at 90th day after treatment[77]. Mohamed and Abdelgaleil[78] reported toxicity efficacy of essential oils from Egyptian plants namely *Achillea santolina, Artemisia judaica, Citrus reticulata, Schinus terebenthifolius, Mentha microphylla, Lantana camara, Majorana hortensis and Eucalyptus camaldulensis*. Essential oils of *Mentha microphylla* and *Artemisia judaica* were the most potent in contact toxicity assay. Essential oil of *M. microphylla* displayed the strongest insecticidal activity against *S. oryzae in* the fumigant assay[78]. Viglianco *et al*. reported the repellency and anti-feeding effects of *Aloysia polystachia, Solanum argentinum* and *Tillandsia recurvata*. Hexane extract of *S. argentinum* had the strongest repellent effects while ethanol and chloroform extracts of all plants recorded moderate repellency[79]. *Melia azdarach, Myrtus communis, Mentha longifolia, Pegnum harmala* and *Cymbopogon citrates* had insecticidal properties against rice weevil[80]. *Melia azadarach* drupes which was the most effective had 61.2 % mortality, followed by *Myrtus communis* (48.40%), *Mentha*

longifolia (47.40%), *Melia azadarach* leaves (46.80%), *Cymbopogon citratus (*35.20%) and *Pegnum harmala* (16.80%) [80]. Lee *et al*.[81] reported the fumigant toxicity effects of essential oi1s extracted from sixteen Korean spices and medicinal plants was reported and the essential oil from *Mentha arvensis* was found to be the most effective. GC−MS analysis of essential oil from *M. arvensis* showed it to be rich in menthol and menthone followed by β-pinene, α-pinene and linalool. Menthone demonstrated the highest insecticidal activity followed by linalool[81].

Table 1: Some plant extracts with insecticidal effects on *Sitophilus oryzae*

Family	Plant	Common name	Activity	Ref
Acanthaceae	*Adhatoda vasica*	Adulsa	Adult emergence, weight loss and seed damage, toxicity, repellent	62, 82
Acanthaceae	*Justicia adhatda*	Malabar nut	Toxicity, adult emergence, grain damage prevention	68
Acanthaceae	*Phlogacanthus thyrsiflorus*	Lalbasak	Toxicity, adult emergence, grain damage prevention	71
Acoraceae	*Acorus calamus*	Sweet flag	Mortality, weight loss, grain damage protection, growth inhibition	60, 83 62, 61
Amaryllidaceae	*Allium sativum*	Garlic	Mortality, adult emergence, grain damage prevention	60
Anacardiaceae	*Hazomalania voyronii*	Hazomalany	Toxicity, adult emergence,	53
Anacardiaceae	*Rhus typhina*	Staghorn sumac	Toxicity	84
Anacardiaceae	*Schinus molle*	Pink peppercorns	Toxicity, prevention of weight loss, damage, and adult emergence	50
Anacardiaceae	*Schinus terebinthifolia*	Rose pepper	Toxicity	78
Annonaceae	*Annona muricata*	Prickly Custard apple	Mortality	85
Annonaceae	*Annona squamosal*	Custard apple	Mortality, adult emergence, grain damage prevention	68
Annonaceae	*Dennettia tripetala*	Pepperfruit	Toxicity, anti-progeny	73
Apiaceae	*Ammi majus*	Khella	Mortality, adult emergence, grain damage prevention	86
Apiaceae	*Carum carvi*	Caraway	Repellent, mortality	59
Apocynaceae	*Calotropis gigentae*	Giant milkweed	Mortality, adult emergence, weight loss, seed damage	51,62
Apocynaceae	*Catharanthus roseus*	Bright eyes	Toxicity, repellent	82
Araliaceae	*Pimpinella bursa-pastoris*	Shepherd's purse	Toxicity	81
Asparagaceae	*Asparagus racemosus.*	Shatawari	Mortality, adult emergence, grain damage prevention	77
Asparagaceae	*Liriope muscari*	Lily turf	Toxicity	81
Asteraceae	*Achillea santolina*	Santolina Yarrow	Mortality	78
Asteraceae	*Ageratum conyzoides*	Goat weed	Mortality, grain damage protection, growth inhibition	67
Asteraceae	*Artemisia judaica*	Wormwood	Mortality	78
Asteraceae	*Artemisia princeps*	Worm wood	Mortality	81
Asteraceae	*Carlina acaulis*	Carline thistle	Mortality, adult emergence,	53
Asteraceae	*Chrysanthemum coronarium*	Chrysanthemum	Mortality	81
Asteraceae	*Chrysanthemum zawdskii*		Mortality	81
Asteraceae	*Eupatorium adenophorum*	Crofton weed	Toxicity, grain damage protection, growth inhibition	67
Asteraceae	*Eupatorium odoratum*	Fragrant Boneset	Toxicity and progeny production	76
Asteraceae	*Matricaria chamomilla*	Chamomile	Toxicity	87
Asteraceae	*Parthenium hysterophorus*	Santa-Maria	Toxicity, adult emergence, grain damage prevention	52, 71
Asteraceae	*Solidago canadensis*	Canada goldenrod	Toxicity	84
Asteraceae	*Solidago gigantea*	Giant goldenrod	Toxicity	84
Asteraceae	*Tagetes erecta*	Marigold	Toxicity and repellent	63
Asteraceae	*Tanacetum parthenium*	Feverfew	Toxicity, *repellent*	55
Asteraceae	*Taraxacum platycarpum*	Dandelion	Toxicity	81
Boraginaceae	*Moltkiopsis ciliate*	Stone seed	Repellent, toxicity	70
Brassicaceae	*Farsetia aegyptia*	Gerba	Repellent, Toxicity	70
Bromeliaceae	*Tillandsia recurvata*	Hanging moss	Repellency and antifeedant	79
Cannabaceae	*Cannabis sative*	Cannabis	Mortality	52
Caprifoliaceae	*Lonicera japonica*	Honeysuckle	Mortality	81
Caricaceae	*Carica papaya*	Papaya	Mortality, adult emergence, grain damage prevention	51, 68

Cupressaceae	*Cupressus sempervirens*	Pencil pine	Toxicity	[88]
Euphorbiaceae	*Jatropha curcas*	Physic nut	Toxicity, antifeedant, progeny reduction	[74]
Euphorbiaceae	*Macaranga postulata*	Melgota	Repellent, toxicity	[89]
Euphorbiaceae	*Ricinis communis*	Castor	Toxicity, repellent	[51, 63]
Fabaceae	*Amorpha fruticosa*	Indigo-bush	mortality	[84]
Fabaceae	*Cassia angustifolia*	Senna	Mortality, adult emergence, grain damage prevention	[77]
Fabaceae	*Cassia tora*		mortality and progeny production	[76]
Fabaceae	*Cesalpinia sappan*	Sappan	Mortality, antifeedant	[90]
Fabaceae	*Garcinia atroviridis*	Asam	Repellent, antifeedant, anti-progeny	[56]
Fabaceae	*Gliciridia sepium*	Gliricidia	Toxicity and growth inhibition	[51, 76]
Fabaceae	*Pueraria thunbergiana*	Arrowroot	Mortality	[81]
Fabaceae	*Senna alata*	Candlesticks	Toxicity	[85]
Fabaceae	*Sesbania grandiflora*	Hummingbird	Toxicity, adult emergence, grain damage prevention	[77]
Labiatae	*Mentha arvensis*	Corn mint	Repellent	[57]
Labiatae	*Mentha arvensis*		Toxicity	[81]
Labiatae	*Mentha citrate*	Bergamot mint	Repellent	[57]
Labiatae	*Mentha cordifolia*	Kitchen mint	repellency, Toxicity, grain weight loss protection and growth inhibition	[75]
Labiatae	*Mentha longifolia*	Mint	Toxicity, repellent, grain damage protection, growth inhibition	[53,64, 67, 80]
Labiatae	*Mentha microphylla*	Spearmint	Toxicity, adult emergence, grain damage prevention	[86, 78]
Labiatae	*Mentha piperita*	Peppermint	Toxicity *and repellency*	[55, 57, 91]
Labiatae	*Mentha pulegium*	Egyptian mint	Repellent, Toxicity	[70]
Labiatae	*Mentha spicata*	Spearmint	Repellent, toxicity	[57, 63, 91]
Lamiaceae	*Anisomales malabarica*	Malabar catmint	Mortality, adult emergence, grain damage prevention	[77]
Lamiaceae	*Leucas aspera Spreng*		Toxicity, adult emergence, grain damage prevention	[77]
Lamiaceae	*Ocimum basilicum*	Basil	Toxicity, repellent, grain damage protection, growth inhibition	[65, 67]
Lamiaceae	*Ocimum canum*	Wild Basil	Toxicity, adult emergence, grain damage prevention	[77]
Lamiaceae	*Ocimum sanctum*	Holy Basil	Toxicity, grain damage protection, growth inhibition, repellent	[63, 67]
Lamiaceae	*Ocimum tenuiflorum*	Sacred Basil	Toxicity, adult emergence, grain damage prevention	[68]
Lamiaceae	*Clerodendrum inerme*	Garden quinine	mortality and progeny production	[76]
Lamiaceae	*Clerodendrum multiflorum*	Headache tree	Mortality, grain damage, oviposition, growth inhibition	[92]
Lamiaceae	*Clerodendrum viscosum*	Glory tree	Toxicity, grain damage, oviposition, growth inhibition	[92]
Lamiaceae	*Hyptis suaveolens*	Mint weed	repellency, Toxicity, grain weight loss protection and growth inhibition	[75]
Lamiaceae	*Lavandula angustifolia*	Lavender	Toxicity, repellent	[65]
Lamiaceae	*Leonurus sibiricus*	Honey weed	Toxicity	[81]
Lamiaceae	*Majorana hortensis*	Sweet marjoram	Mortality	[78]
Lamiaceae	*Origanum majorana*	Marjoram	Toxicity	[87]
Lamiaceae	*Perilla frutescens*	Beefsteak	Mortality	[81]
Lamiaceae	*Rosmarinus officinalis*	Rosemary	Toxicity	[46]
Lamiaceae	*Salvia officinalis*	Common sage	Toxicity, repellency	[55]
Lamiaceae	*Thymus vulgaris*	Thyme	Toxicity, prevention of weight loss, damage, and adult emergence	[50, 87]
Lamiaceae	*Vitex negundo*	Horseshoe vitex	Toxicity, repellency, grain damage, oviposition, growth inhibition	[62, 63 67, 77, 82, 92]
Lamiaceae	*Vitex trifolia*	Chastetree	Toxicity, adult emergence, grain damage prevention	[71]
Leganiaceae	*Strychnuos nuxvomica*	Strychnine tree	Toxicity, adult emergence, grain damage prevention	[77]
Liliaceae	*Glorisa superpa*	Climbing lily	Toxicity, adult emergence, grain damage prevention	[77]
Lythraceae	*Punica granatum*	Pomegranate	Toxicity	[87]
Malvaceae	*Abutilon indicum*	Monkey Bush	Mortality, adult emergence, grain damage	[77]

			prevention	
Meliaceae	*Azadirachta indica*	Neem	*Mortality*, repellent, , growth inhibition, *grain damage protection*	49, 58, 60, 64, 67, 68, 71, 72, 77, 83
Meliaceae	*Melia azedarach*	Azedarach	Toxicity, repellent, prevention of weight loss, damage, and adult emergence	50, 67, 71, 80
Moringaceae	*Moringa oleifera*	Moringa	Mortality	85
Myrtaceae	*Eucalyptus camaldulensis*	Red gum	Fumigant toxicity	66, 78
Myrtaceae	*Eucalyptus citriodora*	Lemon Gum	Toxicity, grain damage protection, growth inhibition	67
Myrtaceae	*Eucalyptus globulus*	Blue gum	Toxicity and repellent	63
Myrtaceae	*Eucalyptus viminalis*	White gum	Fumigant toxicity	66
Myrtaceae	*Myrtus communis*	Habulas	Repellent and toxicity	80
Myrtaceae	*Psidium guajava*	Guava	Repellent	72
Myrtaceae	*Syzygium aromaticum*	Clove	Toxicity, grain damage prevention, repellent	49, 87, 93
Pandanaceae	*Pandanus amaryllifolius*	Pandan	Repellent, antifeedant, anti-progeny	56
Piperaceae	*Piper guineense*	Cubeb pepper	Toxicity, anti-progeny	73
Piperaceae	*Piper nigrum*	Black pepper	Toxicity, grain damage protection, antifeedant, growth inhibition	58, 74, 83
Poaceae	*Cymbopogon citrates*	Lemon grass	Toxicity, repellent	87, 80
Polygonaceae	*Fallopia japonica*	Japanese knotweed	Toxicity	84
Polygonaceae	*Fallopia x bohemica*	Bohemian knotweed	Toxicity	84
Ranunculaceae	*Nigella sativa*	Black seeds	Toxicity, repellent	65
Rutaceae	*Citrus aurantium*	Orange	Toxicity	87
Rutaceae	*Citrus aurantium*	Sour orange	Toxicity and repellent	63
Rutaceae	*Citrus hystrix*	Kaffir lime	repellency, mortality, grain weight loss protection and growth inhibition	75
Rutaceae	*Citrus limon*	Lemon	Toxicity, repellent	72, 87
Rutaceae	*Citrus reticulata*	Mandarine	Repellent, mortality	72, 78
Rutaceae	*Citrus sinensus*	Sweet orange	Repellent	72
Rutaceae	*Murraya koenigii*	Curry tree	Toxicity, repellent, grain damage protection, growth inhibition	63, 67
Rutaceae	*Zanthoxylum acanthopodium*	Sichuan pepper	Toxicity, adult emergence, grain damage prevention	71
Rutaceae	*Zanthoxylum armatum*	Prickly ash	Toxicity, adult emergence, grain damage prevention	60
Sapindaceae	*Cardiospermum halicacabum*	Balloon vine	Mortality, adult emergence, grain damage prevention	77
Sapindaceae	*Dodonaea visicosa*	Hop bush	Toxicity	52
Simaroubaceae	*Ailanthus altissima*	Tree of heaven	mortality	84
Simmondsiaceae	*Simmondsia chinensis*	Goat nut	Toxicity	46
Solanaceae	*Nicotiana tabacum*	Tobacco	Toxicity, grain damage prevention, repellent, growth inhibition	49, 60
Solanaceae	*Solanum argentinum*		Repellency and antifeedant	79
Solanaceae	*Withania somnifera*	Winter cherry	Toxicity, grain damage, oviposition, growth inhibition	92, 77, 76
Sterculiaceae	*Helicteres isora*		Toxicity, adult emergence, grain damage prevention	77
Verbenaceae	*Aloysia polystachia*	Bee brush	Repellency, antifeedant	79
Verbenaceae	*Lantana camara*	Big sage	Toxicity, repellent, adult emergence, grain damage prevention	51, 63, 77, 78, 82
Verbenaceae	*Lippia nodiflora*	Frog fruit	Toxicity, adult emergence, grain damage prevention	77
Verbenaceae	*Nelumbium speciosum*	Lotus	Mortality, adult emergence, grain damage prevention	77
Zingiberaceae	*Alpinia officinarum*	Galangal	Mortality, adult emergence, grain damage prevention	77
Zingiberaceae	*Amomum cardamomum*	Cardamom	Antifeedant	94
Zingiberaceae	*Curcuma longa*	Turmeric	Toxicity and repellent, grain damage protection, growth inhibition	63, 64, 73, 77, 83
Zingiberaceae	*Zingiber officinale*	Ginger	Toxicity, grain damage prevention, repellent, growth inhibition	49, 60, 73, 77, 83
Zingiberaceae	*Zingiber zerumbet*	Sour ginger	Antifeedant	94
Zygophyllaceae	*Pegnum harmala*	Harmal	Repellent and toxicity	80

III. Pure Compounds With Insecticidal Effects On Sitophilus Oryzae

Some pure compounds isolated from plants have shown insecticidal effects on rice weevil are shown in Figure 2. Bioassay guided fractionation of methanolic leaf extract of *Gliricidia sepium* lead to isolation of 4-c-methyl-myo-inositol (**1**) as the toxic compound against rice weevil [51]. α-Cedrol **(2)**, δ-3-carene (**3**) and α-pinene (**4**) isolated from the essential oil of *Cupressus sempervirens* were found to be toxic to rice weevil[88]. After 4 days of exposing weevils to 20 µL/L air, α-cedrol **(2)** caused 100% adult mortality while after 7 days of exposing the insects to 40 µL/L air (%), mortality was found to be 100, 84.3 and 77.5% for α-cedrol (**2**), α-pinene (**4**) and δ-3-carene (**3**) [88]. In another study, terpinolene (**5**), carvacrol (**6**), carene (**3**) and pulegone (**7**) were exhibited insecticidal activity against rice weevil[95]. In another study, 1, 8-cineole (**8**) showed fumigant toxicity effect against the adults of *S. oryzae*[96].

Kłyś *et al*. [59] reported the repellent and mortality effects of L-carvone (**9**) on *S. oryzae*. At a concentration of 0.1%, L-carvone caused 16–100% repellence against the weevils [59]. In a study by Tripathi *et al*, d-limonene **(10)** was investigated for contact and fumigant toxicity, oviposition-deterrent, development inhibition and antifeedant activities against the lesser grain borer, rice weevil, and red flour beetle [97]. A flour disc bioassay indicated 87.7 to 96.8% feeding-deterrence effect by d-limonene (**10**) toward all three insect species tested at 60 mg/g food concentration[97]. Two compounds: 2-methoxy-4-(2-propenyl)-phenol **(11)** and *trans*-caryophyllene **(12)** which were isolated from *Syzygium aromaticum* (clove oil) showed insecticidal activity against rice weevil. The mortality effect from 2-methoxy-4-(2-propenyl)-phenol (**11**) was not significantly different from clove oil but it was more repellant than clove oil. On the other hand, *trans*-caryophyllene (**12**) was less toxic and less repellant than both clove oil and 2-methoxy-4-(2-propenyl)-phenol (**11**)[93].

In a study by Lee *et al*. limonene (**10**), linalool (**13**), menthol **(14),** menthone (**15),** *α*-pinene (**4**) and *β*-pinene (**16**) which were isolated from *M. arv*ensis were evaluated for their insecticidal activity against rice weevil. Menthone (**15**) was found to be the most toxic (LC_{50} = 12.7 µl/litre air) followed by linalool **(13)** (LC_{50} = 39.2 µl/litre air), α-pinene (**4**) (LC_{50} = 54.9 µl/litre air) and *β*-pinene (**16**) (LC_{50} = 78.9 µl/litre air) [81]. Aggarwal *et al*. [98] reported the insecticidal compound in *Mentha piperita* extract to be menthol (**14**). The compound showed a repellency effect of 82-100% against *S. oryzae* at 0.353 µg/cm² concentration [98].

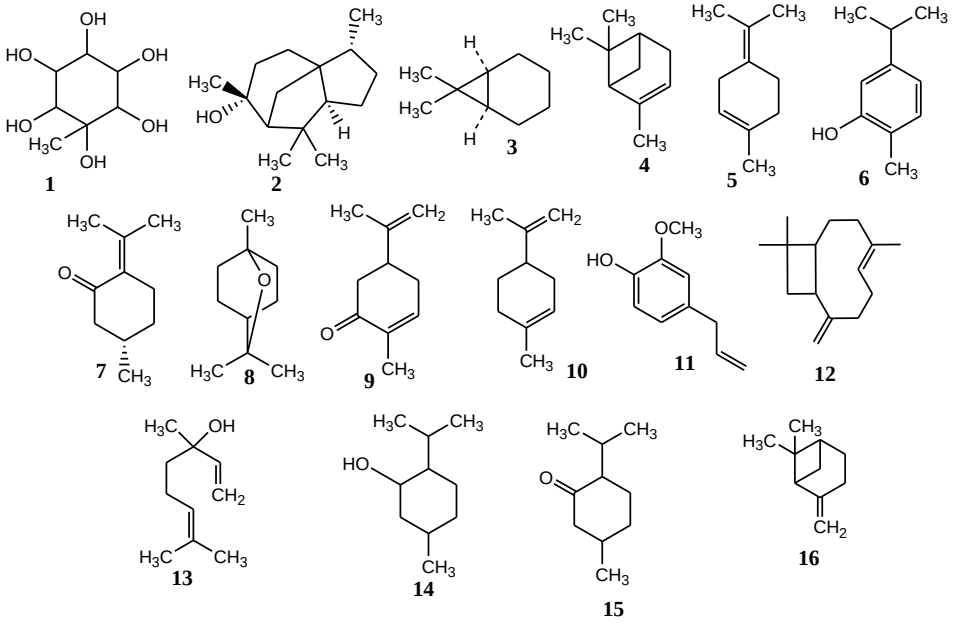

Figure 2. Insecticidal compound against rice weevil

IV. Conclusion

The study's findings indicate that certain plant extracts are highly poisonous, repellant, antifeedant, and have the ability to suppress growth and oviposition in *Sitophilus oryzae* (L.). These extracts may offer an alternate method of preventing weevil damage to stored crops. Numerous plant extracts have been investigated for their potential to repel the rice weevil. However, very little is known about plant-derived insecticidal chemicals. It is strongly recommended to conduct further studies to find such insecticidal ingredients and formulations.

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