

CRC REVIVALS

Glossary of Plant-Derived Insect Deterrents

Martin Jacobson

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U.S. Department of Agriculture (Retired)
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THE AUTHOR

Martin Jacobson received his B.S. degree in chemistry from the City University of New York in 1940. He accepted an offer as a chemist with the Industrial Hygiene Division of the National Institutes of Health in Bethesda, Maryland. In 1942 he transferred to the Bureau of Entomology and Plant Quarantine of the U.S. Department of Agriculture's Agricultural Research Center, Beltsville, Maryland, as a research chemist to isolate, identify, and synthesize phytochemical pesticides, insect hormones, and insect sex pheromones. During this period, he pursued evening graduate studies in chemistry and microbiology at George Washington University, Washington, D.C. He also served as a part-time Research Associate in Chemistry at that university during the period 1944 to 1948.

From 1964 to 1972, Mr. Jacobson was an Investigations Leader with the Entomology Research Division at Beltsville, Chief of the Biologically Active Natural Products Laboratory from 1973 to 1985, and Research Leader (Plant Investigations) with the Insect Chemical Ecology Laboratory until his retirement from Federal Service in 1986. He is currently an agricultural consultant in private practice in Silver Spring, Maryland.

During his long career with the USDA, Mr. Jacobson spent several weeks in 1971 as a Visiting Scientist teaching a graduate course on insect pheromones and hormones in the Department of Chemistry, University of Idaho, Moscow, Idaho. He was invited to speak at and to organize numerous symposia at national and international scientific meetings in the United States, Europe, Asia, and Africa, in the field of pesticides and sex pheromones occurring naturally in plants and insects, respectively. His awards include the Hillebrand Prize of the Chemical Society of Washington in 1971, USDA Certificates of Merit and cash awards for research in 1965, 1967, and 1968, the McGregory Lecture Award in Chemistry at Colgate University (Syracuse, New York), two bronze medals for excellence in research at the 3rd International Congress of Pesticide Chemistry, Helsinki, Finland in 1974, USDA Director's Award on Natural Products research in 1981, and an Inventor's Incentive Award for commercialization of a boll weevil deterrent in 1983.

Mr. Jacobson has been a member of the American Chemical Society, Entomological Society of America, Chemical Society of Washington, Pesticide Science Society of Washington, American Association for the Advancement of Science, New York Academy of Sciences, and a Fellow of the Washington Academy of Sciences. He is the author or coauthor of more than 300 scientific reports in numerous journals, the author of four books (*Insect Sex Attractants*, Wiley, 1965; *Insect Sex Pheromones*, Academic Press, 1972; *Insecticides From Plants. A Review of the Literature, 1941-1953*, USDA Handbook 154, 1958; *Insecticides From Plants/A Review of the Literature, 1954-1971*, USDA Handbook 461, 1975), and editor of the book *Naturally Occurring Insecticides*, Marcel Dekker, 1971. He also holds six U.S. Patents on naturally occurring insecticides.

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To my daughter, Barbara, with love.

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I. Introduction



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I. INTRODUCTION

Crop damage and loss due to feeding by insect larvae and adults is estimated to total billions of dollars each year in the U.S. alone, with comparable losses in many other developed countries. The loss is even more staggering in the developing countries, mainly in Asia and Africa. Many of the synthetic insecticides previously used for insect control have been banned or their use seriously curtailed because of concern about health and environmental effects.

There is ample evidence to show that the plant kingdom is a vast storehouse of chemical substances manufactured and used by these plants for defense from attack by insects, bacteria, and viruses. A wealth of literature has accumulated in reports,¹⁻⁴ scientific journals,⁵⁻²⁰ and books,²¹⁻²³ especially during the past 20 years on the subject of naturally occurring insect feeding deterrents and growth inhibitors. However, feeding by pests and other destructive insects is not limited to crop feeders. Considerable destruction of homes and household items is caused by feeding by such pest insects as termites, cockroaches, ants, and carpet beetles. A large group of blood-feeding insects, including mosquitoes, fleas, bedbugs, ticks, and biting flies cause much discomfort, and bites and stings by wasps, hornets, and enraged bees can make life unpleasant for both man and animals. Plant-derived deterrents to feeding by all of these insect species will be covered in this book, which is expected to serve a very useful purpose in view of the fact that the heretofore published information is completely scattered through the scientific literature. Review articles such as those by Beck,⁵ Rosenthal,¹⁹ Painter,²¹ McIndoo,²⁴ Heal et al.,²⁵ and Jacobson^{26,27} treat the older literature satisfactorily, but coverage of the more recent research is rather fragmentary.^{28,29}

The mechanism by which insects detect feeding deterrents is chemosensory in nature, involving impingement of odor molecules from the plants upon special deterrent receptors usually found on the insect antennae.^{5,15,30} The deterrent may be effective from a long distance, so that the insect will not immediately land on the plant, or from only a few inches. Alternatively, the insect may land on the plant but will not feed, or the insect may bite into the plant but refuse to feed further.³¹⁻³³ There is, however, another mechanism of insect olfaction involving bright coloration or color designs in or on the plant leaves serving to ward off insect attack (or in some cases attract).

This handbook brings together in one place sources which entomologists, chemists, botanists, insect ecologists, physiologists, and pharmacologists may consult for information to supplement that reported herein on the subject of plant-derived feeding deterrents. Almost 1500 plant species from 175 families are treated. It is my intention to report not only those plants found to be effective as feeding deterrents, but also which were tested and found to be ineffective. In addition, results of toxicity, repellency, sterility, or growth disruption are reported for those plants found to be effective as deterrents, as well as the identities, where known, of those chemical compounds identified as being responsible for the activity.

As the reader will see, there is a considerable amount of research that has been done

in this field, as well as follow-up research that is still in progress. A number of the plant species show promise for practical use as insect control agents. However, one must avoid becoming complacent about these insect feeding deterrents. Professor Metcalf and his students³⁴ at the University of Illinois, reporting on their research with the cucurbitacins, have shown that these intensely bitter compounds occurring in plants of the family Cucurbitaceae (squash, melon) that arose to repel herbivores and protect the plants from attack have become specific kairomone *feeding stimulants* for the destructive cucumber beetles of the genus *Diabrotica*. A striking example of counteradaptation by an insect to an insect feeding deterrent is that reported by Carroll and Hoffman³⁵ of the State University of New York at Stony Brook, The squash beetle, *Epilachna borealis* (Fabricius) biting into a squash leaf causes the plant to mobilize deterrent substances to the damaged region within 40 min. However, this wily beetle has learned to adapt to this situation by cutting a circular trench in the leaf before leisurely feeding on the encircled leaf material. Trenching behavior requires approximately 10 min. The beetle's strategy effectively prevents the mobilization of deterrent substances to the feeding area. Question: Who is more cunning, man or beast, in our struggle against harmful insects?

Payne³³ has presented a review of insect interactions with their host trees, Metcalf³⁶ has reviewed insect-plant co-evolution, and Dowd et al.³⁷ have reviewed the detoxification of plant toxins by insects. Duffy³⁸ has reviewed very well the sequestration of plant products by insects. Excellent discussions of the chemical aspects of deterrence are those by Grisebach and Ebel,³⁹ Meinwald et al.,⁹ Rembold and Winter,⁴⁰ and Picman.⁴¹

II. Methods for Antifeedent Bioassay



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II. METHODS FOR ANTIFEEDANT BIOASSAY

A. Crop Pests

In general, the test methods of choice or no-choice with vegetable and fruit insects involve incorporation of the plant extract or test compound(s) into the diet at definite concentration, exposure to the insect, and comparison of the percentage feeding over a period of time with the test material and with an untreated control. For field trials, the test materials are sprayed or dusted on the crop. Using various modifications of these methods, the occurrence of deterrence or acceptance was experimentally determined for *Spodoptera frugiperda*,⁴⁰ *S. littoralis*,^{41,42} *Oncopeltus fasciatus*,⁴⁰ *Ostrinia nubilalis*,⁴³ *Plutella xylostella*,⁴⁴ *Plathypena scabra*,⁴⁵ *Argyrotaenia velutinana*,⁴⁶ *Cydia pomonella*,⁴⁶ *Conotrachelus nenuphar*,⁴⁷ *Carpophilus hemipterus*,⁴⁷ *Amyelois transitella*,⁴⁸ *Acalymma vittatum*,⁴⁹⁻⁵¹ *Diabrotica undecimpunctata howardi*,⁵² and *Nilaparvata lugens*.⁵³

Using an electronic device, Saxena and Khan^{54,55} monitored the feeding behavior of *Nephotettix virescens* on rice plants sprayed with neem oil (*Melia azadirachta*) as compared with a control (plants sprayed with acetone alone).

Antonius et al.⁵⁶ were able to determine, by the use of electrophysiological responses, the primary sites of feeding deterrence on *Spodoptera litura* by various plant extracts. Electrophysiological and behavioral analyses were used by Dethier⁵⁷ to compare the gustatory sensitivity of *Danaus plexippus* and of *Manduca sexta* with that of *Phormia regina*. Similar methods were used by Norris⁵⁸ to measure the deterrence of *Scolytus multistriatus* by various plant-derived quinones.

Adler and Uebel⁵⁹ measured the feeding deterrence of a commercial preparation (Margosan-O) of neem seed kernels to adult *Dissosteira carolina*, *Diaperomera femorata*, and *Gryllus pennsylvanicus*. Application of the extract was made to pieces of corn leaves for *D. carolina* and to white oak leaf squares for *D. femorata* and *G. pennsylvanicus*.

B. Household Pests

Olfactory repellency of *Blattella germanica* by various plant essential oils was determined by a test tube method and beaker method.⁶⁰ Of 92 such substances, several mint oils were highly repellent to the roaches. Oils of lavender, citronella, rosemary, and spearmint, which are strong mosquito repellents, had little or no effect on the cockroach. The choice method of Goodhue and Tissol⁶² using glass dishes was employed to test for repellency to four species of cockroaches.⁶³

C. Blood-Feeding Pests

For several years, the Entomology and Plant Quarantine station of the U.S. Department of Agriculture at Gainesville, Florida used human subjects to test thousands of synthetic and natural substances as possible repellents for mosquitoes in the laboratory. These subjects, all of whom were staff members of the facility, smeared a bare arm with a solution of the test-substance and then inserted the treated arm through

a cloth sleeve into a wire screen cage containing several hundred adult mosquitoes. Rabbits, which later replaced the human subjects, were shaved on a patch of skin to which the test material was then applied. The effectiveness of the test materials was determined by the number of mosquito strikes made to the test site.⁶⁴

III. Biological Test Results



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III. BIOLOGICAL TEST RESULTS

The biological test results obtained with plant extracts or their components are given. The scientific and common names of the plant, in alphabetical order, are supplied within each plant family. The plant part used, test method utilized, and the test insects are discussed. For those plants shown to be effective the substance(s) responsible (of known) and their method of isolation are given, together with any available reported toxicity test results and pharmacological or toxicological properties reported for animal life.

A. Cryptogams

1. Algae

***Dictyota dichotoma* Lamour**, brown alga: Volatile components obtained by steam distillation of the fresh plants, impregnated on castor bean leaf disks at 1000 ppm, strongly deterred 4th instar larvae of *Spodoptera littoralis*.⁶⁵ The component responsible for this activity was identified as 1-(1,3,4,5,6,7-hexahydro-4-hydroxy-3,8-dimethyl-5-azulenyl)ethanone. The crude distillate possessed insecticidal activity against *Musca domestica* and *Sitophilus oryzae*.

***Sargassum tortile* C. A. Ag.**, brown alga: The insect growth inhibitor, crinitol (3,7,11,15-tetramethyl-2,6,10,14-hexadecatetraen-1,9-diol), isolated from a methanol extract of this alga inhibited the growth of *Pectinophora gossypiella* larvae after incorporation into the diet at 500 ppm.⁶⁶ It also completely inhibited the growth of *Escherichia coli* microorganisms.

2. Lichens

***Letharia vulpina* (L.) Rue**, wolf lichen, waino: Vulpinic acid and atranorin ($\alpha\beta$ -orcinoldep- side) isolated from this lichen inhibited feeding by larvae of *Spodoptera ornithogalli* exposed to broccoli leaf disks at <0.6 and <0.03%, respectively, in Petri dishes in the laboratory.⁶⁷

3. Fungi

***Lactarius rufus* Fr.**: Aqueous extracts of this

fungus contain lactorufin A, lactorufin B, isolactorufin, and a mixture of monohydroxy lactones.⁶⁸ Compound A and the mixture were strongly deterrent to feeding by adults of *Sitophilus granarius* and by larvae of *Tribolium confusum* and *Trogoderma granarium* in laboratory choice and nochoice tests. Lactorufin B was fairly deterrent and isolactorufin was only slightly deterrent.

***Plagiochila fruticosa* Schust.**, liverwort

***Plagiochila hattoriana* Blomquist**, liverwort

***Plagiochila ovalifolia* Mitt.**, liverwort

***Plagiochila yokogurensis* Inoue**, liverwort: Of four *ent*-seaquiterpene hemiacetals and two pungent methoxylagiochilines isolated from these liverworts,⁶⁹ only plagiogchiline A was very strongly deterrent to feeding by *Spodoptera exempta* at 1 to 10 ng/cm².⁷⁰

4. Ferns

***Pteridium aquilinum* (L.) Kuhn**, bracken fern, eagle fern: Fresh bracken and crude extracts thereof deterred feeding or settling of nine species of insects in no-choice laboratory bioassays.⁷¹ The insect species used were *Liocoris tripustulatus*, *Brachypterus glaber*, *Phyllobius pyri*, *P. argentatus*, *Pieris brassicae*, *Chilo partellus*, and *Schistocerca gregaria*. The resistance of these ferns was present all year but it was highest in May and June. The most active compounds isolated were several sesquiterpene pterosins, such as pterosin F.⁷²

B. Phanerogams

FAMILY ACANTHACEAE

***Justicia adhatoda* L.**, adhatoda, malabar nut tree: A mixture of 8 parts of the powdered leaves with 92 parts of gram seed exposed to adult *Callosobruchus chinensis* did not prevent feeding,⁷³ and 0.05 and 1% admixtures of the leaves with groundnut kernels was likewise ineffective against *Sitotroga cerealella* larvae.^{74,75} However, Chellapa and Chelliah⁷⁶ reported that 1% powdered leaves in rice was very effective against *S. cerealella* and fairly effective against *Rhyzoper-*

thadominica larvae. Five alkaloids (vasicine, vasicinol, deoxyvasicine, vasicinone, and deoxyvasicinone) isolated by Saxena et al.⁷⁷ from an ethanol extract of the leaves were tested at 0.05 and 0.1% in Petri dishes against *Acaulophora foveicollis* and *Epilachna vigintioctopunctata* beetles. All compounds were effective in reducing feeding, with deoxyvasicine the most effective against the former and vasicine most effective against the latter species. Vasicinol induced severe antifertility effects in *Dysdercus koenigii* and *Tribolium castaneum* when applied at 0.1 and 0.3%, respectively, to the insect's drinking water, due to blockage of oocytes in the oviduct. An ethanol extract of the powdered leaves applied as a 1% spray to filter papers on which adult *T. castaneum* were confined for 24 h killed 75% in 2 d and 100% in 4 d. The extract is said to be harmless to man.⁷⁸ The spray was not toxic to *Musca domestica* and to *Aedes aegypti* mosquitos.⁷⁹

***Justicia gendarussa* Burm. f.:** In India the natives scattered the leaves among their clothes to preserve them from insects.⁸⁰ A 5% aqueous extract of the leaves killed 100% of the larvae of *Spodoptera litura* and *Euproctis fraternata*. Powdered roots, leaves, and stems dusted upon *Callosobruchus chinensis* killed 75 to 80% in 5 d.⁸¹

***Justicia procumbens* Linnaeus:** A methanol extract of the leaves incorporated into an artificial diet was a moderate repellent for larvae of *Bombyx mori*. Those larvae that fed showed growth retardation over a 6-d period.⁸² Two active compounds were isolated from the extract and identified as justicidin A and B, which gave 100 and 90% mortality, respectively, of feeding 4th instars at 20 ppm.⁸³

FAMILY ACERACEAE

***Acer negundo* L.,** boxelder, ash-leaved maple
***Acer pennsylvanicum* L.,** striped maple:
 Aqueous extracts of the leaves of these species did not deter feeding by *Lymantria dispar* larvae.⁸⁴
***Acer platanoides* L.,** Norway maple

***Acer rudrum* L.,** red maple: Aqueous extracts of the leaves of these species deterred feeding by *Lymantria dispar* larvae,⁸⁵ but the wood failed to deter feeding by *Reticulitermes flavipes* termites and did not prevent attack by the brown-rot fungus, *Lenzites trabea*.⁸⁶ The wood was also susceptible to feeding by *Cryptotermes brevis* termites.⁸⁶ However, *Coptotermes formosanus* termites refused to feed on the wood in both force-feeding and choice-feeding tests.⁸⁷ Red maple was not infested during an outbreak of *Malacosoma disstria* in southern Louisiana.⁸⁸
***Acer saccharinum* L.,** sugar maple: The wood is susceptible to attack by *Coptotermes formosanus* termites.⁸⁷

FAMILY ADIANTACEAE

***Adiantum pedatum* L.:** A diet supplemented with the dried leaves deterred feeding by *Eurema hecabe mandarina* larvae.⁹⁰

FAMILY AIZOACEAE

***Dianthus cercidifolia* Maxim.:** Leaves of this plant were not accepted for feeding by larvae of *Spodoptera littoralis*.⁹¹

***Mesembryanthemum chilense* Nolina:** An ether extract of the combined stems, leaves, and flowers placed on cantaloupe leaves was highly deterrent to feeding by adult *Acalymma vittatum*.⁸⁹

FAMILY ALTINGIACEAE

***Liquidambar formosana* Hance:** An ether extract of the fruits placed on cantaloupe leaves was highly deterrent to feeding by adult *Acalymma vittatum*.⁸⁹

***Liquidambar styraciflua* L.,** sweetgum, redgum: The wood is susceptible to attack by *Coptotermes formosanus* termites.⁸⁷

FAMILY AMARANTHACEAE

***Achyranthes japonica* Nakai:** Leaves of this plant were normally accepted for feeding by larvae of *Spodoptera littoralis*.⁹¹
***Achyranthes caudatus* L.,** love-lies-bleeding:

An acetone solution containing 45 mg of the stem extract failed to deter feeding by *Leptinotarsa decemlineata* or *Mythimna unipuncta*.⁹²

FAMILY AMARYLLIDACEAE

***Agave americana* L.**, century plant: Wallpaper in India is impregnated with the expressed juice of this plant to protect it from white ants.⁹³ An infusion of the leaves is used as an insecticide in the Philippine Islands.⁹⁴ An aqueous extract of the leaves was toxic to *Periplaneta americana* when injected into the blood stream, but *Blattella germanica* and *Oncopeltus fasciatus* were not affected by immersion in the extract.²⁵

***Allium ampeloprasum* var. *porrum* (L.)** Regel, leek, elephant garlic: In Belgium, an infusion prepared by immersing small pieces of the plant in water for 1 week was said to repel flies (unidentified)⁹⁵ and *Delia antiqua*.⁹⁶

***Allium cepa* L.**, onion: Gram seeds (100 parts) mixed with 153 parts of a petroleum ether extract of onion did not repel *Callosobruchus chinensis*.⁷³

***Allium sativum* L.**, garlic: Gram seeds mixed with 1 to 3 parts of a petroleum ether extract of garlic repelled *Callosobruchus chinensis* for at least 135 d.⁷³ However, garlic bulbs stored with grain in closed containers did not protect the grain from attack by *Sitophilus oryzae*.⁹⁷ Exposure of *Epilachna varivestis* larvae to a methanol extract of garlic bulbs strongly deterred feeding and caused larval and pupal mortality. The adults that developed from exposed pupae showed deformed wings.⁹⁸ Garlic is attacked by *Delia antiqua*.⁹⁶ Many sources attest to the value of garlic for repelling and killing mosquitos. The odor of garlic stunned mosquitos in 5 to 10 min and killed them in 5 h.¹⁰⁰ Greenstock and Larrea¹⁰¹ reported that the essential oil distilled from garlic repelled not only mosquitos but also killed a large variety of crop pests in the field; this was played up in several newspapers^{102,103} and a journal.¹⁰⁴ Laboratory tests showed that 5% extracts of five

kinds of garlic quickly killed *Culex pipiens* larvae.^{105,106} Steam-distilled garlic oil and a crude methanol extract of garlic killed 3rd instar larvae of *Spodoptera litura* and 2nd and 4th instar larvae of *Euproctis* sp.¹⁰⁶ Crude garlic juice was highly potent as a contact toxicant. Crude extracts of garlic at 1.25, 2.5, and 5% concentrations in laboratory dishes killed *Syrphus carollae* plant lice and larval and pupal forms of *Chrysopa carnea* and *Coccinella septempunctata*.¹⁰⁷ Garlic oil was highly repellent to adult *Blattella germanica*.⁶¹ Application of an acetone extract of the whole garlic plant to the tergum of thoracic and abdominal segments of *Dysdercus cingulatus* larvae and *Spodoptera litura* larvae failed to cause malformations.¹⁰⁸ Larvae of *Pericallia ricini* allowed to feed on cabbage leaves smeared with the extract showed no effect. Applications of a petroleum ether extract of garlic rhizomes to abdominal tergites of 5th instar *D. cingulatus* resulted in death.¹⁰⁹ The mosquito larvicidal principles of garlic have been isolated and identified as diallyl disulfide and diallyl trisulfide, which are fatal to *Culex* mosquitos at 5 ppm.¹¹⁰

***Crinum asiaticum* L.**

***Crinum bulbospermum* Milne-Redhead**

***Hippeastrum hybridum* Herb.**

***Hymenocallis littoralis* Salisb.**

***Zephyranthes grandiflora* Lindl.**: Leaf pieces of each of these five plants offered to 24-h-old starved *Schistocerca gregaria* were not fed upon.^{111,112} Acetone extracts of *Z. grandiflora* leaf cell sap completely inhibited feeding by the locusts at 0.5%⁹⁹ Lycorine, an alkaloid isolated from the bulbs of *H. littoralis* (350 mg from 3 kg), sprayed on cabbage leaves inhibited feeding by the locusts.¹¹³ It is highly likely that lycorine or a closely related alkaloid is responsible for the activity of all five plant species.

***Hypoxis obtusa* Busch**: The rhizome is protected from mold and insect attack in East Africa. A new glycoside, designated "hypoxide", isolated from the rhizome may be responsible for this activity.¹¹⁴

***Lycoris radiata* Herb**: A diet supplemented with the dried leaves deterred feeding by larvae of *Eurema hecabe mandarina*.⁹⁰

FAMILY ANACARDIACEAE

Anacardium excelsum (Bert. & Balb.) Skiels, espave: The wood is resistant to termites.^{86,115}

An aqueous extract of the stem bark was slightly toxic to *Periplaneta americana* and *Oncopeltus fasciatus* but not to *Blattella germanica*.²⁵

Anacardium occidentale L., cashew, scajou: Cashew nut shell oil is used in India to preserve floors, timbers, and books from termite attack. The tree yields a gum that is useful in bookbinding because of its insect-repellent properties.^{80,116,117} Oil extracted from the husk of the nuts prevented termite attack on treated wood for only a short time, but a 1% solution of anacardic acid, obtained from the oil, prevented attack for more than 3 months.^{118,119}

An extract of the pericarp of the nuts gave complete protection against *Amphicerus cornutus* for 7 months when brushed on timber,¹²⁰ and laboratory tests demonstrated the toxicity of the nut oil to the stored product insects *Oryzaephilus surinamensis* and *Ahasverus advena*.¹²¹ A mixture of the shell oil and kerosene was tested in India against the mosquito *Armigeres obturbans*; it caused nearly 100% mortality of the larvae and pupae within 2 h.^{121,122} These effects are due to cardol and anacardic acid, both of which are present in the oil. An acetone extract of the stems applied topically to the last immature instar stage of *Dysdercus cingulatus* caused juvenomimetic activity.¹²³

Cotinus cocgyarta Scop., smoke tree: Fustic crystals obtained from this tree were not repellent to termites when tested at considerable dilution.¹¹⁸

Mangifera indica L., Indian mango: The powdered plant is used in India as a fumigant against mosquitos.¹¹⁶ Extracts of the leaves had no effect on feeding by *Bombyx mori* larvae.⁸² An ether extract of the fruit did not deter feeding by *Lymantria dispar* larvae.¹²⁴ The wood is susceptible to termite attack.¹²⁴ The gum resin, mixed with lime juice or oil, was used as a cure for scabies, and the powdered flowers were used for fumigating against mosquitos.¹²⁵

Metopium toxiferum (L.) Krug & Urban, poisonwood: An ether extract of all parts of the plant failed to deter feeding by *Lymantria dispar* larvae.⁸⁴ The wood is susceptible to termite attack.⁸⁶

Pistacia chinensis Bunge: An ether extract of all parts of the plant deterred feeding by *Lymantria dispar* larvae.⁸⁴

Rhus canadensis Marsh: Extracts of the whole plant did not repel *Popillia japonica* adults.¹²⁶

Rhus viminalis Vahl.: The wood is reputed to be indestructible and is not subject to insect attack.¹¹⁶

Schinopsis quebracho-colorado (Schlecht. Barkl. & T. Meyer), red quebracho: A susceptible wood treated with an extract of red quebracho wood remained susceptible to termite attack.¹¹⁸

Schinus molle L., California pepper tree

Tapirira guianensis Aubl.: Ether extracts of the stem bark of these two species were moderately deterrent to feeding by adult *Acalymma vittatum*.⁸⁹

FAMILY ANNONACEAE

Annona cherimola Mill., cherimoya: The seeds were reported to contain a poisonous substance, irritating to the eyes, that is used as an insecticide in West Africa to destroy human parasites.¹²¹

Annona muricata L., sour sop: The roots and leaves are said to be parasiticial and the seed to be insecticidal especially to *Pediculus humanus capitis*.¹¹⁶

Annona glabra L., pond-apple, alligator apple: An aqueous extract of the seeds deterred feeding by *Attagenus megatoma*.¹²⁵

Annona purpurea Moc. & Sesse: An ether extract of the twigs strongly deterred feeding by adult *Acalymma vittatum* at 0.5% and showed moderate deterency at 0.1%.⁸⁹

Annona reticulata L., custard apple: An aqueous extract of the seeds was deterrent and toxic to *Aphis fabae* and *Oryzaephilus surinamensis*.¹²⁷ A mixture of the leaves with sorghum millet and cowpeas gave complete protection from *Callosobruchus maculatus* for 3 months.^{129,130} The powdered seed was

toxic to *Spodoptera eridania* and *Acyrtosiphon pisum* but not to *Udea rubigalis*, *Oncopeltus fasciatus*, and *Tetranychus urticae*.¹²⁸ The plant is used in India on domestic animals and the seed is used in the Philippines to kill *Pediculus humanus capitis*.¹¹⁶

***Annona squamosa* L.**, custard apple, sweetsop: An ether extract of the seeds deterred feeding by *Oncopeltus fasciatus*.²⁵ The powdered seeds are used in the Philippines as an insecticide and against *Pediculus humanus capitis*.⁹⁴ Hexane extracts of the leaves and seeds strongly deterred feeding by *Nialparvata lugens*, *Nephotettix virescens*, *Dicladisopa armigera*,¹³¹ and *Callosobruchus chinensis*.¹³² Numerous species of insects have been reported to be susceptible to either the powdered seeds or an extract of these,²⁶ but an ether extract of the seeds was much less effective than DDT as a toxicant for *Tribolium castaneum*.¹³² Oil extracted from the seeds was highly effective in reducing the survival of *Nephotettix virescens*, and its transmission of the rice tungro virus.¹³³⁻¹³⁷ The oil has also been reported¹³⁸ to be used by farmers for protecting rice from leafhoppers and planthoppers.¹³⁹

***Annona* spp.** (Chemistry): Although the specific compounds responsible for the pesticidal effects of species of *Annona* have not been identified, a considerable number of compounds have recently been isolated and characterized which may prove to be implicated. These are described here. The 47 volatile flavor components of *A. atemoya* were all monoterpenes or sesquiterpenes, the most prolific being α -pinene, β -pinene, germacrene D, and bicyclogermacrene.¹⁴⁰ Bulatantriol, a sesquiterpene, was isolated from the leaves of *A. bullata* Rich.¹⁴¹ Annonacin, a polyketide with antimicrobial properties and cytotoxic to KB cells (mouse leukemia) in vitro, was isolated from the stem bark of *A. densicoma*.¹⁴² An alkaloid, annonelliptine, was isolated from the leaves and stems of *A. elliptica* R. E. Fries.¹⁴³ Annonaquinone A, isolated from the stem bark of *A. montana*,¹⁴⁴ is also cytotoxic (KB). Several kaurane dit-

erpenes were isolated from the stem bark of *A. reticulata*.¹⁴⁵ Three bis-indole alkaloids, annonidines A, C, and D were isolated from *Annidium mannii* Engl. & Diels, and synthesized.¹⁴⁶ Coniothalenol, a tetrahydrofurano-2-pyrone, was isolated from an ethanol extract of the stem bark of *Coniothalamus giganteus* Hook fil. & Thomas.¹⁴⁷

***Asimina triloba* (L.) Dunal**, pawpaw: Pawpaw trees planted to serve as a mosquito repellent were found to have no value for this purpose.¹⁴⁸

***Canangas odorata* (Lam.) Hook f. & Thoms.**, ylang-ylang: Ylang-ylang oil, whose chief constituent is geraniol, was moderately repellent to worker bees, *Apis florea*, at 0.0625% and strongly repellent at 0.3 to 0.5%.¹⁴⁹ Adult *Callosobruchus chinensis* kept for 48 h in a mixture of mung seed and the powdered roots, leaves, or pericarp of this plant showed little mortality, but mung mixed with caraway seeds caused significant mortality.¹⁵⁰

***Dennettia tripetala* G. Baker**: Oil obtained by steam distillation of the edible fruits conferred effective protection as a seed preservative for up to 14 weeks in laboratory tests.¹⁵¹ Topical application of the oil to nymphs and adults of *Periplancta americana* and to adult *Zonocerus variegatus* was highly toxic to these insects.¹⁵²

***Desmas elegans* (Thw.) Safford**: *Callosobruchus chinensis* kept for 48 h in contact with a powdered mixture of mung seed and *Desmas* roots or leaves showed no harmful effects.¹⁵⁰

***Eriosanthum acuminatus* (Thw.) Airy-Shaw**: *Callosobruchus chinensis* kept for 48 h in contact with a powdered mixture of the flowers or seeds of this plant showed little or no deterrence or harmful effects.¹⁵⁰

***Monodora tenuifolia* Benth.**: Larvae of *Acrea aponina* exposed to the dry fruits or the essential oil of the fruits were not deterred from feeding.¹⁵¹ Topical application of the oil to the larvae of this insect and to adults of *Dysdercus suturellus*, *Ootheca mutabilis*, and *Riptortus densipes* was not toxic to these insects.¹⁵²