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A REVIEW OF PLANT MATERIALS USED FOR CONTROLLING INSECT PESTS OF STORED PRODUCTS

Overseas Development Administration

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M. J. Dales

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Contents

CLASSIFICATION OF THE INSECTS INCLUDED IN THIS REVIEW

Species	Genus	Family	Order
A. obtectus	*Acanthoscelides*	Bruchidae	Coleoptera
C. analis *C. chinensis* *C. maculatus* *C. rhodesianus*	*Callosobruchus*	Bruchidae	Coleoptera
C. serratus	*Caryedon*	Bruchidae	Coleoptera
C. cephalonica	*Corcyra*	Pyralidae	Lepidoptera
D. maculatus	*Dermestes*	Dermestidae	Coleoptera
D. distinctus	*Dinoderus*	Bostrichidae	Coleoptera
E. cautella *E. kuehniella*	*Ephestia*	Pyralidae	Lepidoptera
L. serricorne	*Lasioderma*	Anobiidae	Coleoptera
O. surinamensis	*Oryzaephilus*	Silvanidae	Coleoptera
P. truncatus	*Prostephanus*	Bostrichidae	Coleoptera
R. dominica	*Rhyzopertha*	Bostrichidae	Coleoptera
S. granarius *S. oryzae* *S. zeamais*	*Sitophilus*	Curculionidae	Coleoptera
S. cerealella	*Sitotroga*	Gelechiidae	Lepidoptera
T. castaneum *T. confusum*	*Tribolium*	Tenebrionidae	Coleoptera
T. granarium	*Trogoderma*	Dermestidae	Coleoptera
Z. subfasciatus	*Zabrotes*	Bruchidae	Coleoptera

Summaries

SUMMARY

The use of plant materials for the protection of stored products against insect pests is reviewed. Following an outline of the different methods used for assessing their insecticidal activity, over 120 plants and plant products are listed alphabetically with a brief description of traditional uses (where appropriate), and a summary of the laboratory data currently available; where possible, information on constituents and toxicology is also included. Of these, only a few, all species in the genera *Azadirachta, Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper* and *Tetradenia*, have been sufficiently tested in the laboratory to give an indication of their potential usefulness as stored product protectants. The neem tree, *Azadirachta indica*, is considered in a separate section as it has been more extensively studied than the other plants; the traditional uses of neem, its constituents, effects, pests and diseases, toxicity, field trials and commercial applications are outlined, and results of laboratory trials are summarized. It is concluded that more rigorous testing is required if the considerable potential for botanical protectants is to be realized. Standardized assessments of residual effectiveness against all stages of the insect's life cycle need to be undertaken, and mammalian toxicity requires more detailed evaluation. More attention may need to be given to the characterization and quantification of chemical constituents, and to variations which may occur in different karyotypes. It may also be necessary to determine the availability of appropriate extraction and application technology if the use of plant protectants is to be assimilated in developing countries.

RÉSUMÉ

L'utilisation de matériel végétal pour protéger les produits entreposés contre les insectes ravageurs est examinée. Après une esquisse des différentes méthodes utilisées pour évaluer leur activité en tant qu'insecticide, plus de 120 plantes et produits végétaux sont énumérés par ordre alphabétique et accompagnés d'une brève description de leur utilisation traditionnelle (lorsqu'approprié) et d'un résumé des données de laboratoire actuellement disponibles. Là où cela est possible, une information sur les éléments constituants et sur la toxicologie est également incluse. Un petit nombre seulement de ces plantes, consistant toutes en espèces des genres *Azadirachta, Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper* et *Tetradenia*, a été suffisamment testé au laboratoire pour donner une indication de leur utilité potentielle en tant que protecteurs des produits entreposés. *Azadirachta indica* est examinée dans une section séparée car elle a été étudiée de façon plus approfondie que les autres plantes. Ses utilisations traditionnelles, ses éléments constituants, ses effets, ses ravageurs et maladies, sa toxicité, les essais en champ et les applications commerciales sont ébauchés et les résultats des tests en laboratoire sont résumés. On conclut que des tests plus rigoureux sont requis si le potentiel considérable des protecteurs botaniques doit être réalisé. Des évaluations normalisées de l'efficacité résiduelle contre tous les stades du cycle biologique d'un insecte doivent être effectuées et la toxicité pour les mammifères requière une évaluation plus détaillée. Une attention plus grande doit être accordée à la caractérisation et à la quantification des éléments constituants chimiques et aux variations qui peuvent se produire dans différents caryotypes. Il peut également s'avérer nécessaire de déterminer la disponibilité d'une technologie appropriée pour l'extraction et l'application si l'utilisation de végétaux protecteurs doit être assimilée dans les pays en développement.

RESUMEN

El artículo investiga el uso de materiales vegetales para la protección de productos almacenados contra las plagas de insectos. Tras la presentación de las líneas generales de los distintos métodos utilizados para evaluar su actividad insecticida, se presenta, por orden alfabético, una lista de más de 120 plantas y productos botánicos con una breve descripción de sus usos tradicionales (en casos apropiados), junto con un resumen de los datos de laboratorio actualmente disponibles. También se incluye, siempre que resulta posible, información relativa a los elementos constitutivos y toxicología de las plantas. De todas estas especies, solamente un número reducido (géneros *Azadirachta, Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper* y *Tetradenia*) han sido suficientemente analizadas en laboratorio para presentar cierta indicación sobre su utilidad

potencial para la protección de productos almacenados. En sección aparte se estudia el neem o maranggo (*Azadirachta indica*), dado que este árbol ha sido sometido a un estudio mucho más profundo que el de otras plantas. En dicha sección se analizan los usos tradicionales del neem, sus elementos constitutivos, efectos, plagas y enfermedades, toxicidad, pruebas sobre el terreno y aplicaciones comerciales, junto con un resumen de las pruebas de laboratorio. En conclusión, se sugiere la necesidad de pruebas más rigurosas para poder aprovechar su considerable potencial como protector botánico. También será necesario realizar evaluaciones normalizadas de la eficacia residual contra todas las etapas del ciclo vital de los insectos, así como un estudio más detallado de su toxicidad para los mamíferos. Tal vez deba prestarse mayor atención a la caracterización y cuantificación de los elementos químicos constitutivos y a las variaciones que puedan producirse en distintos cariotipos. De igual manera, puede que sea asimismo necesario determinar la disponibilidad de tecnología apropiada de extracción y aplicación, de manera que el uso de los protectores botánicos pueda ser asimilado en los países en desarrollo.

Section 1

Introduction

The use of plant materials for the protection of field crops and stored commodities against insect attack has a long history. Many of the plant species concerned have also been used in traditional medicine by local communities, and were collected in the field or cultivated specifically for this purpose. Leaves, roots, twigs and flowers have been mixed, with various commodities in different parts of the world (particularly in India, China and Africa) for use as protectants.

The wide-scale commercial use of plant extracts as insecticides began in the 1850s with the introduction of nicotine from *Nicotiana tabacum,* rotenone from *Lonchocarpus* sp., derris dust from *Derris elliptica* and pyrethrum from the flower heads of *Chrysanthemum cinerariaefolium.* The genera *Derris* and *Lonchocarpus,* which belong to the Fabaceae, were found to contain 3-20% of rotenone; they also contain rotenoids which possess insecticidal activity. The flower heads of *Chrysanthemum,* which belongs to the Asteraceae, contain six active compounds identified as pyrethrins I and II, cinerins I and II and jasmolins I and II.

Pyrethrum has been used extensively as a protectant for stored products in both temperate and tropical climates because it is effective against a wide variety of insect pests including moths and their larvae. It can be formulated as a dust and mixed with food commodities, but the extracts are only stable on grain if they are combined with a suitable anti-oxidant, such as piperonyl butoxide; the anti-oxidant also potentiates the efficacy of the extract (Snelson, 1987). The varieties grown in Kenya produce the highest yield of active ingredients, but pyrethrum is also grown in other countries including Iran, Japan and New Guinea. However, since the introduction of synthetic organochlorine and organophosphorus insecticides in the 1940s, the use of pyrethrum has declined, particularly because of its cost and its high instability when exposed to light.

Several other traditionally-used plant preparations, such as *Ryania* (Flacourtiaceae), which contains an insecticidal alkaloid, and *Haplophyton* spp. (Apocynaceae), which have been used in the West Indies and Mexico, have been marketed commercially. Nicotine, an alkaloid from some species of *Nicotiana* (Solanaceae), and the related compound anabasine from *Anabasis* spp., continue to be used against various insect pests even though they are highly toxic to mammals.

Constituents of many aromatic plants used for flavouring or for medicinal purposes have been found to possess insecticidal properties. During recent surveys of desert and semi-desert plants, a range of repellent or cytotoxic sesquiterpenes, benzopyrans, chromenes, and prenylated quinones were discovered (Bell *et al.,* 1990). Some plant families may accumulate a limited number of secondary metabolites with anti-insect properties, while others may possess a wide variety of compounds with different types of structure. Appendix 3 shows that the dominant insect repellents in terms of numbers are the alcohols, alkaloids and terpenes.

The renewed interest in plant materials as stored product protectants can be attributed to various factors including the development of resistance to synthetic insecticides, fears over their misuse and overuse (during application), and fears about the potential effect of insecticide residues on consumers, wildlife and the environment. In addition to these problems, the increased cost of insecticide development has led to a reduction in the number of new pesticides being evaluated by chemical companies for use in storage situations. The high cost of imported synthetic insecticides will probably lead to a decline in their use in developing countries, so the use of local plant materials for insect control would reduce the demand for hard currency and perhaps increase local employment as well.

In general, research workers have concentrated on the efficacy of locally-available plants for controlling insect pests. Research is being undertaken in many countries including India, Bangladesh, Pakistan, The Philippines, Japan, Rwanda, Nigeria, Ghana, Kenya, Egypt, Israel, the UK and the US. However, in most of the published work the information provided is insufficient to enable the use of plant materials to be recommended for pest control in practice; data on mammalian toxicity are also lacking.

In 1980, Golob and Webley produced a bibliography which summarized the traditional methods used by farmers throughout the world to protect stored products. They also collated published scientific research on the use of plant extracts. Grainge and Ahmed (1988) compiled a database of the 2400 plant species which had been reported to possess pest control properties. In 1993, Rees *et al.* produced a bibliographic database of 1100 references which cite alternative methods to conventional synthetic insecticides for the control of stored product insect pests; these methods include the use of plant materials, extracts and oils. The database formed the framework for this study, which continues the original bibliography by Golob and Webley (1980) and reviews publications between 1980 and 1993. Information is also included on the constituents isolated from the plant or oil. Details of mammalian toxicity are given for those plant species for which several references have been found.

The text is presented in six sections. In Section 2, the different methods used in the trials are outlined, and in Section 3 plants are listed alphabetically and reviewed. The merits of the different methods and considerations necessary for the potential use of plant materials are examined in Section 4. Information on neem, *Azadirachta indica,* which is considered separately because it has been most extensively studied, is collated in Section 5. In Section 6, the most promising materials for stored commodity protection are identified, and priorities for future research are outlined. The appendices include a list of toxins found in the plant material examined and an indication of their relative toxicity.

Section 2

Methods used to determine insecticidal action

Various methods have been used to determine the effectiveness of plant materials and their extracts, and most trials have been laboratory-based and of short duration. Examination methods can be classified into the following two types: direct mixture of a plant material with a commodity; and use of a plant-derived solvent extract or essential oil.

Both fresh and dried material have been evaluated, and although various parts of the plant have been assessed (rhizomes, roots, stems, bark, seeds, and fruits) most trials have used leaves. Fresh or dry powdered material may be added to a commodity, usually at a rate of 1 to 5% weight for weight (w/w), although higher concentrations, such as 18 g/100 g for citrus peel (Don-Pedro, 1985), have been used.

Extraction of a plant material depends on the solubility of the active components. Various solvents can be used, but the most common are chloroform, petroleum ether, hexane, methanol, ethanol and acetone. Unfortunately, few workers have reported isolation and identification of the active components of an extract, and the weight or yield resulting from a particular extraction technique is rarely given. Therefore, the concentration of the extract at its final application to the commodity is not known, although serial dilutions may often be used in insect bioassay. The essential and vegetable oils used in tests may either be extracted from the appropriate plant species in the laboratory, or they may be bought commercially. Vegetable oils are usually applied at 5-10 ml/kg of commodity, but higher values, in excess of 50 ml kg, have been reported (Don-Pedro, 1989b).

In trials using a plant material mixed with a commodity, parameters such as contact toxicity to adult insects, number of eggs laid, number of eggs that hatch, or the percentage of first filial (F1) adult emergence are usually assessed directly. Indirect measurements can be made by recording the loss in weight of the commodity resulting from insect feeding damage, or the number of damaged grains. An assessment of adult mortality may be made 3–24 h after treatment, or it may be delayed until 7 or 15 days later.

Trials for assessing repellency usually incorporate modifications of the Loschiavo food preference apparatus, described by Laudani and Swank (1954). This apparatus, which was developed to assess the repellency of pyrethrum on maize, consists of a rimmed platform with circular, evenly-spaced holes around the outer edge. The holes accommodate paper cups that can be filled with treated and untreated commodity. The platform is enclosed by a lid fitted with a central hatch/access portal through which insects can be lowered to the test platform. The insects are then allowed free movement across the surface of the base for a specified period of time, after which the numbers present in each cup can be recorded. Adult mortality and subsequent F1 emergence can also be assessed.

Extracts can be applied to filter paper for insect bioassays such as repellency trials, anti-feedant tests and vapour/fumigation trials. In repellency trials, the standard methodology described by Laudani *et al.* (1955) is used. Extract at concentrations up to a maximum of 800 $\mu g/cm^2$ is applied to filter paper or aluminium foil-laminated paper. A strip of the treated paper is attached to an untreated strip edge-to-edge and covered by a glass arena so that the joined edge bisects the ring. Insects, usually 10 adult *T. castaneum*, are introduced into the arena and the numbers present on the treated and untreated halves recorded twice daily at 09:00 hours and 16:00 hours for five consecutive days. The average count for each 5-day period is expressed as a percentage of repellency and the results are assigned to a repellency class using the following scale: class 0, <0.1%; class I, 0.1–20%; class II, 20.1–40%; class III, 40.1–60%; class IV, 60.1–80%; class V, 80.1–100%. Repellency may be assessed immediately after application and then reassessed 1–4 weeks or 1–4 months later.

In anti-feedant tests, extract is applied to wafer discs, filter paper or paper packing material. The holes produced by boring insects are then counted per unit of time, usually for a 7-day exposure period.

When assessing the vapour or fumigant toxicity of essential oils the extract is usually applied to filter paper, left to dry and then suspended in a glass fumigation chamber. Insects are introduced into the chamber and adult mortality at a given concentration is recorded within a defined period of time. These trials generally extend over 24 h.

Section 3

Alphabetical list of plant species

Alphabetical list of plant species

Botanical/common names	Descriptors	Remarks	References
Acorus calamus (Araceae)			Rehm and Espig, 1991
Sweetflag, sweet rush	Uses	Oil produced from the rhizome is used in drinks, perfumery and pharmacy.	Rehm and Espig, 1991
	Powdered rhizome	At 1% (w/w), the level of damage by *S. oryzae* on sorghum over 180 days of storage was reduced to 15% compared with 80% on the untreated controls; 1% (w/w) on wheat reduced damage by *T. granarium* to 5% compared with 55% in the untreated controls, and 1% powdered extract completely prevented *C. chinensis* from damaging green gram.	Chander and Ahmed, 1983
		A 1% (w/w) application to wheat caused 100% mortality of 1st instar *C. cephalonica* after 2 months of storage.	Chander and Ahmed, 1986
	Extract	0.2% (w/w) applied to milled rice stored for 6 months caused 71% mortality of adult *S. oryzae* within 14 days and prevented F1 adult emergence. Adult *T. castaneum* were less susceptible, showing 16% mortality within 14 days. F1 progeny of *T. castaneum* were reduced by 50%.	Chander *et al.*, 1990
	Rhizome extract	0.2% (w/w) protected chickpea seeds for 120 days; F1 emergence and damage by *C. chinensis* were prevented.	Khan, 1986
	Oil	0.01% (w/w) on maize significantly reduced the amount of damage by *P. truncatus* over a 21-day trial when measured as the amount of maize dust produced.	Schmidt and Streloke, 1994
		Topical application of 30 µg per insect caused 100% mortality in adult *L. serricorne* within 72 h. Application of 50 µg per insect caused 98% mortality in adult *C. maculatus*, 62% mortality in *S. oryzae* and 3% mortality in *T. confusum*. Application of 1000 ppm oil to insect medium of wheat and black-eyed peas prevented F1 adult emergence of *S. oryzae* and *C. maculatus*.	Su, 1991a
		400 µg/cm² oil applied to filter paper in choice-chamber experiments produced Class IV, (86%) repellency amongst adult *T. castaneum* 1 week after treatment; repellency had declined to 45% at 8 weeks.	Jilani *et al.*, 1988

Botanical/common names	Descriptors	Remarks	References
Acorus calamus (*contd*)	Oil (*contd*)	400 μg/cm² oil applied to filter paper in choice-chamber experiments produced 53% repellency against adult *R. dominica* 8 weeks after application, compared with 72% 1 week after application.	Jilani and Saxena, 1990
	Oil vapour	10 μl oil applied to filter paper in a 400 ml fumigation chamber caused 100% mortality of adult *C. chinensis* exposed for 48 h, and 86% mortality of adult *S. granarius* exposed for 168 h. Assessments were made after 168 h of recovery. Exposure to 10 μl for 192 h caused 76% mortality in adult *S. oryzae* when assessed after 1 week of recovery. *R. dominica* was unaffected by exposure to 10 μl of oil over an exposure period of 264 h.	El-Nahal *et al.*, 1989
		Immature stages of *C. chinensis*, *S. granarius* and *S. oryzae* were exposed to vapour from 10 μ oil in a 400 ml desiccator for 72 h. The vapour caused 98.9% mortality in 0-24 h-old eggs of *C. chinensis*; *S. oryzae* and *S. granarius* were less susceptible and showed 17% and 33% mortality, respectively. The younger embryonic stages were found to be more susceptible than the later stages. Larvae and pupae were not as susceptible to the vapours as the eggs.	Risha *et al.*, 1990
		S. granarius exposed to 10 μl per 400 ml air for 96 h showed a 92% reduction in F1 progeny during treatment, and a 40% reduction in the 3 week post-treatment period on untreated food medium. *S. oryzae*, following 192 h of exposure, showed a 78% reduction in F1 progeny during the treatment and a 95% reduction post-treatment. Adult *C. chinensis* exposed to 10 μl for 48 h died before laying eggs. *T. confusum* adults were unaffected by the treatment.	Schmidt *et al.*, 1991
	Effects on treated commodities	Rice admixed with 0.2% powdered rhizome and stored for 8 months retained its cooking qualities; no off-flavours were detected when the rice was examined by a tasting panel.	Chander *et al.*, 1990
	Mode of action	The oil is reported to exert a specific effect on insect gonads by blocking interstitial cell secretions. The first target in females is the terminal oocyte. In males, sperm malformation and agglutination occur.	Saxena and Koul, 1982
	Karotypes	Three karotypes have been found. Of these, only the tetraploid form (4n=48) *A. calamus* var. *angulatus*, which grows in India, East Asia and Japan, contains a significant amount of β-asarone (70-96%)	Streloke *et al.*, 1989
	Constituents	The active ingredient in *A. calamus* is asarone. β-asarone belongs to the phenyl propanoid family.	Baxter *et al.*, 1960
		Include: eugenol, methyl-eugenol, acorin, calamenol, calamene, calameone.	Woodley, 1991
		Cineole, linalol, pinene, resins, safrole and tannins are also reported.	Duke, 1985
	Commercial application	A commercial preparation containing 70% β-asarone is marketed by Aldrich, Weinheim FRG.	Streloke *et al.*, 1989
	β-asarone	This compound bears a strong structural resemblance to precocene II, an anti-juvenile hormone.	Smet *et al.*, 1986
	Toxicity	Oil of calamus has been shown to possess considerable toxicity in long-term feeding trials with rats; it may be carcinogenic due, possibly, to its asarone or safrole content. Malignant tumours were found after 59 weeks when rats were fed 500-5000 ppm.	Duke, 1985
		The EC has recommended limits of 0.1 mg/kg in food and beverages, and 1 mg/kg in spirits and spices used for snacks. The use of β-asarone is prohibited in the US and Canada.	Lander and Schreier, 1990

Adhatoda vasica (Acanthaceae) Adulsa (India)			Duke, 1985
	Description/uses	This small evergreen shrub found in India is used as an insecticide and a traditional medicine.	Duke, 1985
	Extract	4% extract applied to cowpea slightly reduced the number of eggs laid by *C. maculatus* although the effect was of short duration.	Bhaduri *et al.*, 1985
	Extracted alkaloids	0.5% vasicine applied to the food medium of 1st instar *T. castaneum* larvae caused 50% mortality. Surviving females that were allowed to oviposit showed a reduction in fecundity.	Saxena *et al.*, 1986
	Constituents	Include: adhatodine, vasicinine, vasicol and vasicoline.	Southon and Buckingham, 1988
Aegle marmelos (Rutaceae) Bengal quince, bel (India)			Rehm and Espig, 1991
	Uses	Cultivated in India, the fruits are eaten fresh, processed into drinks, or dried. It is also used as a traditional medicine in the West Indies.	Rehm and Espig, 1991
	Dried leaves	2% (w/w) admixed with paddy rice reduced damage by natural insect infestations in a store by 50% over a 270-day trial.	Prakash *et al.*, 1982
		2% (w/w) admixed with rice reduced the level of damage caused by natural insect infestations in a store during a 6-month storage period to 2% compared with 10% in the untreated control. The main pests were *S. cerealella, R. dominica* and *S. oryzae.*	Prakash *et al.*, 1983
		2% (w/w) admixed with paddy rice had no significant effect on the development of eggs of *C. cephalonica*; most of them developed into adults.	Prusty *et al.*, 1989
	Constituents	Include: aegeline and marmeline.	Southon and Buckingham, 1988
Aframomum melegueta (Zingiberaceae) Melegueta pepper (West Africa)			Rehm and Espig, 1991
	Description/uses	Cultivated in house gardens, it is used as a spicy masticatory in West Africa.	Pal *et al.*, 1988
	Powder	Admixed with maize, the powder caused mortality in adult *S. zeamais* within 24 h (LC_{50} of 0.398 g/5 g maize).	Lale, 1992
Ageratum conyzoides (Compositae) Goatweed (West Africa), sharkland (India), Bulak-manok (Philippines)			Morallo-Rejesus, *et al.*, 1990
	Description/uses	This annual herb and common weed is found throughout the tropics and used in traditional medicine.	Woodley, 1991
	Petroleum ether extract	0.5-1.5% (w/w) of benzene diluted extract applied to green gram repelled 99% of *C. chinensis* over a 10-day exposure period. Admixture of 1.5% (w/w) reduced the weight loss of infested green gram to 0.46% compared to 38% in the untreated control. The benzene control samples also repelled 99% of *C. chinensis* and reduced weight loss to 8%.	Pandey *et al.*, 1986

Botanical/common names	Descriptors	Remarks	References
Ageratum conyzoides (*contd*)	Oil	5 mg/50 g mung bean seed caused 97% mortality in adult *C. chinensis* within 24 h and completely prevented egg-laying.	Morallo-Rejesus *et al.*, 1990
		Essential oil extracted from Indian varieties has yielded a high percentage of chromenes (85%). It was suggested that the amount of chromenes present in the oil may be dependent upon the climatic and growing conditions experienced by the plant.	Aalbersberg and Singh, 1991
		Essential oil extracted from Indian varieties yielded a high percentage of precocene II; plants from Nigeria and Cameroon were rich in precocene I, while oil from Vietnamese and Fijian (Suva) plants contained roughly the same amount of both compounds.	Menut *et al.*, 1993
	Constituents	Terpenoids, steroids, flavenols, glucosides and polyoxygenated flavones have been isolated from plants from India, China, Nigeria and North Vietnam. Monoterpene α-pinene and eugenol have been detected in Indian plants, and β-cubebene, α-farnesene, humulene and caryophyllene oxide have been identified in Fijian plants. The anti-juvenile hormones ageratochromene and 7-methoxy-2,2-methylchromene (precocene I) form 60% of the total essential oils of the flowers, leaves and stems of a Fijian variety.	Aalbersberg and Singh, 1991
Allium sativum (Liliaceae) Garlic	Uses	Fresh cloves are used as a flavouring in cooking. They are also used in traditional medicine in the West Indies.	Ayensu, 1981
	Powder	2% (w/w) admixed with wheat caused a reduction in the percentage of damage caused by *T. granarium* larvae; 4 months after the initial introduction of the larvae, the percentage of damage was 25% compared with 70% in the control.	Jood *et al.*, 1993
	Extract	0.02% applied to paddy at a rate of 21/100 kg reduced the number of *C. cephalonica* larvae emerging from eggs that had been introduced into the rice; however, the results, when analysed, were not statistically significant.	Prusty *et al.*, 1989
		1% (w/w) protected gram against attack by *C. chinensis* for 135 days	Agarwal *et al.*, 1988
	Oil	1 ml of 1% oil applied to filter paper and stored for 4 months produced 88% repellancy against adult *T. castaneum* in a choice-chamber experiment, when assessed after 5 days of exposure. The level of repellancy had declined to 48% after 8 weeks.	Mohiuddin *et al.*, 1987
	Constituents	Include: allicin	Mohiudden *et al.*, 1987
	Toxicity	Garlic is considered to be a safe flavouring in food. The recommended safe levels are 800-1300 ppm of garlic, or 10-15 ppm garlic oil. Very high doses of garlic components are toxic. The LD_{50} value for allicin in mice is 60 mg/kg body weight.	Jospeph and Sundaresh, 1989

Alpina galanga (Zingiberaceae) Greater gangal			Rehm and Espig, 1991
	Uses	This is a spice widely used in Malaysia and Java; it is also used for medicinal purposes.	Rehm and Espig, 1991
	Oil	0.5% (w/w) applied to green gram caused 100% mortality in adult *C. chinensis* within 15 days and prevented oviposition.	Ahmed and Ahamad, 1992
Anabasis setifera (Chenopodiaceae)	Description	This is a fragrant undershrub found in western desert areas of Egypt.	Saleh, 1986
	Oil extract in acetone	The LD_{50} for adult *S. zeamais* confined on a treated glass surface for 36 h was 8.4 μg/cm².	Saleh, 1986
	Constituents	Include: carvacrol and thymol	Saleh, 1986
Anacardium occidentale (Anacardiaceae) Cashew			Bhaduri *et al.*, 1985
	Description/uses	This is an edible nut whose shell liquid is processed to make synthetic resins used for brake linings and paint materials.	Bhaduri *et al.*, 1985
	Cashew nut shell liquid	Liquid applied to cowpeas protected them against damage and infestation by *C. maculatus*.	Echendu, 1991
	Extract	4% extract applied to cowpea slightly reduced the number of eggs laid by *C. maculatus*; the effect was of short duration.	Bhaduri *et al.*, 1985
	Seed viability	Shell liquid had no adverse effect on cowpea seed germination.	Echendu, 1991
	Constituents	Include: anacardic acid, cardanol and cardol.	Rehm and Espig, 1991
		Quercetin and kaempferol glycosides have also been reported.	Oliver-Bever, 1986
Anethum graveolens (Umbelliferae) Dill			Rehm and Espig, 1991
	Uses	Seeds and leaves are used as flavouring in food, and for medicinal purposes.	Rehm and Espig, 1991
	Pulverized seed powder and acetone extract	0.5% seed powder and 2% (w/w) extract applied to wheat repelled *S. oryzae*. Application of 680 μg/cm² on paper produced a repellency of 75% over a 2-month period against *T. confusum*, equivalent to a Class IV repellent. Topical application of 50 μg of extract caused 60% mortality in *S. oryzae* within 24 h; it showed only slight toxicity against *L. serricorne, C. maculatus* and *T. confusum*.	Su, 1985a
	Extract	680 μg/cm² applied to paper and stored for 12 months produced 61% repellency for *T. confusum*, declining to 41% at 24 months.	Su, 1987

Botanical/common names	Descriptors	Remarks	References
Anethum graveolens (*contd*)	Extract yields	A 225 g sample of pulverized dill seed yielded 21 g of extract.	Su, 1985a
	Constituents	Acetone extract of seed contained 2-methyl-5-(1-methylethenyl)-2-cyclohexen-1-one (d-carvone) and 4,5-dimethoxy-6-(2-propenyl)-1,3-benzodioxole (dillapiol).	Su and Horvat, 1988
		Minor components of seed include limonene (34.4%), dihydrocarvone (0.1%) and traces of eugenol, anisic aldehyde, anethole and thymol.	Southon and Buckingham, 1988
	Toxicity	The acute oral LD_{50} for rats of dill seed oil is 4.6 g/kg.	Opdyke and Letizia, 1982
		Dill seed oil has been shown to be a potential photosensitizer and/or can cause dermatitis.	Duke, 1985
Angelica silvestris (Apiaceae) Wild angelica			Grainge and Ahmed, 1988
	Extract	Bisabolangelone applied to wheat at 50-250 mg/kg protected the grains from damage by larvae of *T. granarium* and *T. confusum*. Topical application to *T. confusum* and *T. granarium* larvae caused mortality, and when applied to pupae it induced morphogenetic changes.	Nawrot *et al.*, 1987
		Topical application of 0.01 mg bisabolangelone to *T. confusum* larvae caused 63% mortality and 60% mortality in adult insects. Topical application was less effective against *T. granarium* and *S. granarius*.	Nawrot *et al.*, 1984
Annona reticulata (Annonaceae) Bullock's heart (Central America)			Rehm and Espig, 1991
	Description/uses	Parts of this small, fruit-bearing tree are used in traditional medicine in West Africa.	Oliver-Bever, 1986
	Seed powder	5% (w/w) admixed with stored wheat significantly reduced the F1 adult production of *S. oryzae*, over a 75-day storage period, following repeated adult introduction.	Rout, 1986
	Extract	Extracts applied at 0.1% reduced egg-laying in *C. chinensis* by 70-80% and inhibited F1 adult emergence.	Islam, 1987
	Constituents	Include: anonaine, roemerine, corydine and isocorydine; many other aporphine alkaloids have been isolated from leaves and stems.	Oliver-Bever, 1986
Annona squamosa (Annonaceae) Custard apple, sweet sop			Rehm and Espig, 1991
	Uses	Fruit are consumed fresh in India, Thailand and China. Leaves are used as insecticides in the Gambia.	Oliver-Bever, 1986

	Extract	Extracts applied at 0.1% reduced egg-laying in *C. chinensis* by 70-80% and inhibited F1 adult emergence	Islam, 1987
		An ether extract has been tested against adult *T. castaneum* and found to be moderately toxic.	Oliver-Bever, 1986
	Constituents	Include: aporphine alkaloids: anonaine, roemerine, norcorydine, corydine, noriso-corydine and glaucine, have been isolated from the bark, roots, seeds and stems.	Oliver-Bever, 1986
		Carvone, linalool, limonene, α- and β-pinene have also been reported.	Ekundayo, 1989
Arachis hypogaea (Fabaceae) Groundnut			Rehm and Espig, 1991
	Uses	This oil is used for cooking and the nuts can be processed into peanut butter.	Rehm and Espig, 1991
	Oil	5 ml/kg cowpea reduced damage by *C. maculatus* over a 24-week storage period, particularly when applied to a bruchid resistant variety.	Cockfield, 1992
		10 ml/kg maize, stored for 60 days, caused 97% mortality in adult *S. oryzae* within 24 h and reduced F1 emergence by 98%.	Ivbijaro *et al.*, 1985
		0.5% oil applied in ether to black gram reduced the number of eggs laid by *C. chinensis* and prevented the emergence of F1 adults.	Sujatha and Punnaiah, 1984
		56 ml/kg dried trout reduced emergence of adult *D. maculatus* to 31% compared with 70% in the controls.	Don-Pedro, 1989b
	Seed viability	0.5% oil applied to black gram did not reduce seed germination.	Sujatha and Punnaiah, 1984
Artemisia vulgaris (Asteraceae) Damong maria (Philippines), mugwort			Grainge and Ahmed, 1988
	Description/uses	This is a herb and medicinal plant with bactericidal, fungicidal and insecticidal properties.	Ferrolino-Calumpang and Padolina, 1985
	Extract	Topical application caused 90% mortality in adult *S. zeamais*, and 100% mortality in *T. castaneum*, within 24 h.	Ferrolino-Calumpang and Padolina, 1985
	Constituents	Cineole is the major constituent; β-pinene, sitosterol and thujone are also present.	Duke, 1985
Atriplex lentiformis (Chenopodiaceae) Saltbush			Rehm and Espig, 1991
	Uses	This is a plant used as animal fodder.	Rehm and Espig, 1991
	Extract	5.0% (w/w) applied to cowpea caused 58% mortality in adult *C. chinensis* within 3 days, and prevented F1 emergence.	El-Ghar and El-Sheikh, 1987

Alphabetical list of plant species

Botanical/common names	Descriptors	Remarks	References
Bassia latiflora	Oil seed cake	7.5% (w/w) powdered oil seed cake, admixed with maize, reduced damage by *S. oryzae*, although *Azadirachta indica* at 2.5% was more effective.	Bowry *et al.*, 1984
	Oil	1% oil applied to 400 g pea seeds reduced damage by *C. chinensis* over a 3-month storage period.	Kumari *et al.*, 1990
		1 ml/100 g of gram seed caused 100% mortality in adult *C. chinensis* within 3 days and prevented egg hatch.	Ali *et al.*, 1983
	Seed viability	7.5% (w/w) admixed with maize seed did not reduce seed viability.	Bowry *et al.*, 1984
Begonia picta (Begoniaceae)	Fresh leaves	2.5% (w/w) admixed with rice seed protected 100 kg samples for 9 months against insect attack by natural infestations in rice stores.	Prakash *et al.*, 1982
	Seed viability	2.5% (w/w) caused no reduction in rice seed germination.	Prakash *et al.*, 1982
Blumea balsamifera (Asteraceae) Sambong (Philippines), ngai camphor			Grainge and Ahmed, 1988
	Uses	Extracts of the leaves are used in traditional medicine in South-East Asia.	Perry, 1980
	Oil	0.1% admixed with mung beans caused 73% mortality in adult *C. chinensis* within 24 h, and almost completely prevented egg-laying.	Morallo-Rejesus *et al.*, 1990
	Seed viability	Application of 5 ml/kg wheat reduced germination by 23%.	Gupta *et al.*, 1988
	Constituents	Essential oil contains borneol, cineole, limonene, and palmitic and myristic acids.	Perry, 1980
Boscia senegalensis (Capparaceae)	Uses	Used both as a famine food and in traditional medicine, this plant has also been used traditionally by farmers as a stored grain protectant.	Seck *et al.*, 1993
	Fresh ground leaves	4% (w/w) admixed with cowpeas caused 100% mortality in adult *C. maculatus* within 24 h and prevented egg-laying. Admixture of fresh whole leaves and dry leaf powder was less effective.	Seck *et al.*, 1993
	Acetone extract of fruits	Acetone extract in a glass desiccator caused 100% mortality in adult *S. cereallela* within 1.5 h; the LT_{50} values for *C. maculatus* and *P. truncatus* were 2.3 and 3.8 h respectively.	Seck *et al.*, 1993
	Constituents	Include: methylisothiocyanate which is liberated from a glucosinolate precursor, glucocapparin found in the fruits and leaves.	Seck *et al.*, 1993
		3-hydroxystachydine is also reported to be present.	Southon and Buckingham, 1988

Brassica juncea (Cruciferae) Brown mustard Chinese mustard			Rehm and Espig, 1991
	Uses	The seeds are used for oil extraction or as a seasoning. The leaves are eaten as a vegetable in southern and eastern Asia.	
	Powdered oil seed cake	7.5% (w/w) admixed with maize reduced damage by *S. oryzae.*	Bowry *et al.*, 1984
	Oil	10 ml/kg chickpea caused 100% mortality in adult *C. chinensis* within 4 days and prevented F1 production.	Das, 1986
		7.5 ml/kg chickpea gave protection from damage for 5 months following repeated introductions of *C. chinensis.*	Khalique *et al.*, 1988
		1% (w/w) applied to green gram and stored for 6 months gave complete protection against damage by *C. chinensis* and *C. maculatus.*	Doharey *et al.*, 1990
Butea frondosa (Fabaceae)	Uses	The gum and leaves are used in traditional medicine in India and Indonesia.	Perry, 1980
	Oil	5 ml/kg wheat prevented attack by natural infestations of insects in a store for 12 months. The oil treatment reduced infestation to 3.3% compared with 63% in the untreated control.	Gupta *et al.*, 1991
	Seed viability	Application of 5 ml/kg wheat reduced germination by 8%.	Gupta *et al.*, 1991
Bystropogon spp. (Lamiaceae)	Uses	The leaves are used as a protectant for stored products and a traditional medicine in the Andes, South America.	Schulz, 1986
	Essential oil	100 µl of oil applied to filter paper discs in 1 litre fumigation chambers caused 100% mortality in adult *C. maculatus, E. kuehniella, S. cerealella* and *A. obtectus* after a 2 h exposure period. Adult mortality in *S. granarius was 59%, in T. castaneum* 53%, and in *P. truncatus* 38%; *O. surinamensis* was unaffected.	Schulz, 1986
	Seed viability	The oil had no effect on the seed viability of pea, lentil or wheat, although treatment produced a peppermint-like smell in the seed which was lost following aeration.	Schulz, 1986
Calophyllum inophyllum (Clusiaceae) Undi (India), laurelwood			Grainge and Ahmed, 1988
	Uses	All parts of the tree are used in traditional medicine. Leaves are used as a fish poison.	Oliver-Bever, 1986
	Oil	5 ml/kg applied to wheat seeds prevented attack by natural infestations of insects for 12 months in a store. The oil treatment reduced infestation to 18% compared with 63% in the untreated control.	Gupta *et al.*, 1988
	Seed viability	Application of the oil at 5 ml/kg reduced wheat germination by 28%.	Gupta *et al.*, 1988

Botanical/common names	Descriptors	Remarks	References
Calophyllum inophyllum (*contd*)	Constituents	Leaves contain friedelin and its triterpenes canophyllol, canophyllal and canophyllic acid. Derivatives of 4-phenylcoumarin have been isolated from seeds.	Oliver-Bever, 1986
Canangium odoratum (Annonaceae) Ylang-ylang			Sighamony *et al.*, 1991
	Uses	The high-value oil is used in perfumery.	Rehm and Espig, 1991
	Oil	Preliminary trials indicated that 3rd instar larvae of *T. granarium* were susceptible to the oil in contact toxicity trials. The oil also showed repellent properties.	Sighamony *et al.*, 1991
	Constituents	Include: sesquiterpenes; linalool, pinene, iso-eugenol, eugenol, geraniol, methyl anthranilate, methyl benzoate, methyl salicylate.	Oliver-Bever, 1986
		Pinene and benzyl alcohol, farnesol, nerol and valeric acid may also be present in some oils.	Jouhar and Poucher, 1991
	Toxicity	The oil is accepted as an allergen as it can produce dermatitis in sensitized individuals.	Duke, 1985
Capsicum annuum (Solanaceae) Red pepper			Rehm and Espig, 1991
	Uses	The whole dried fruits of this culinary pepper are used as a traditional grain protectant in West Africa and in traditional medicine.	Ivbijaro and Agbaje, 1986
	Dry powder	Admixture of 1.5 g/20 g cowpea caused 46% mortality in adult *C. maculatus* within 48 h and reduced F1 production by 45%; the effect was not as significant as that produced by *Piper guineense*.	Ivbijaro and Agbaje, 1986
Capsicum frutescens (Solanaceae) Africa pepper			Oliver-Bever, 1986
	Uses	This small, very hot red pepper is used for culinary purposes and as a traditional medicine.	Ivbijaro and Agbaje, 1986
	Dry powder	Admixture of 1.5 g/20 g cowpea caused 30% mortality in adult *C. maculatus* and reduced F1 production by 60%. The effect was not as significant as that produced by *Piper guineense*.	Ivbijaro and Agbaje, 1986
	Constituents	Include: capsaicin, also called capsicin.	Ayensu, 1981
Capsicum spp. (Solanaceae)	Toxicity	Capsaicin and chilli extracts showed evidence of mutagenicity in the Ames test, although neither induced point mutations in mammalian cells *in vitro*. Capsaicin caused cytogenetic damage in the bone marrow, and inhibited DNA synthesis in the testes, in mice given high doses by intraperitoneal injection.	BIBRA, 1989

		Intraperitoneal injection of 1.6 ppm/body weight into albino mice did not affect sperm production or development, nor did it induce dominant-lethal mutations.	Muralidhara and Narasimhamurthy, 1988.
Carum carvi (Umbelliferae) Caraway			Rehm and Espig, 1991
	Uses	Caraway is a fruit used as a culinary spice and as a flavouring for liqueurs.	Rehm and Espig, 1991
	Fruit powder extract	Extracts were admixed with wheat and mortality in adult insects was assessed at 24 h. The LC_{50} of the extracts were: for *S. oryzae* 250 ppm methanol, 260 ppm petroleum ether, 370 ppm acetone and 400 ppm chloroform; for *R. dominica* 420 ppm petroleum ether, 610 ppm chloroform, 680 ppm methanol and 840 ppm acetone. The methanol extract at 400 and 800 ppm against *S. oryzae* caused 100% mortality within 24 h; 5 and 14 days, respectively, were required for *R. dominica*.	
	Constituents	The major component of oil is carvone.	Nawrot, 1983
		Dried fruits contain sterols, triterpenes, unsaturated steroids, saponins, flavonoids, glycosides, pyrogallol tannin and phloroglucinol.	Afifi *et al.*, 1989
Carum roxburghianum *(Trachyspermum roxburghianum)* (Umbelliferae) Bishops weed (India)			Chander and Ahmed, 1983
	Powdered seed	5% (w/w) reduced *S. oryzae* damage on sorghum to 30% compared with 60% on untreated controls over a 180-day period. 5% applied to wheat reduced *T. granarium* damage to 14% compared with 54% in the untreated control after 120 days. This plant was regarded as a promising local control measure, although it was not as effective as *Acorus calamus*.	Chander and Ahmed, 1983
Cassia nigricans (Fabaceae)	Uses	Leaves are used to protect cowpeas from attack by pulse beetles; this is a traditional method of control in the Upper Volta.	Lambert *et al.*, 1985
	Extract	An ethanol extract (1 g plant material, 1 ml of ethanol) was applied at 300 µl/10 g beans. At this dosage, egg-laying by *A. obtectus* was prevented.	Lambert *et al.*, 1985
Celastrus angulatus (Celastraceae) Chinese bittersweet			Zhang and Zhao, 1983
	Uses	In China, the root bark is used as a traditional method of protecting vegetables against insects.	Zhang and Zhao, 1983
Celastrus angulatus (*contd*)	Root bark powder	Powder mixed with rice at 0.5% (w/w) reduced population growth in *S. zeamais* and *S. oryzae* by 90% by inhibiting development of eggs and young larvae.	Zhang and Zhao, 1983
		It is reported to be an antifeedant and stomach poison, producing a narcotic effect in *S. zeamais*. An ethyl ether extract applied to rice at 2.6 mg/g completely prevented insect reproduction. The extract was found to be relatively stable in sunlight and heat.	Chiu, 1989

Botanical/common names	Descriptors	Remarks	References
Celastrus angulatus (*contd*)	Constituents	At least seven sesquiterpene alkaloids and four sesquiterpene esters have been isolated and identified and include maytansine, triptolide, maytoline and evonine. All the compounds contain a common mother nucleus-agarofuran. Celangalin is thought to be the most active compound in the root bark and seed oil.	Chiu, 1989
Cestrum nocturnum (Solanaceae) Night-blooming jessamine			Kingsbury, 1964
	Description	Ornamental plant found in US and Hawaii.	Kingsbury, 1964
	Leaves	5% (w/w) admixed with stored grains, were effective against *S. oryzae* and *T. granarium* but not against *C. chinensis*. The treatment significantly reduced the amount of damage observed from repeated introductions of insects over a 3-month storage period.	Chander and Ahmed, 1983
	Fresh powdered leaves	5% (w/w) admixed with wheat caused mortality in introduced 1st instar *C. cephalonica* larvae and prevented them from developing into adults.	Chander and Ahmed, 1986
Chenopodium ambrosioides (Chenopodiaceae) Mexican tea, wormseed, ambroisine, paic, gandibooti			Rehm and Espig, 1991
	Uses	The plant's major use is as a fragrance component in creams, perfumes and soaps.	Duke, 1985
		The oil is also used in both human and veterinary medicine. The active substance, ascaridole, is a terpenic peroxide. In addition it has been used as a traditional protectant for stored beans and groundnuts in the Congo.	Peterson *et al.*, 1989
	Ethanol and hexane extracts of fruits	Following a 24-h exposure on treated glass, the LC_{50} for *T. castaneum* was 80 µg/cm² and for *S. granarius* 55 µ/cm². The compounds isolated were eicosadienoate, hexadecanoate, and dicarboxylic acid derivatives.	Peterson *et al.*, 1989
	Powder	Admixture of 25g/kg groundnuts caused 90% mortality in adult *C. serratus* within 13 days and prevented egg-laying and F1 production.	Delobel and Malonga, 1987
	Petroleum ether: acetone extract of leaves	A 1% solution applied to filter paper was classified as a Class III repellent (47%) against adult *T. castaneum*, 4 weeks after treatment, when assessed over 5 days. Antifeedant activity was assessed by counting puncture holes produced by *R. dominica* confined on treated filter papers for 4 days. The 1% extract produced the same level of anti-feedant activity as an *Azadirachta indica* extract.	Malik and Mujtaba Naqvi, 1984
	Oil	Topical application of the oil at 40 µg/insect caused 100% mortality in adult *C. maculatus*; 50 µg/insect caused 92% mortality in adult *L. serricorne* within 3 days. *S. oryzae* and *T. confusum* were less susceptible; 50 µg/insect caused 52% and 15% mortality respectively.	Su, 1986

	Constituents	Include: 20-30% terpenoids; *p-cymene*, limonene and terpene. Also 60-80% ascaridol.	Su, 1991b
		Hydrocyanic acid, geraniol, myrcene, camphor and methyl salicylate are also reported.	Duke, 1985
	Toxicity	The oil is poisonous, producing fatalities in overdose. The therapeutic dose in human medicine is very close to the minimum toxic level.	Duke, 1985
Chrysanthemum cinerariifolium (Compositae) Pyrethrum, dalmatian insect flower			Duke, 1985
	Uses	Synergized pyrethrins were widely used for the protection of stored products until they were replaced by the organo-phosphorus compounds, particularly malathion. Until the recent introduction of 10 mg/kg for pirimiphos-methyl, they were the only insecticides for which maximum residue limits (of 3 mg/kg pyrethrins and 20 mg/kg piperonyl butoxide) in dried fish had been recommended by the FAO/WHO.	Casida, 1973
	Plant	Dipping dried fish in 0.009% pyrethrum and 0.018% piperonyl butoxide was found to be effective against *D. maculatus* 6 months after treatment, although the residue levels exceeded FAO/WHO approved levels.	Gjerstad, 1989
	Pyrethrum marc 0.4% synergized and anti-oxidant	10 ppm admixed with maize caused 100% mortality in adult *P. truncatus* within 72 h and prevented the emergence of F1 adults, 3 months after application.	Makundi, 1989
		The effectiveness of 2 mg/kg pyrethrum admixed with maize was compared with 2.5 mg/kg permethrin, 1 mg/kg deltamethrin and an untreated control. Four replicates of 10 kg of maize were compared at three sites in Kenya, and the percentage of holed grains was assessed. The 2 mg/kg pyrethrum treatment was as effective as the pyrethroids and significantly reduced the amount of damage caused by natural insect infestation over the 6-12 month period examined.	Warui *et al.*, 1990
	Constituents	Alcohol extracts of flowers yield several sesquiterpene lactones; among them are β-cyclopyrethrosin, chrysanolide, chrysanin and β-amyrin.	Duke, 1985
Chrysanthemum indicum (Compositae) Manzanilla			Morallo-Rejesus *et al.*, 1990
	Uses	An aromatic plant used in traditional medicine in West Africa.	Burkhill, 1985
	Oil	5 mg/kg admixed with mung bean seed caused 100% mortality in adult *C. chinensis* within 24 h and prevented egg-laying	Morallo-Rejesus *et al.*, 1990
Cinnamomum aromaticum, C. cassia (Lauraceae) Chinese cassia			Su, 1985b
	Description/uses	This aromatic spice used for culinary and medicinal purposes is found in southern China and South-East Asia.	Su, 1985b
	Extract of bark and cinnamon oil	600 μg/cm^2 applied to paper in repellency tests produced Class III (45%) repellency against *T. confusum*, declining to Class II (18%) repellency 2 months after treatment. Topical application of either treatment at 50 μg/insect caused low mortality in adult *C. maculatus, T. confusum* and *L. serricorne*.	Su, 1985b

Botanical/common names	Descriptors	Remarks	References
Cinnamomum aromaticum, C. cassia (*contd*)	Constituents	Include: cinnamomum, cinnamolaurine, laurolitsine and norcinnamolaurine.	Southon and Buckingham, 1988
Citrus crematifolia (Rutaceae)	Peel	Dried peel at 0.20 g/50 seeds reduced percentage hatch of *C. maculatus* eggs.	Rajapakse, 1990
	Constituents	Limonene was regarded as the major volatile component.	Giga and Munetsi, 1990
Citrus limon (Rutaceae) Lemon			Rajapakse, 1990
	Leaf powder	2% (w/w) admixed with wheat reduced the percentage of damage caused by *T. granarium* larvae to 18%, compared with 70% in the untreated control 4 months after introduction of the larvae. At 6 months, damage was 38% in the treated wheat and 90% in the control.	Jood *et al.*, 1993
	Constituents	The four major components isolated from lemon peel oil using hexane are: 5,7-dimethoxy-2H-1-benzopyran-2-one; 9-[(3,7-dimethyl-2,6-octadienyl) oxy]-7H-furo[3,2-g]-[1] benzopyran-7-one; 4-[(3,7-dimethyl-2,6-octadienyl) oxy]-7H-furo[3,2-g] [1] benzopyran-7-one; and 5-[(3,7-dimethyl-2,6-octadienyl)oxy]-7-methoxy-2H-1-benzopyran-2-one. The insecticidal potency of these compounds was less than the potency of the original oil when bioassayed against *S. oryzae* and *C. maculatus*. The last three compounds showed the greatest toxicity.	Su and Horvat, 1987
Citrus paradisi (Rutaceae) Grapefruit			Rehm and Espig, 1991
	Peel	0.25% (w/w) applied to wheat caused 94% mortality in adult *S. granarius* within 16 days compared to 24% mortality in the controls; it significantly reduced the production of F1 progeny.	El-Ghar and El-Sheikh, 1987
Citrus sinensis (Rutaceae) Sweet orange			Rehm and Espig, 1991
	Dried peel	Peel admixed with cowpea and dried fish chips produced an LD_{50} of 4% (w/w) for *C. maculatus* and 14% (w/w) for *D. maculatus*. In repellency trials, 10% (w/w) admixed with cowpeas or fish chips repelled both insect species. At 18% (w/w) on fish chips, larval emergence of *D. maculatus* was reduced by 60%; only 37% of the larvae developed into adults compared with 88% in the untreated controls.	Don Pedro, 1985
	Constituents	Include: citacridone, citbrasine and noradrenaline.	Duke, 1985
Citrus, mid-season and Valencia cultivars	Oil	Citrus oil evaluated against *C. rhodesianus* at 5 ml/kg cowpea was very ineffective at inducing adult mortality and reducing F1 production.	Giga and Munetsi, 1990

Clerodendron inerme (Verbenaceae) Garden quinine, banjui, Indian privet			Chander and Ahmed, 1983
	Petroleum ether leaf extract	2.5% (w/v) on 2 g samples of cowpea reduced egg laying in adult *C. chinensis* and completely prevented F1 emergence for 1 month after treatment.	El-Ghar and El-Sheikh, 1987
	Powdered leaves	2% and 5% (w/w) admixed with wheat protected grain for at least 2 months by killing introduced 1st instar *C. cephalonica* larvae and preventing them from completing their development.	Chander and Ahmed, 1986
		5% (w/w) admixed with sorghum gave protection for 180 days and reduced damage by adult *S. oryzae* to 18%; in the controls, 67% of the sorghum was damaged	Chander and Ahmed, 1983
Cocos nucifera (Palmae) Coconut palm			Rehm and Espig, 1991
	Uses	Products produced from the palm include oil, copra, coconut flakes, animal fodder and coir.	Rehm and Espig, 1991
	Oil	1% (w/w) applied to paddy rice protected the grains for 6 months against introduced infestations of *R. dominica* and *S. cerealella*.	Ambika Devi and Mohandas, 1982
		5 ml/kg admixed with 50 g samples of cowpeas reduced the number of eggs laid by adult *C. maculatus* by approximately 50% compared to the untreated controls when examined 1 day after treatment. The emergence of F1 adults was reduced by 95%.	Messina and Renwick, 1983
		14 ml/kg had not reduced the number of eggs laid by *C. maculatus* on cowpeas 12 h after treatment, although it completely prevented emergence of F1 adults.	Don-Pedro, 1989d
		1 ml/100 g gram seed caused 100% mortality in adult *C. chinensis* within 3 days and prevented egg laying.	Ali *et al.*, 1983
		Application of 0.5% oil to green gram reduced the number of eggs laid by two pairs of *C. chinensis* by 50% compared to the untreated control, and totally prevented emergence of F1 adults.	Sujatha and Punnaiah, 1985
		5 g samples of green gram treated with 1% coconut oil prevented F1 adult emergence of *C. maculatus* and *C. chinensis* from eggs laid by adults introduced 6 months after treatment.	Doharey *et al.*, 1990
		20 ppm of oil admixed with mung beans reduced the number of eggs laid by adult *C. chinensis* and prevented emergence of F1 adults. 100 mg/50 g seed caused 73% adult mortality within 24 h.	Morallo-Rejesus *et al.*, 1990
		5 ml/kg chickpeas prevented emergence of F1 *C. chinensis* adults and reduced the percentage damage to 0.8%.	Singal and Singh, 1990
		10 ml/kg maize caused 100% mortality in adult *S. oryzae* within 3 h and prevented reproduction and F1 emergence.	Salas, 1985
		10 ml/kg admixed with maize and stored for 60 days caused 97% mortality in adult *S. oryzae* within 24 h and reduced F1 production by 99%.	Ivbijaro and Agbaje, 1986
		10 ml/kg pigeon pea caused 97.5% mortality in adult *A. obtectus* and 100% mortality in *C. maculatus* within 1 h. It also prevented reproduction and F1 emergence.	Salas and Hernandez, 1985

Alphabetical list of plant species

Botanical/common names	Descriptors	Remarks	References
Cocos nucifera (*contd*)	Oil (*contd*)	56 ml/kg applied to dried trout reduced the development of progeny and emergence of adults in *D. maculatus* to 42% following release of parents on the treated surface; this compared to 70% in the untreated controls. At 112 ml/kg, the emergence of F1 adults was completely prevented.	Don-Pedro, 1989b
	Seed viability	1% coconut oil applied to paddy rice and stored for 6 months reduced the germination rate to 39% compared with 56% for the untreated controls.	Ambika Devi and Mohandas, 1982
		Green gram treated with 0.5% coconut oil had a germination rate of 96%.	Sujatha and Punnaiah, 1985
		Chickpeas treated with 5% coconut oil had a germination rate of 98% after 3 months of storage.	Singal and Singh, 1990
		Maize seed treated with 5 ml/kg and stored for 6 weeks had a germination rate of 94%	Ivbijaro *et al.*, 1985
		The germination rate of maize seed treated with 10 ml/kg of coconut oil was 54%.	Salas, 1985
	Constituents	Coconut oil contains high proportions of saturated fatty acids, especially lauric acid.	Messina and Renwick, 1983
		Trimyristin, trilaurin, tripalmitin, tristearin and other glycerides have also been recorded.	Jouhar and Poucher, 1991
Coleus amboinicus (Plectranthus amboinicus) (Labiatae) Indian borage, oreille, oregano (Philippines)			Rehm and Espig, 1991
	Description	The leaves are used as seasoning for fish and meat, and as a vegetable.	Rehm and Espig, 1991
	Oil	100 mg/ml acetone applied to filter paper caused 100% mortality in adult *C. chinensis* confined on the treated paper within 48 h. 5-100 mg/50 g mung bean seed caused 97-100% adult mortality within 24 h and prevented egg laying.	Morallo-Rejesus *et al.*, 1990
Convolvulus arvensis (Convolvulaceae) Field bindweed			Peterson *et al.*, 1989
	Uses	The plant is used in Europe as a dressing for wounds, and as a purgative in Vietnam.	Watt and Breyer-Brandwijk, 1962
	Leaves	Ethanol extracts applied to glass produced LC_{50} values for *T. castaneum* and *S. granarius* of 85-1275 µg/cm² and 55-300 µg/cm², respectively, when the insects were confined for 24 h on the treated surface and then returned to food media; mortality was assessed at 7 days.	Peterson *et al.*, 1989
	Constituents	Include: hexadecanoate, penta-, hepta-, and nona-decanoate, octadecanoate and dicarboxylic acid derivatives.	Peterson *et al.*, 1989
Conyza dioscoridis (Burseraceae)	Flowers	Ethanol extracts applied to glass produced LC_{50} values for *T. castaneum* and *S. granarius* of 100-125 µg/cm² and 80-90 µg/cm², respectively, when the insects were confined for 24 h on the treated surface and then returned to food media; mortality was assessed at 7 days.	Peterson *et al.*, 1989

	Constituents	Include: eicosadienoate, hexadecanoate, and penta-, hepta-, and nona-decanoate derivatives.	Peterson *et al.*, 1989
	Uses	Fruits are harvested as a culinary spice in tropical and subtropical countries.	
Coriandrum sativum (Umbelliferae) Coriander			Rehm and Espig, 1991
	Acetone extract of seed	600 $\mu g/cm^2$ applied to filter paper in repellency tests produced Class IV (74%) repellency against *T. confusum* 4 months after application. Topical application of 50 μg/insect caused 40% mortality in *S. oryzae* when assessed 48 h after application; *C. maculatus, L. serricorne* and *T. confusum* were only very slightly susceptible.	Su, 1986
	Constituents	Include: geraniol, *l*-borneol, dipentene, terpinene, cymene, pinene, and phellandrene.	Jouhar and Poucher, 1991
Cuminum cyminum (Umbelliferae) Cumin, Comino, Jira, Zeera			Mohiuddin *et al.*, 1987
	Uses	The fruit is used as a culinary spice in eastern Asia and India. Cumin oil is commercially insignificant and world production is currently low.	Rehm and Espig, 1991
	Oil	1% of oil in acetone applied to filter paper produced Class III (59%) repellency against *T. castaneum*, 60 days after treatment, when assessed in a 5-day exposure trial.	Mohiuddin *et al.*, 1987
	Constituents	Include: α-pinene, β-pinene, limonene, linalool, terpinen-4-ol, 1,8-cineol, dillapiole, β-bisabolene and β-farnesene.	Verghese, 1991
Cupressus sempervirens (Cupressaceae) Cypress			Stamopoulos, 1991
	Oil	In ovipositional-site choice-chamber tests over 10 days, female *A. obtectus* showed a significant preference for egg-laying on untreated seeds when 25 μl of oil was placed on a diffuser above kidney beans in the apparatus.	Stamopoulos, 1991
	Constituents	Include: *d*-pinene, furfural, cymene, *d*-camphene, *d*-terpineol and *l*-cadinene.	Jouhar and Poucher, 1991
Curcuma longa (Zingiberaceae) Turmeric			Pranata, 1984
	Description/uses	The rhizome is used as a culinary spice and as a dye. It is cultivated in southern, South-East and eastern Asia. Powdered turmeric at 2% admixed with grain is a traditional protectant of stored cereal grains in Pakistan and southern Asia.	Rehm and Espig, 1991
	Rhizome powder	4% powder (w/w) admixed with rice and stored for 6 months reduced *S. oryzae* F1 progeny by 78%. At 1% (w/w), 50% suppression occurred at 6 months. Treatment of rice with a combination of turmeric powder at 2.5 g/kg and mustard oil at 4 ml/kg, prevented the emergence of F1 adults for 6 months.	Chander *et al.*, 1991

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Curcuma longa (*contd*)	Petroleum ether extract	Extract applied to green gram produced an LD_{50} for adult female *C. maculatus* of 0.05 ppm, and an $LD_{99.9}$ of 4.1 ppm, following a 24 h exposure period. Male insects were slightly more susceptible with an LD_{50} of 0.01 ppm and $LD_{99.9}$ of 1.5 ppm.	Pranata, 1984
	Petroleum ether extract of rhizome	680 µg/cm² extract applied to filter paper produced Class IV (67%) repellency against *T. castaneum*, 4 weeks after application.	Jilani and Su, 1983
	Effects on commodity	A cooking trial of stored treated rice indicated that application of 4% (w/w) dried rhizome powder of *C. longa* admixed with rice produced no significant change in its taste and aroma.	Chander *et al.*, 1991
	Constituents	Turmeric is known to contain pungent odoriferous oils, oleoresins and other related compounds. The oleoresins consist of curcumin and other related compounds. The chief components of turmeric oil are sesquiterpene ketones in the form of turmerone and ar-turmerone.	Jilani and Su, 1983
	Toxicology	A single acute dose treatment of 500 mg/kg body weight of a methanol extract of turmeric powder has been found to produce chromosomal aberrations in treated mice. The extract did not induce micronucleated polychromatic erythrocytes significantly. The authors suggested that the active clastogenic component of turmeric was possibly curcumin, which has been found to be clastogenic in cultured mammalian cells. Curcumin is generally found in turmeric at an average level of 3%, indicating that 0.003 g/kg body weight is potentially genotoxic.	Jain *et al.*, 1987
Cymbopogon martinii (Graminae) Gingergrass			Rehm and Espig, 1991
	Description/uses	Gingergrass oil is used in perfumery and in the food industry. It has a high geraniol content and is also known as 'East Indian geranium oil'.	Rehm and Espig, 1991
	Essential oil	0.4% oil on red gram prevented oviposition by *C. chinensis*.	Srivastava *et al.*, 1988
Cymbopogon nardus (Graminae) Citronella			Rehm and Espig, 1991
	Uses	Citronella is used in perfumery and for the production of geraniol.	Rehm and Espig, 1991
	Oil	0.5 ml of 1% oil applied to filter paper in repellency trials against *T. castaneum* and *C. chinensis* repelled the insects for 52 h.	Saraswathi and Rao, 1987
		0.2 mg/g cowpea did not reduce the number of eggs laid by *C. maculatus* and significantly increased the number of F1 adults emerging. The LC_{50} for a residual deposit on filter paper was 4.34 mg/cm² when assessed after 24 h.	Lale, 1991

Eichhornia crassipes (Pontederaceae) Water hyacinth			Grainge and Ahmed, 1988
	Description	This aquatic weed is a serious pest in the tropics.	Jamil *et al.*, 1984
	Petiole extract	At very high concentrations, acetone extract showed activity as a juvenile hormone mimic when applied to the diet of *T. castaneum*. 0.5 mg extract/5 g of rice caused 100% larval mortality.	Jamil *et al.*, 1984
	Petroleum ether extract	1% (w/w) applied to rice caused 100% mortality in 4th instar *T. castaneum* within 6 days; the effect persisted for 7 months. Topical application of 0.1% extract caused 100% mortality in adult *C. maculatus* within 2 days.	Rani and Jamil, 1989
Elaeis guineensis (Palmae) African oil palm			Rehm and Espig, 1991
	Description	This is an edible oil.	
	Oil	14 ml/kg applied to wheat produced a 97% reduction in F1 adult emergence of *S. zeamais* immediately after treatment.	Don-Pedro, 1989c
		10 ml/kg applied to maize or sorghum caused 100% mortality in adult *R. dominica* when tested immediately after treatment. It also prevented the emergence of F1 adults.	Kumar and Okonronkwo, 1991
		1ml/100 g gram seed caused 100% mortality in adult *C. chinensis* within 3 days and reduced egg hatching of F1 by 96%.	Ali *et al.*, 1983
		10 ml/kg applied to maize caused 66% mortality in adult *S. oryzae* within 24 h, 60 days after treatment; it reduced F1 emergence by 92%.	Ivbijaro *et al.*, 1985
		112 ml/kg applied to dried trout significantly reduced the number of F1 emerging *D. maculatus* larvae when parent insects were retained on the treated surface for 10 days.	Don-Pedro, 1989b
		5 ml/kg bambara groundnut reduced percentage hatch of *C. maculatus* immediately after application, although at this application rate, parents were heavily coated with oil.	Pereira, 1983
		0.25% (w/w) applied to green gram reduced the number of eggs laid by *C. chinensis* by 57%; it also prevented F1 emergence.	Sujatha and Punnaiah, 1985
		4 ml/kg chickpea prevented adult F1 emergence in *C. chinenesis*; it only reduced egg laying by 30%.	Sube *et al.*, 1991
	Seed viability	Seed germination was reduced by 4%, 6 weeks after treatment with oil at 5 ml/kg maize.	Ivbijaro *et al.*, 1985
Embelia ribes (Myrsinaceae) Barberang (India)			Bhaduri *et al.*, 1985
	Seed extract	4% (w/w) admixed with cowpea caused some reduction in *C. maculatus* damage. Solvent extracts only caused a 50% reduction in F1 production 30 days after application.	Bhaduri *et al.*, 1985

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Embelia ribes (*contd*)	Ethyl acetate extract	0.1% (w/w) extract admixed with wheat caused 76% mortality in *T. castaneum* and 68% mortality in adult *R. dominica*, when assessed after 14 days.	Chander and Ahmed, 1987a
	Embelin	0.1% (w/w) admixed with wheat caused 90% mortality in adult *S. oryzae* within 7 days, and reduced F1 adult emergence by 87%. Adult *R. dominica* were less susceptible; 70% mortality occurred in 7 days and F1 production was reduced by 76%.	Chander and Ahmed, 1989
		0.1% (w/w) admixed with wheat infested with 1st instar larvae of *C. cephalonica* and *E. cautella* 8 months after treatment caused 100% larval mortality. *T. granarium* larvae were less susceptible; a 71% reduction in adult emergence occurred 8 months after treatment.	Chander and Ahmed, 1987b
		0.375% (w/w) admixed with wheat after 8 months of storage caused 98% mortality in adult *T. castaneum* within 14 days, and prevented F1 emergence.	Chander and Ahmed, 1985
	Seed viability	0.375% (w/w) admixed with wheat did not reduce seed germination following 8 months of storage.	Chander and Ahmed, 1985
	Formula	Chemical formula of embelin: 2,5-dihydroxy-3-undecyl-1,4-benzoquinone.	Chander and Ahmed, 1987b
	Toxicology	Seeds administered to female rats at 100 mg/kg body weight significantly inhibited implantation during pregnancy, and thus showed antifertility activity.	Garg, 1981
Eruca vesicaria sativa (Cruciferae) Tarmira (India), garden rocket			Pal *et al.*, 1988
	Uses	The leaves are used as a salad and seasoning. It is cultivated for oil production in Asia.	Rehm and Espig, 1991
	Oil	0.5% (w/v) of oil applied to green gram reduced F1 emergence in *C. chinensis* by 88% and in *C. maculatus*, by 75%, when parent insects were added 6 months after treatment.	Doharey *et al.*, 1990
Erythrophleum suaveolens (Caesalpiniaceae) Ordeal tree, red water tree			Niber *et al.*, 1992
	Uses	The extract is used as an arrow poison, in folk medicine, and as a tanning agent.	Duke, 1985
	Extract	Topical application of extract to adult *A. obtectus* and *P. truncatus* reduced survival.	Niber *et al.*, 1992
	Bark	2 g plant powder added to 500 cowpea seeds reduced oviposition and egg hatch in *C. maculatus*.	Ofuya, 1990
	Constituents	Main alkaloids are erythrophleine, cassaine, cassaidine and norcassaidine.	Duke, 1985
Eucalyptus spp. (Myrtaceae)	Uses	Eucalyptus trees are grown for timber and pulp; they are also used in medicine, perfumery and industry.	Dakshinamurthy, 1988

Eucalyptus citriodora	Oil	Vapour from 0.044 ml of oil/litre of air in a fumigation chamber, caused 50% mortality of *C. chinensis* eggs within 6 days.	Pajni and Gill, 1991
Eucalyptus globus Blue gum tree			Oliver-Bever, 1986
	Leaf powder	The LD_{50} for exposure to leaf powder for 7 days was 4.1 g/100 g rice for adult *S. oryzae*. *S. granarius* was less susceptible at 4.86 g/100 g rice. The leaves showed repellent activity against both species.	Sharaby, 1989
	Oil	0.4% admixed with red gram prevented emergence of F1 adults in *C. chinensis*.	Srivastava *et al.*, 1988
Eucalyptus terreticornis	Leaf powder	1% (w/w) admixed with freshly harvested paddy, field-infested with *S. cerealella*, significantly reduced the number of emerging F1 adults during 4 months of storage.	Dakshinamurthy, 1988
	Oil	The vapour from 200 mg oil in 860 ml desiccators caused 100% mortality in adult *C. chinensis* within 24 h.	Ahmed and Eapen, 1986
	Commercial oil	25 µl oil in choice-chamber experiments showed significant repellency against *A. obtectus*; it also showed direct ovicidal and larvicidal effects.	Stamopoulos, 1991
		Exposure to oil vapour caused mortality in adult *C. cephalonica*.	Pathak and Krishna, 1991
	Constituents	These are mainly terpenes and include α-pinene, cineole and limonene.	Boland *et al.*, 1991
Gaultheria procumbens (Ericaceae) Wintergreen oil			Jouhar and Poucher, 1991
	Oil	The oil is used in medicine and perfumery.	Jouhar and Poucher, 1991
Gaultheria spp.	Oil	The vapour from 200 mg of oil in 860 ml desiccators caused 98% mortality in *C. chinensis* within 24 h. The LD_{50} following vapour exposure for 24 h was 0.88 mg/litre for adult *C. chinensis* and 4.62 mg/litre for adult *S. oryzae*.	Ahmed and Eapen, 1986
	Constituents	Include: methyl salicylate (98-99%) and gaultheric acid.	Duke, 1985
Glycine max (Leguminosae) Soya bean			Rehm and Espig, 1991
	Uses	This edible vegetable oil is also used in pharmacy and other industries.	Rehm and Espig, 1991
	Oil	10 ml/kg applied to wheat stored for 2 months caused 67% mortality in adult *S. granarius* within 7 days and prevented the emergence of F1 adults.	Qi and Burkholder, 1981

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Glycine max (*contd*)	Oil (*contd*)	10 ml/kg applied to chickpea seed caused 100% mortality in adult *C. chinensis* within 4 days, and prevented the emergence of F1 adults.	Das, 1986
		10 ml/kg applied to pigeon pea seed caused 100% mortality in adult *C. maculatus* and 97% mortality in *A. obtectus* within 1 h; and it also prevented egg laying.	Salas and Hernandez, 1985
		10 ml/kg applied to maize seed caused 100% mortality in adult *S. oryzae* within 3 h and prevented F1 production	Salas, 1985
		5 ml/kg applied to chickpea seed did not prevent egg laying by adult *C. chinensis* but reduced the emergence of F1 by 98%.	Singal and Singh, 1990
	Blend of soya oil and cotton seed oil	7.5 ml/kg applied to cowpea seed and stored for 12 weeks reduced the emergence of adult F1 *C. rhodesianus* to 53% compared to 72% for the untreated controls.	Giga and Munetsi, 1990
	Seed viability	10 ml/kg applied to maize seed reduced germination by 25% compared to the untreated controls.	Salas, 1985
		10 ml/kg applied to cowpea seed and stored for 3 months caused no reduction in seed viability.	Das, 1986
		10 ml/kg applied to pigeon pea seed had no effect on seed viability.	Salas and Hernanadez, 1985
		5 ml/kg applied to chickpea had no effect on seed viability.	Singal and Singh, 1990
Gossypium spp. (Malvaceae) Cotton			Rehm and Espig, 1991
	Uses	The oil extracted following cotton production is used for culinary purposes.	Rehm and Espig, 1991
	Oil	0.25% (w/w) applied to green gram prevented the emergence of adult F1 *C. chinensis.*	Sujatha and Punnaiah, 1985
		10 ml/kg applied to wheat stored for 2 months caused 40% mortality in adult *S. granarius* within 7 days and prevented the emergence of F1 adults.	Qi and Burkholder, 1981
	Blend of soya oil and cotton seed oil	7.5 ml/kg applied to cowpea seed and stored for 12 weeks reduced the emergence of adult F1 *C. rhodesianus* to 53% compared to 72% for the untreated controls.	Giga and Munetsi, 1990
	Seed viability	0.25% (w/w) applied to green gram did not reduce seed viability.	Sujatha and Punnaiah, 1985
	Constituents	Include: furfurol, quercetin, betaine, choline, phytosterine, various terpenes and formic, acetic, succinic, salicylic, palmitic, butyric, valerianic and capronic acids. Seeds contain gossypol.	Oliver-Bever, 1986
	Toxicity	Gossypol is toxic and, cumulatively, may cause anorexia and circulatory problems. It also has a spermicidal action and is used for human contraception in China.	Oliver-Bever, 1986
Helenium aromaticum (Compositae)	Extract helenalin	Application of 50 and 250 mg/kg wheat protected the grain from damage by *T. granarium* and *T. confusum* larvae.	Nawrot *et al.*, 1987

	Helenalin	Topical application of 0.02 mg of helenalin caused significant insect mortality in *T. granarium* within 5 days of application (84% mortality amongst 15-20 day old larvae, 26% mortality in pupae and 76% in adults).	Nawrot *et al.*, 1984
		50 μg/cm² applied to flour wrapping paper and parchment wrapping paper significantly reduced the number of damage holes produced by *R. dominica* in a 7-day exposure period.	Bloszyk *et al.*, 1990
	Constituents	Sesquiterpene, lactone and helenalin.	Bloszyk *et al.*, 1990
Helianthus annuus (Compositae) Sunflower			Doharey *et al.*, 1988
	Uses	A culinary oil is produced from the seeds; it is also used for animal fodder.	Doharey *et al.*, 1988
	Oil	0.5% (w/w) completely protected green gram from damage by *C. maculatus* and *C. chinensis* for 2 months.	Doharey *et al.*, 1990
		2.5 ml/kg applied to *Phaseolus vulgaris* protected the beans against attack by *A. obtectus* for 6 months. Damage by *A. obtectus* following initial artificial infestation was 6.3% compared with 88.7% in the untreated controls.	Rheenen *et al.*, 1989
	Seed viability	2.5 ml/kg applied to *Phaseolus vulgaris* did not reduce seed viability when stored for 3 months.	Rheenen *et al.*, 1989
	Constituents	Linoleic acid (58-67%).	Rheenen *et al.*, 1989
		Dicaffeoylputrescine and di-4-coumaroylspermidine also reported.	Southon and Buckingham, 1988
Homogyne alpina	Extract bakkenolide A	Topical application of 0.01 mg/insect did not reduce survival in larvae of *T. granarium*, *T. confusum* and *S. granarius*.	Nawrot *et al.*, 1984
		20 μg/cm² applied to filter paper had no effect on damage by *R. dominica*.	Nawrot *et al.*, 1987
Hyptis spicigera (Labiatae) Mono, nino, kindi, hard simsim (Africa), black sesame			Rehm and Espig, 1991
	Uses	The seeds are eaten and used for oil production. In Upper Volta, whole plants are used in traditional stores to protect cowpeas against damage by *Callosobruchus* spp.	Lambert *et al.*, 1985
	Ethanol extract	Application of 3-300 μl/10 g cowpeas reduced oviposition and egg hatching in *A. obtectus*.	Lambert *et al.*, 1985
Intsia bijuga (Leguminosae) Iple iple (India)			Perry, 1980
	Uses	This plant is grown for forage, wood and soil improvement in tropical lowlands.	Mohiuddin *et al.*, 1987

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Intsia bijuga (*contd*)	Oil	1% oil in acetone applied to filter paper showed Class V repellent activity (94%) against *T. castaneum*, 8 weeks after application, when assessed by a 5-day repellency trial.	Mohiuddin *et al.*, 1987
Ipomoea carnea (Convolvulaceae) Sadabahar (India), morning glory			Bhaduri *et al.*, 1985
	Leaf extract	4% (w/w) extract applied to cowpeas slightly reduced damage by F1 *C. maculatus*, 30 days after treatment.	Bhaduri *et al.*, 1985
	Powder	15 g/kg admixed with wheat significantly reduced the percentage of damage by *S. oryzae* over a 90-day storage period, following the introduction of adult insects at the beginning of the trial.	Singh and Mall, 1991
	Constituents	Include: agroclavine, ergine, chanoclavine I and II and lysergol.	Southon and Buckingham, 1988
Ipomoea palmata (Convolvulaceae)	Leaf extract	0.5% (w/v) applied to cowpea seed caused 44% mortality in adult *C. chinensis* within 3 days, and prevented F1 emergence.	El-Ghar and El-Sheikh, 1987
Jatropha curcas (Euphorbiaceae) Barbados nut, purge nut, ratanjyothi oil (India)			Grainge and Ahmed, 1988
	Uses	This is used as a traditional medicine and as a molluscicide and rodenticide.	Duke, 1985
	Oil	0.2% (w/v) admixed with stored gram reduced the numbers of eggs laid by adult *C. maculatus*, and prevented egg hatch, 33 days after treatment. The treatment did not cause adult mortality.	Jadhav and Jadhav, 1984
	Seed viability	0.2% (v/w) admixed with stored gram did not reduce seed germination.	Jadhav and Jadhav, 1984
	Toxicity	Poisoning in humans from overdoses of the oil or ingestion of the seed has been reported in the UK, Africa and the US. There are two strains, one with toxic seeds, one without. They cannot be distinguished visually.	Kingsbury, 1964
	Constituents	Bark, fruit, leaf and root are all reported to contain hydrogen cyanide; the plant also contains toxalbumin and curcin.	Duke, 1985
Juniperus virginiana (Cupressaceae) Eastern red cedar			Rehm and Espig, 1991
	Uses	This tree is cultivated as a windbreak in the US.	Rehm and Espig, 1991

	Oil	10.38 mg/cm² oil in acetone applied to filter paper produced a Class IV repellent activity response (70%) amongst *T. castaneum*, 8 weeks after application, when assessed by a 3-day repellency trial.	Sighamony *et al.*, 1984
		25 ppm applied to wheat and stored for 15 days caused 100% mortality in adult *S. oryzae* and 21% mortality in adult *R. dominica* within 24 h. The level of mortality 30 days after application had been reduced to 10% in both species.	Sighamony *et al.*, 1984
Justicia betonica (Acanthaceae)	Plant	2% (w/w) admixed with sorghum reduced damage by *S. oryzae* to 48% compared to 84% for untreated controls over a 135-day storage period.	Chander and Ahmed, 1983
		2% (w/w) admixed with wheat caused high mortality amongst 1st instar larvae of *C. cephalonica*, and reduced the number of emerging adults by 75%.	Chander and Ahmed, 1986
Lantana camara (Verbenaceae) Aripple (India), wild sage			Oliver-Bever, 1986
	Uses	This plant is used as a traditional medicine in Nigeria and Senegal.	Oliver-Beever, 1986
	Extract	A deposit from a 5% solution applied to a glass container caused 40% mortality in adult *C. chinensis* within 7 days. Application of 40 mg/100 g gram prevented oviposition.	Saxena *et al.*, 1992
	Constituents	Leaves, stems and flowers contain the triterpenes α-amyrine, β-sitosterol, lantaden B and rehmannic acid. Essential oil contains caryophyllene, eugenol, α-phellandrene, dipentene, terpineol, geraniol, linalool, cineol, citral and phellandrone.	Oliver-Beever, 1986
Laurus nobilis (Lauraceae) Sweet bay, laurel			Rehm and Espig, 1991
	Uses	Leaves are used for culinary flavouring and in traditional medicine. Oil has bactericidal and fungicidal action.	Duke, 1985
	Oil	15 µl/litre of air in fumigation chambers caused 100% mortality in adult *R. dominica* within 24 h.	Shaaya *et al.*, 1991
	Plant	15 volatile components from bay were tested for their repellent activity against adult *T. castaneum* in a choice chamber. Benzaldehyde at 50 ppm showed the highest repellency of 71% over a 24-hour test period. Piperidine and geraniol at 50 ppm showed moderate repellency.	Saim and Meloan, 1986
	Constituents	The 19 volatile compounds identified include four chlorinated compounds: chloroform, ethylene trichloride, 1,1,2-trichloroethane and methylene dichloride.	Verma, 1980
		Pinene, phellandrene, cineole, linalool and geraniol have already been reported.	Duke, 1985

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Lavendula spp. (Labiatae) Lavender			Rehm and Espig, 1991
	Uses	Lavender is used in perfumery.	Rehm and Espig, 1991
	Oil	15 µl/litre of air in fumigation chambers caused 100% mortality in adult *R. dominica*, and over 90% mortality in adult *O. surinamensis*, within 24 h.	Shaaya *et al.*, 1991
	Constituents	Include: linalyl acetate, geranyl acetate, linalool, geraniol, limonene, *d*-pinene, coumarin, furfurol, *d*-borneol, cineol.	Jouhar and Poucher, 1991
	Toxicity	Large doses of the oil produce a narcotic effect and have also been shown to cause dermatitis.	Duke, 1985
Linum usitatissimum (Linaceae) Linseed, flax	Uses	Linseed oil is used in painting materials; the seeds are eaten and pressed cakes are used as fodder.	Rehm and Espig, 1991
	Oil seed cake	7.5% (w/w) applied to maize seed in a choice-chamber test produced a repellant effect against *S. oryzae* and reduced the number of eggs laid.	Bowry *et al.*, 1984
		5% (w/w) admixed with wheat significantly reduced the number of adult *S. cerealella* emerging from eggs placed on the treated grains.	Verma *et al.*, 1983
	Oil	1 ml/kg oil admixed with wheat reduced grain damage by adult *S. oryzae* to 10% compared with 72% in the untreated control, over a 90-day storage period.	Singh and Mall, 1991
		3 ml/kg oil admixed with wheat seed caused 99% mortality in adult *S. oryzae* within 72 h and slightly reduced damage by F1 insects.	Pal *et al.*, 1988
	Seed viability	5% (w/w) admixed with wheat did not reduce germination.	Verma *et al.*, 1983
Lippia geminata (Verbenaceae) Wild sage (India)			Rehm and Espig, 1991
	Leaves	When 2% (w/w) was admixed with paddy rice in a choice-chamber trial and compared with untreated paddy rice, *S. cerealella, R. dominica* and *S. oryzae* adults showed a preference for F1 production on untreated rice.	Prakash and Jagadiswari, 1989
Lonchocarpus salvado-rensis (Leguminosae)	Description	This is a tropical legume tree.	Birch *et al.*, 1985

	Seed extract	The seed extracts, rotenone and degulin, applied at 0.5% (w/w) to artificial test seeds made of cowpea flour, prevented the emergence of F1 adults following oviposition by *C. maculatus*.	Birch *et al.*, 1985
	Components	Seeds contain degulin (0.29%) rotenone (0.22%), elliptone (0.06%) and toxicarol (0.003%).	Birch *et al.*, 1985
Lycopersicon esculentum (Solanaceae) Tomato			Cooke-Stinson, 1986
	Uses	The fruit is eaten both raw and cooked and is also used in traditional medicine.	Duke, 1985
	2-tridecanone, extract from leaf	200 ppm 2-tridecanone applied to wheat almost completely prevented emergence of F1 *S. granarius* 12 weeks after introduction of adults. It was also effective against *S. oryzae* and *S. zeamais* but showed little effect against *T. castaneum, T. confusum* and *R. dominica*.	Cooke-Stinson, 1986
	Constituents	Include: coumaroylputrescine, tomatidine, tomatine, diferuloylputrescine and 2-tridecanone.	Southon and Buckingham, 1988
Melia azadirachta/azedarach (Meliaceae) Chinaberry, Persian lilac	Description/uses	The tree is found in south-western Asia and is naturalized in the south-eastern US. It is used as an anthelmintic in China, as a fish poison, and in traditional medicine in Colombia and India	Duke, 1985
	Oil	1 ml/100g gram seed caused 100% mortality in adult *C. chinensis* within 3 days and prevented the emergence of F1.	Ali *et al.*, 1983
	Constituents	Include: azadirachta. Four toxic tetranortriterpenoids have been identified in seed kernels from Australia.	Morgan and Mandava, 1987
		Include: 1-cinnamoyl-3-feruloyl-11-hydroxymeliacarpin. This compound identified in the leaves is very similar to azadirachtin D.	Rembold, 1989
	Toxicity	The drupes of the tree have produced death in humans when ingested. Symptoms of poisoning include digestive irritation, dysfunction of the nervous system and kidney malfunction.	Blackwell, 1990
		The LD_{50} for an oral dose of the toxic principles (meliatoxins) for a pig is 6.4 mg/kg.	Morgan and Mandava, 1987
Mentha arvensis (Labiatae) Japanese mint			Ahmed and Eapen, 1986
	Uses	This source of peppermint oil has a high menthol content (82-86%).	Rehm and Espig, 1991
	Oil	The vapour from 200 mg of oil in 860 ml desiccators caused 70% mortality in adult *C. chinensis* within 24 h. The LD_{50} following vapour exposure for 24 h was 2.18 mg/litre for adult *C. chinenis* and 3.3 mg/litre for adult *S. oryzae*.	Ahmed and Eapen, 1986
		0.2% (w/w) applied to red gram prevented egg laying by *C. chinensis*.	Srivastava *et al.*, 1988
	Constituents	Include: menthol, menthone and menthyl acetate.	Singh *et al.*, 1989

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Botanical/common names	Descriptors	Remarks	References
Mentha longifolia	Oil	10 g wheat treated with 2 ml of 2% solution in acetone caused 100% mortality in *S. oryzae* within 48 h.	Mathela *et al.*, 1989
	Constituents	Include: menthol, menthone, piperitone, piperitenone, linalool, carvone and eucalyptol.	Mathela *et al.*, 1989
Mentha piperita Peppermint			Rehm and Espig, 1991
	Uses	Peppermint is used in the food and cosmetics industries, and in pharmacy.	Rehm and Espig, 1991
	Oil	Exposure of *T. castaneum* to 4 µl/litre, in a fumigation chamber for 48 h caused 91% mortality in 1st instar larvae, 71% mortality in 2nd instar larvae and 60% mortality in adults. 7 µl/litre caused 92% mortality in adults within 24 h.	Mishra and Kumar, 1983
		Exposure to 6 µg/litre for 3 h in a fumigation chamber caused 100% mortality in *S. cerealella* and 50% mortality in adult *A. obtectus.*	Klingauf *et al.*, 1983
		Exposure to 15 µl/litre in a fumigation chamber for 3 h caused >75% mortality in adult *T. castaneum, R. dominica, O. surinamensis* and *S. oryzae.*	Shaaya *et al.*, 1991
	Constituents	Include: menthol, menthone and menthyl acetate.	Singh *et al.*, 1989
Mentha spicata Spearmint			Rehm and Espig, 1991
	Uses	Spearmint is used as an aromatizer in the food industry.	Rehm and Espig, 1991
	Leaf powder	10 (w/w) admixed with green gram prevented oviposition in adult *C. analis* and the production of F1.	George and Patel, 1992
		2% (w/w) admixed with milled rice had little effect on the development of *C. cephalonica.*	Prusty *et al.*, 1989
Momordica charantia (Cucurbitaceae) Balsam pear, bitter gourd, karela			Rehm and Espig, 1991
	Uses	It is eaten in Asia as a vegetable, and used as a medicinal plant in the West Indies and South America.	Rehm and Espig, 1991; Ayensu, 1981
	Leaf powder	2% (w/w) admixed with wheat reduced damage by *T. granarium* larvae; 6 months after initial introduction of larvae, the observed damage was 32% in the treated wheat compared with 90% in the control.	Jood *et al.*, 1993
	Seed oil	1% oil in acetone applied to filter paper showed Class IV repellent activity (75%) against *T. castaneum* 4 weeks after application, when assessed by a 5-day repellency trial.	Mohiuddin *et al.*, 1987

	Constituents	Include: charantin, momordicin and foetidin; 5-hydroxytryptamine, diosgenin and β-sitosterol.	Oliver-Bever, 1986
	Toxicity: seed oil	50 mg/kg of charantin reduces hyperglycaemia in rabbits by 42%. It has also shown antifertility effects in both males and females.	Oliver-Bever, 1986
Monodora myristica (Annonaceae) Jamaican nutmeg, calabash nutmeg			Rehm and Espig, 1991
	Uses	It is used locally as a seasoning in cooking or eaten alone as a stimulant.	Ofuya *et al.*, 1991
	Ether extract of seeds	Cowpea, pigeon pea and bambara seeds rubbed with extract were protected from attack by F1 *C. maculatus* following the introduction of adult insects.	Ofuya *et al.*, 1991
	Constituents	Include: β-phellandrene, α-pinene, limonene, (Z) and (E) ocimene, linalool, methyl chavicol, terpinen-4-ol, thymol and carvacrol.	Ekundayo, 1989
Myristica fragrans (Myristicaceae) Nutmeg and mace			Rehm and Espig, 1991
	Uses	This culinary spice is also used in perfumes and as a medicinal plant in the West Indies.	Ayensu, 1981
	Acetone extracts of nutmeg and mace	2000 ppm of extract applied to wheat reduced F1 emergence of *S. oryzae* when the adults were introduced 14 weeks after treatment. Nutmeg extract was most effective, reducing F1 emergence by approximately 66%; mace extract reduced F1 emergence by approximately 50%.	Su, 1989
	Constituents	Include: eugenol, iso-eugenol, terpineol, borneol, linalool, geraniol, safrole, myristicin, pinene, camphene, terpenes and free acids.	Jouhar and Poucher, 1991
	Toxicology	Volatile oils from nutmeg and mace in overdose at 5 g (equivalent to one whole nutmeg) are intoxicant and potentially hallucinogenic. The LD_{50} in rats is less than 1 g/kg.	Oliver-Bever, 1986
Nerium oleander (Apocynaceae) Oleander			El-Ghar and El-Sheikh, 1987
	Description	Oleander is a garden shrub.	Ayensu, 1981
	Plant	5% (w/w) admixed with cowpeas caused 95% mortality in adult *C. chinensis* within 3 days and prevented the production of F1 progeny.	El-Ghar and El-Sheikh, 1987
	Constituents	Include: various digitalis-like cardiac glycosides, oleandrin, digitalin, adynerin and neriantin.	Oliver-Bever, 1986
	Toxicology	All parts of the plant, both green and dry, are considered to be toxic to livestock. The cardioactive substances in oleander increase the contractility of heart muscle and may cause cardiac arrest.	Kingsbury, 1964

Botanical/common names	Descriptors	Remarks	References
Nicotiana tabacum (Solanaceae) Tobacco			Rehm and Espig, 1991
	Uses	Tobacco is used for cigarettes and as a local medicine in West Indies. Tobacco seed oil is used as a culinary oil	Rehm and Espig, 1991
	Powder	2 g (w/w) admixed with 500 cowpea seeds significantly reduced the numbers of eggs laid by *C. maculatus* and reduced subsequent egg hatch by 75%.	Ofuya, 1990
	Dust	30% medium-grade tobacco dust admixed with maize reduced damage by natural infestations of *S. zeamais* and *S. cerealella* over a 33-week storage period.	Golob *et al.*, 1982
	Constituents	Nicotine, nornicotine and anabasine.	Oliver-Bever, 1986
Ocimum basilicum (Labiatae) Sweet basil, albahaca			Rehm and Espig, 1991
	Uses	This is used as a culinary herb and the distilled oil is used in perfumery; it is also used as a herbal medicine in the West Indies.	Ayensu, 1981
	Oil	15 μl/litre in a fumigation chamber caused 100% mortality in adult *O. surinamensis*, 80% mortality in *R. dominica* and approximately 45% mortality in *S. oryzae*, within 24 h.	Shaaya *et al.*, 1991
		1% oil in acetone applied to filter paper showed class V repellent activity (98%) against *T. castaneum*, 8 weeks after application, when assessed by a 5-day repellency trial; the responses were lower over the first 4 weeks.	Mohiuddin *et al.*, 1987
	Constituents	Oil contains linalool, methyl chavicol, eugenol, 1,8-cineole, α-pinene, (Z)-and also (E)-ocimene, camphor and borneol.	Jouhar and Poucher, 1991
		Also thymol.	Oliver-Bever, 1986
	Toxicity	The two carcinogens safrole and estragole (methyl chavicol) have been reported in some oils.	Duke, 1985
Ocimum canum Hoary or American basil			Oliver-Bever, 1986
	Uses	The leaves are used as a traditional medicine in West Africa.	Oliver-Bever, 1986
		It is also used in Rwanda to protect against post-harvest insect damage.	Weaver *et al.*, 1991a
	Dried milled leaves	Contact with 1 g of leaves in an arena caused 100% mortality in adult male *Z. subfasciatus* after 24 h and 50% mortality in adult females after 48 h.	Weaver *et al.*, 1991a

	Extract from leaves	The LC_{50} values for linalool applied to filter paper in a 24-h exposure trial were 412 µg/cm² for *A. obtectus*, 427 µg/cm² for *S. oryzae*, 429 µg/cm² for *Z. subfasciatus* and 430 µg/cm² for *R. dominica*. A dose of 750 µg/cm² caused 100% mortality in all four species within 24 h.	Weaver *et al.*, 1991b
	Constituents	Linalool is the major component of the oil, forming 60-90% of the total volatiles collected.	Weaver *et al.*, 1991b
		Composition of the essential oil varies according to its origin. In East Africa it contains 16-25% camphor, while in Central Africa methyl cinnamate predominates; in West Africa it may contain 75% methylchavicol (estragol).	Oliver-Bever, 1986
	Mode of action	Linalool is an oxygenated monoterpenoid which acts as a reversible competitive inhibitor of acetylcholinesterase.	Weaver *et al.*, 1991b
Ocimum suave	Uses	This shrub found in East Africa is used as a traditional medicine and grain protectant.	Hassanali and Lwande, 1989
	Oil	The oil showed repellent properties against *S. zeamais* when assessed 1 h after application in an olfactometer.	Hassanali *et al.*, 1990
	Constituents	Include: eugenol and mono- and sesquiterpenoids.	Hassanali *et al.*, 1990
Olea europaea (Oleaceae) Olive oil			Ahmed *et al.*, 1988
	Uses	This culinary oil is also used in soap.	Ahmed *et al.*, 1988
	Oil	10 ml/kg admixed with maize caused 100% mortality in adult *S. oryzae* within 3 h.	Salas, 1985
		10 ml/kg admixed with pigeon pea caused 100% mortality in adult *C. maculatus* and 96% mortality in adult *A. obtectus* within 1 h.	Salas and Hernandez, 1985
		15 ml/kg admixed with mung bean reduced damage by *C. maculatus*, 4 months after application, by at least 95% compared with the untreated control.	Ahmed *et al.*, 1988
	Constituents	Include: cinchonidine, cinchonine and hydrocinchonine.	Duke, 1985
Origanum vulgare (Labiatae) Oregano, wild marjoram			Rehm and Espig, 1991
	Uses	Oregano is a culinary herb used in Mediterranean countries.	Rehm and Espig, 1991
Origanum spp.	Oil	10 µl/litre of air in a fumigation chamber caused 100% mortality in adult *O. surinamensis*; 15 µl/litre caused 75% mortality in *R. dominica* and 40% mortality in *S. oryzae*, within 24 h.	Shaaya and Pisarev, 1991
	Constituents	Include: carvacrol, thymol, linalool, cedrol, cymene, pinene and origanene.	Jouhar and Poucher, 1991

Botanical/common names	Descriptors	Remarks	References
Oryza sativa (Gramineae) Rice			Rehm and Espig, 1991
	Uses	Rice is a staple food. Oil, wax and animal feed can be produced from rice mill residues.	Rehm and Espig, 1991
	Bran oil	1% (w/w) admixed with green gram prevented oviposition in *C. chinensis* and reduced egg laying in *C. maculatus* by 96%; 0.5% (w/w) totally prevented emergence of F1 adults in both species.	Doharey *et al.*, 1988
Pimpinella anisum (Umbelliferae) Aniseed, anise, anis			Rehm and Espig, 1991
	Uses	The fruits are used in baking and the essential oil is used to produce liqueurs.	Rehm and Espig, 1991
	Oil	15 µl/litre of air in a fumigation chamber caused 100% mortality in adult *T. castaneum*, 75% mortality in adult R. dominica and 12% mortality in *S. oryzae* within 24 h.	Shaaya and Pisarev, 1991
	Constituents	Include: anethole, with traces of pinene, phellandrene, dipentene, *l*-limonene, hydroquinone ethyl ether, methyl chaicol, anisic analdehyde, anisic acid, *p*-cymene, cineol, safrole and terpineol.	Jouhar and Poucher, 1991
	Toxicology	Anethole is a moderately acute toxin, with an oral LD_{50} for rats of 4.52 ml/kg.	Duke, 1985
Piper cubeba (Piperaceae) Java long pepper			Rehm and Espig, 1991
	Description/uses	This is an evergreen shrub. Oil is extracted from the unripe fruit and is used as a flavouring and in traditional medicine.	Su, 1990
	Cubebin extract	50 µg/cm^2 applied to wrapping paper in choice chamber tests did not reduce the amount of feeding damage by *R. dominica* and *S. granarius* in a 7 day trial.	Nawrot *et al.*, 1987
	Fruit extract	Topical application of cubeba hexane extract at 50 µg/insect caused 72% mortality in adult *S. oryzae* and 87% mortality in *C. maculatus*, when mortality was assessed at 7 days. Extract admixed with wheat at 0.2% reduced F1 production of *S. oryzae* and *C. maculatus* by 71% and 42%, respectively. Extract showed repellent properties in choice-chamber tests against both species.	Su, 1990
Piper guineense Orange pepper, West Africa black pepper			Ivbijaro and Agbaje, 1986
	Uses	This pepper is used as a culinary spice. It is also used in traditional medicine in Africa and China.	Oliver-Bever, 1986
	Powder	1.5 g/20 g admixed with cowpea seeds caused 96% mortality in adult *C. maculatus* when assessed at 48 h, and significantly reduced F1 emergence.	Ivbijaro and Agbaje, 1986

	Oil extracted in hexane	2 ml/kg cowpea seed caused 100% mortality in adult *C. maculatus* within 24 h and prevented the emergence of F1 adults.	Ivbijaro, 1990
		1000 ppm applied to cowpeas reduced F1 emergence by 74% in *C. maculatus* and by 97% in *S. oryzae* on wheat.	Su, 1983
	Oil	0.02% oil applied to cowpeas completely prevented oviposition by adult *C. maculatus*.	Olaifa and Erhun, 1988
	Seed viability	Surface treatment of cowpea seed with 1.5 g/20 g seed did not reduce seed germination.	Ivbijaro and Agbaje, 1986
	Constituents	Fruits contain the amides piperine, N-iso-butyloctadeca-trans-2-trans-4-dienamide, sylvatine, α, β-dihydro-piperine and trichostachine. The essential oil from the berries is composed of the terpenes phellandrene, pinene and limonene.	Oliver-Bever, 1986
Piper nigrum Black pepper			Rehm and Espig, 1991
	Uses	Pepper is used as a seasoning.	Rehm and Espig, 1991
	Powder	600 ppm ground powder applied to maize caused 100% mortality in adult *S. zeamais* within 6 days, declining to 78% after 2 months of storage. A crude ethanol extract applied at 250 ppm caused 98% adult mortality within 6 days immediately after treatment, and 100% mortality within 10 days, 2 months after treatment	Javier and Morallo-Rejesus, 1986
		300 ppm ground powder applied to mung bean caused 100% mortality in adult *C. chinensis* within 5 days, 6 months after treatment.	Morallo-Rejesus *et al.*, 1990
	Acetone extract	10.38 mg/cm² applied to filter paper in choice-chamber tests showed Class V repellency (81% repellency) against *T. castaneum* when assessed over 4 weeks.	Sighamony *et al.*, 1984
	Oil	200 ppm admixed with wheat caused 100% mortality in adult *S. oryzae* and *R. dominica* within 24 h when assessed 15 days after treatment. When assessed at 30 and 60 days after treatment, mortality in *S. oryzae* was 100% and 20%, respectively, whereas mortality in *R. dominica* was 80% and 24% respectively.	Sighamony *et al.*, 1986
	Oil extracted in hexane	1000 ppm applied to cowpeas reduced F1 emergence of *C. maculatus* by 96% and emergence of F1 adult *S. oryzae* on wheat by 97%.	Su, 1983
	Constituents	Include: pipercide, dihydropipercide and guineensine.	Miyakado, *et al.*, 1989
Pongamia glabra (Fabaceae) Karanja (India)			Ketkar, 1987
	Uses	Parts of this tree are used to produce a non-edible oil	Ketkar, 1987
	Oil	200 ppm admixed with wheat caused 100% mortality in adult *S. oryzae* and 80% mortality in adult *R. dominica* within 24 h when assessed 15 days after treatment. When assessed at 30 and 60 days after treatment, mortality in *S. oryzae* was 90% and 40%, respectively, whereas mortality in *R. dominica* was 40% and 0%, respectively.	Sighamony *et al.*, 1986

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Pongamia glabra (*contd*)	Oil (*contd*)	5 ml/kg applied to wheat held in a store for 12 months prevented attack by natural infestations of insects. The treatment maintained the percentage infestation at below 4% compared with 63% in the controls.	Gupta *et al.*, 1988
		0.2% (v/w) admixed with green gram reduced weight loss caused by adult *C. chinensis* to 4% compared with 92% in untreated controls, 40 days after treatment.	Ketkar, 1987
		10 ml/kg admixed with mung bean and stored for 18 months prevented the emergence of F1 adult *C. chinensis*, following artificial introductions of adult insects throughout the trial.	Babu *et al.*, 1989
		10.38 mg/cm² applied to filter paper in choice chamber tests showed Class V repellency (87% repellency) against *T. castaneum*, when assessed over 8 weeks.	Sighamony *et al.*, 1984
	Seed viability	200 ppm admixed with wheat had not reduced seed viability when assessed 3 days after application.	Sighamony *et al.*, 1986
		10 ml/kg admixed with mung bean had not reduced seed viability when assessed 18 months after application.	Babu *et al.*, 1989
	Constituents	4,5-dihydroxy-1-methyl 2-piperidinecarboxylic acid.	Southon and Buckingham, 1988
Psidium guajava (Myrtaceae) Guava, goyave			Sharaby, 1989
	Uses	The fruit is canned or made into jam. The leaves are used medicinally in India and West Indies for digestive disorders.	Rehm and Espig, 1991
	Leaves	The LD_{50} for leaf powder admixed with rice assessed for *S. oryzae* and *S. granarius* at 7 days was 2.251% and 2.278% (w/w), respectively. Admixture of 15% w/w with rice prevented the production of F1 adults of both species.	Sharaby, 1989
	Constituents	Leaves contain an essential oil rich in cineol, tannins, four triterpenic acids, and ursolic and oleanolic acids; three flavonoids have been identified in the leaves: quercetin, 3-L-4-arabinofuranoside and 3-L-4-pyranoside.	Oliver-Bever, 1986
Raphanus sativus (Brassicaceae) Fodder radish, karad			Grainge and Ahmed, 1988
	Uses	Radish is cultivated for animal fodder.	Rehm and Espig, 1991
	Oil	3 ml/kg admixed with wheat caused 100% mortality in adult *S. oryzae* within 72 h and significantly reduced the extent of damage by the F1 generation.	Pal *et al.*, 1988

	Seed viability	3 ml/kg admixed with wheat did not reduce seed germination.	Pal *et al.*, 1988
	Constituents	Include: alkaloid spirobrassinin.	Southon and Buckingham, 1988
Ricinus communis (Euphorbiaceae) Castor			Rehm and Espig, 1991
	Uses	Fermented castor seeds are used as a condiment in eastern Nigeria, and unripe and roasted ripe seeds are eaten in Indonesia. The press cake is poisonous and is only used as a fertilizer. Castor oil is also used as a lubricant, an additive in rubber, and as a plasticizer in the plastics industry. It is also used as a traditional medicine.	Rehm and Espig, 1991
	Dried ground leaves	16 g/kg admixed with cowpea caused 100% mortality in adult *C. maculatus* within 7 days and reduced F1 emergence.	Okonkwo and Okoye, 1992
	Oil	10 ml/kg admixed with maize caused 100% mortality in adult *S. oryzae* within 3 h.	Salas, 1985
		10 ml/kg admixed with pigeon pea caused 100% mortality in adult *A. obtectus* and *C. maculatus* within 18 h.	Salas and Hernandez, 1985
		12.5 ml/kg admixed with cowpea seed caused 60% mortality in adult *C. maculatus* within 4 days and prevented the production of F1 adults. When treated cowpeas were stored for 3 months, adult mortality increased to 90% within 4 days.	Mueke and Apuuli, 1986
		10 ml/kg admixed with mung bean and stored for 18 months prevented the emergence of F1 adult *C. chinensis* following artificial inoculation with adult insects.	Babu *et al.*, 1989
	Plant	3 ml/kg admixed with wheat caused 92% mortality in adult *S. oryzae* within 72 h; reduction in damage by the F1 generation was slight compared to the untreated control.	Pal *et al.*, 1988
	Seed viability	10 ml/kg reduced maize seed germination by 62%.	Salas, 1985
		10 ml/kg did not reduce pigeon pea seed viability.	Salas and Hernandez, 1985
		10 ml/kg applied to mung bean and stored for 18 months reduced seed viability by 25%.	Babu *et al.*, 1989
		3 ml/kg applied to wheat seed did not reduce seed viability.	Pal *et al.*, 1988
	Constituents	Leaf: alkaloid ricinine, cyanogenic glycoside, flavonoids, steroidal sapogenin, gallic acid and potassium nitrate. Oil: ricinoleic, stearic, dihydroxystearic, oleic and linoleic acids.	Ayensu, 1981
	Toxicity	Poisoning of livestock and humans by castor beans has been reported. Ingestion of two to four seeds may cause serious poisoning and human fatalities.	Kingsbury, 1964
Rosmarinus officinalis (Labiatae) Rosemary, romero, alecrim			Rehm and Espig, 1991
	Uses	Rosemary is a culinary herb used in Europe. Its essential oil is used in seasoning and as an aroma for soaps.	Rehm and Espig, 1991

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Rosmarinus officinalis (*contd*)	Oil	15 µl/litre of air caused 100% mortality in adult *R. dominica, O. surinamensis* and *S. oryzae* within 24 h.	Shaaya and Pisarev, 1991
	Constituents of oil	Include: limonene, α-pinene, β-pinene, camphor, camphene, limonene, 1,8-cineole, linalool, terpinen-4-ol, bornyl acetate and borneol.	Lawrence and Reynolds, 1989
Salvia officinalis (Labiatae) Sage, sauge, salvia			Rehm and Espig, 1991
	Description/uses	Sage is a culinary herb also used for oil production, and medicinally.	Rehm and Espig, 1991
	Oil	15 µl/litre of air in a fumigation chamber caused 100% mortality in adult *R. dominica* and *S. oryzae*, and >95% mortality in *O. surinamenis*, within 24 h.	Shaaya *et al.*, 1991
	Constituents	Include: α-pinene, limonene, linalool, camphor, terpineol, 1,8-cineole and *p*-cymene.	Lawrence and Reynolds, 1991
Salvia triloba Three-lobed sage			Shaaya and Pisarev, 1991
	Oil	15 µl/litre of air in a fumigation chamber caused 100% mortality in adult *R. dominica*, 92% mortality in *O. surinamensis* and 24% mortality in *S. oryzae* within 24 h.	Shaaya *et al.*, 1991
Saussurea lappa, S. costus (Compositae) Costus, kuth, kut			Rehm and Espig, 1991
	Uses	Resin and essential oil are used for perfumes and also as a treatment for skin diseases.	Rehm and Espig, 1991
	Rhizome petroleum ether-acetone extract	1% extract applied to filter paper showed 79% repellency for *T. castaneum* (Class IV) 1 week after treatment; repellency declined to 52% (Class III) 8 weeks after treatment.	Malik and Mujtaba Naqvi, 1984
	Constituents	Active substances include the alkaloid saussurine.	Rehm and Espig, 1991
Schleichera trijuga (Sapindaceae) Kusum oil			Grainge and Ahmed, 1988
	Oil	0.5% applied to green gram caused 90% mortality in adult *C. chinensis*, and completely prevented weight loss of the commodity during a 90-day storage period, compared with 92% weight loss in the untreated controls.	Ketkar, 1987

Sesamum orientale (Pedaliaceae) Sesame, gingelly, sim-sim, benniseed			Rehm and Espig, 1991
	Uses	The fresh leaves are used as a vegetable. Shelled seeds are used in baking, as a condiment, and in medicines. Cake is used for animal fodder.	Rehm and Espig, 1991
	Oil	0.5% applied in ether to black gram reduced egg laying by adult *C. chinensis* and completely prevented the emergence of F1 adults.	Sujatha and Punnaiah, 1984
		1% (w/w) applied to chickpea and stored for 6 months significantly reduced egg laying by *C. chinensis* and prevented seed damage.	Choudhary, 1990
		1 ml/100 g applied to gram caused 100% mortality in adult *C. chinensis* within 3 days and completely prevented egg laying and the emergence of F1 adults.	Ali *et al.*, 1983
		0.25% applied in ether to green gram reduced egg laying by adult *C. chinensis* by reducing adult longevity; the emergence of F1 adults was completely prevented.	Sujatha and Punnaiah, 1985
		10 ml/kg applied to chickpea caused 100% mortality in adult *C. chinensis* within 4 days and prevented egg laying.	Das, 1986
		0.5% (w/w) applied to green gram reduced the number of eggs laid by *C. maculatus* and prevented F1 emergence.	Doharey *et al.*, 1988
		10 ml/kg applied to pigeon pea caused 92.5% mortality in adult *A. obtectus* and 98.5% mortality in adult *C. maculatus* within 1 h; it also prevented F1 emergence.	Salas and Hernandez, 1985
		10 ml/kg applied to maize caused 100% mortality in adult *S. oryzae* within 3 h.	Salas, 1985
		14 ml/kg applied to wheat reduced the number of eggs laid by *S. zeamais* and prevented the emergence of F1 adults.	Don-Pedro, 1989c
	Seed viability	0.25% oil applied to green gram did not reduce germination.	Sujatha and Punnaiah, 1985
		10 ml/kg reduced the germination of maize seed by 20% compared to the control.	Salas, 1985
Shorea robusta (Dipterocarpaceae) Sal tree			Ketkar, 1987
	Uses	The tree supplies resin for paints. The bark is used in tanning, and the seeds are used for vegetable oil and press cakes.	Ketkar, 1987
	Oil	0.5% applied to green gram reduced damage by *C. chinensis* to 1.3% compared to 92% in untreated controls, during a 90-day storage period.	Ketkar, 1987

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Syzygium aromaticum (Myrtaceae) Clove, girofle			Rehm and Espig, 1991
	Uses	Clove is a culinary spice also used to make kretek cigarettes in Indonesia.	Rehm and Espig, 1991
	Oil	10.38 mg/cm^2 applied to filter paper showed 70% repellency (Class IV) for *T. castaneum* 4 weeks after application declining to 37% (Class II) at 8 weeks. This response was less than that observed for dimethyl phthalate which was used as a standard in repellency test trials.	Sighamony *et al.*, 1984
	Constituents	The oil contains eugenol, a sesquiterpene and caryophylline.	Schauenberg and Paris, 1977
Tagetes erecta (Asteraceae) African marigold			Grainge and Ahmed, 1988
	Plant	The LD_{50} for topical application of root extract against *R. dominica* and *T. castaneum* was 8.1 and 4.3 mg/g, respectively, when assessed at 24 h.	Morallo-Rejesus and Decena, 1982
	Oil	1% oil in acetone applied to filter paper showed Class IV (72%) repellency against *T. castaneum* 8 weeks after application when assessed by a 5-day repellency trial.	Mohiuddin *et al.*, 1987
	Constituents	Include: 5-(3-buten-1-ynyl) 2-2 bithienyl and α-terthienyl.	Morallo-Rejesus and Decena, 1982
Telekia speciosa	Lactone fraction	0.8% extract applied to wafer disc showed Class III feeding deterrence activity against *S. granarius, T. confusum* and *T. granarium.*	Nawrot *et al.*, 1982
Tephrosia vogelii (Leguminosae) Igongo			Delobel and Malonga, 1987
	Uses	This green manure plant is used as a fish poison in East Africa.	Delobel and Malonga, 1987
	Powder	2.5% (w/w) admixed with unshelled groundnuts caused 99% mortality in adult *C. serratus* within 13 days.	Delobel and Malonga, 1987
	Constituents	Deguelin, rotenone and teprosin are found in the leaves, roots, fruit capsules and seeds.	Oliver-Bever, 1986
	Toxicology	Intravenous injection of leaf extract corresponding to 0.01 g/kg of tephrosin has killed dogs in 5 mins, whilst guinea pigs are able to ingest 5 g/kg without adverse effect.	Oliver-Bever, 1986

Tetradenia riparia (Lamiaceae) Umuruvumba (Rwanda)			Dunkel *et al.*, 1991b
	Uses	This perennial mint is used as a traditional medicine in Rwanda.	Dunkel *et al.*, 1991b
	Dried milled leaves	2% (w/w) admixed with pinto beans significantly decreased the number of eggs laid by *A. obtectus*.	Dunkel *et al.*, 1991b
		10% (w/w) admixed with pinto beans reduced oviposition in *Z. subfasciatus* by 40% and reduced the number of eggs which hatched by 50%.	Weaver *et al.*, 1992
	Constituents	Include: 8(14), 15-sandaracopimaradiene-7α, 18-diol, a diterpenol.	Dunkel *et al.*, 1991b
Thymus vulgaris (Labiatae) Garden thyme, frigoule, tomillo			Rehm and Espig, 1991
	Description/uses	Thyme is a culinary herb. The essential oil is used in liqueurs and medicines.	Rehm and Espig, 1991
	Oil	31.4 μl/litre of air in a fumigation chamber caused 90% mortality in adult *A. obtectus* after 3 h of exposure.	Klingauf *et al.*, 1983
		15 μl/litre of air in a fumigation chamber caused less than 70% mortality in adult *O. surinamensis* and *R. dominica* following 24 h of exposure.	Shaaya and Pisarev, 1991
	Constituents	Thymol and terpinen-4-ol	Duke, 1985
	Toxicity	The oil is poisonous and has caused dermatitis.	Duke, 1985
Trewia nudiflora	Extract	1.25% of the nudiflorine extract applied to glass containers caused 90% mortality in adult *S. oryzae* within 12 h when confined on the treated surface.	Chatterjee *et al.*, 1988
	Constituents	Include: dehydrotrewiasine, nudiflorine, ricinidine, treflorine, trenudine and trewiasine.	Southon and Buckingham, 1988
Tridax procumbens (Asteraceae) Coat buttons			Grainge and Ahmed, 1988
	Petroleum ether extract of flower	4% (w/w) of extract admixed with cowpea significantly reduced the damage by *C. maculatus* immediately after treatment.	Bhaduri *et al.*, 1985
Trigonella foenum-graecum (Leguminosae) Fenugreek			Jilani and Su, 1983
	Uses	Fenugreek is used as a seasoning, a medicinal plant and a gum.	Rehm and Espig, 1991
	Petroleum ether extract of leaves	680 μg/cm^2 applied to paper in repellency tests produced Class IV repellency (79% repellency) against adult *T. castaneum* 1 week after treatment; repellency declining to Class III (31%) 8 weeks after treatment. This indicated that the material was not a good repellent.	Jilani and Su, 1983

Alphabetical list of plant species

Botanical/common names	Descriptors	Remarks	References
Trigonella foenum-graecum (*contd*)	Petroleum ether extract of leaves (*contd*)	1% extract applied to filter paper in repellency tests produced Class IV (74%) repellency against *T. castaneum* 1 week after treatment, repellency declined to Class III (45%), 4 weeks after treatment.	Malik and Mujtaba Naqvi, 1984
	Constituents	Include: the alkaloid trigonelline and a steroidal sapogenin, diosgenin.	Southon and Buckingham, 1988
Tylophora asthmatica (Asclepiadaceae)	Leaves	5% (w/w) admixed with wheat and stored for 2 months caused high mortality in 1st instar *C. cephalonica* and prevented adult emergence.	Chander and Ahmed, 1986
	Constituents	Include: anhydrodehydrotylophorinine, antofine, septicine and tylophorine.	Southon and Buckingham, 1988
Vegetable oil (unspecified)	Oil	5 ml/kg on maize caused 100% mortality in adult *R. dominica* and *D. distinctus* and prevented emergence of F1 adults, immediately after application. 10 ml/kg was required to produce the same response in both species on wheat and sorghum. Wheat and sorghum treated with 10 ml/kg caused 100% mortality of adult *D. distinctus* and prevented F1 production, 3 months after treatment.	Kumar and Okonronkwo, 1991
		5 ml/kg on *P. vulgaris* reduced damage by *A. obtectus* significantly and prevented emergence of F1 adults.	Baier and Webster, 1992
	Seed viability	10 ml/kg on maize, wheat and sorghum seed did not significantly reduce germination.	Kumar and Okonronkwo, 1991
Venidium hirsutum (Compositae)	Petroleum benzene and chloroform extracts	0.8% extract applied to wafer disc produced Class IV (very good deterrent) feeding deterrent activity against *T. confusum* and *T. granarium*.	Nawrot *et al.*, 1982
Vitex negundo (Verbenaceae) Lagundi, nishinda, begunia, huangjing			Prakash and Jagadiswari, 1989
	Uses	This is used as a traditional medicine in China, Indo-China, Indonesia and the Philippines.	Perry, 1980
	Oil	Exposure to a combination of citronella and lagundi oil (1:1) in a fumigation flask caused knockdown of adult *S. cerealella*. No figures were given.	Krishnarajah *et al.*, 1985
		5 mg/50 g mung bean caused 80% mortality in adult *C. chinensis* within 48 h and prevented egg laying.	Morallo-Rejesus *et al.*, 1990
	Leaves	Admixture of 5% (w/w) leaves did not significantly reduce the percentage of infestation and damage by *S. zeamais* on maize, compared to the control, during a 6-month storage period.	Buiyah and Quiniones, 1990
	Plant	2% admixed with milled rice did not reduce the rate of development of *C. cephalonica* larvae.	Prusty *et al.*, 1989
		3% admixed with black gram reduced damage by natural infestations of *C. chinensis* significantly during a 9-month storage period.	Prakash and Jagadiswari, 1989

		1% admixed with freshly harvested paddy, field-infested with *S. cerealella*, significantly reduced the number of emerging F1 adults during 4 months of storage.	Dakshinamurthy, 1988
	Z-heptatriacontanone isolated from leaves	400 ppm admixed with rice reduced oviposition in *S. cerealella, R. dominica* and *S. oryzae*.	Prakash *et al.*, 1990
	Constituents	The leaves contain: an alkaloidal material; crystalline substances, apparently gluconoitol; p-hydroxybenzoic acid and a second glycoside.	Perry, 1980
Zanthoxylum alatum (Rutaceae) Prickly ash, tejbal, tumru, hua-jiao, timur (Nepal)			Su, 1984
	Uses	This is used as a flavouring in cooking and as an anthelminthic. In Nepal, seed oil and crush seeds are added to cereal seeds and legumes to protect against damage by stored grain pests.	Gyawali, 1993
	Acetone extract of dried pericarp	340 µ/cm² on filter paper produced 53% (Class III) repellency against *T. confusum* adults 1 month after treatment; repellency declined to 44% (Class III) 2 months after treatment. The extract admixed at 5% (w/w) to food media caused no oral toxicity in *S. oryzae* adults and *C. maculatus* larvae when applied as a commodity treatment.	Su, 1984
	Constituents	Include: chelelactam, fagarine, haplopine, nitidine, robustine, sanguinarine.	Southon and Buckingham, 1988
Zea mays (Andropogonoideae) Maize, mais, maiz, corn	Description/uses	A staple food in many African and Central American countries, is also used for the production of vegetable oil and fructose corn syrup, and as an animal fodder.	Rehm and Espig, 1991
	Oil	10 ml/kg admixed with wheat caused 97% mortality in adult *S. granarius* within 2 weeks, immediately after application, declining to 53%, 60 days after treatment. At both time intervals, >99% reduction in adult F1 emergence ocurred.	Qi and Burkholder, 1981
		2.5 mg/kg admixed with cowpea caused 98.5% mortality in adult *C. maculatus* within 3 days, and almost completely prevented F1 emergence.	El-Sayed *et al.*, 1989
		14 ml/kg admixed with wheat reduced the number of eggs laid by *S. zeamais* and prevented the emergence of F1 adults.	Don-Pedro, 1989c
		7.5 ml/kg admixed with cowpea and stored for 12 weeks, reduced the number of eggs laid by *C. rhodesianus*, and reduced the emergence of F1 adults to 26%, compared with 72% in the untreated controls.	Giga and Munetsi, 1990
	Seed viability	10 ml/kg of oil admixed with wheat seed and stored for 4 months, reduced the germination rate by 65%.	Qi and Burkholder, 1981

Botanical/common names	Descriptors	Remarks	References
Zingiber officinale (Zingiberaceae) Ginger, ginembre, gengibre			Rehm and Espig, 1991
	Uses	Ginger is used as a culinary spice, and as a traditional medicine in the West Indies and China.	Rehm and Espig, 1991
	Powdered rhizome	3% (w/w) admixed with wheat caused 56% mortality in adult *S. oryzae* in 30 days, compared with 29% in the untreated controls. The emergence of F1 adults was reduced by 60% compared to the controls.	Ahamad and Ahmed, 1991
		2.5 g of powder admixed with 500 brown cowpeas reduced egg laying by adult *C. maculatus* and reduced the emergence of F1 adults by 96%, compared to the untreated controls.	Echendu, 1991
	Seed viability	2.5 g of powder admixed with 500 brown cowpea seeds and stored for 3 months did not reduce seed viability.	Echendu, 1991
	Constituents	Include: sesquiterpene zingiberine, zingerone, β-camphene, β-phallandrine, cineole, citral, borneol and zingiberol.	Ayensu, 1981
		Methylheptenone, nonylaldehyde and linalool have also been reported.	Jouhar and Poucher, 1991

Section 4

Discussion

Published research on the use of plant materials for the control of stored product insect pests shows that a large number of plant species from a wide range of families has been evaluated over the past 12 years. Jacobson (1989) noted that the most promising botanical pesticides were to be found amongst the Meliaceae, Rutaceae, Asteraceae, Annonaceae, Labiatae and Canellaceae. During the present review, references to trials using plant species from 50 families were found (*see* Appendix 2). The families for which there were references to the most species were the Compositae (ten), Fabaceae (six), Labiatae (nine), Leguminosae (six), Solanaceae (seven) and Umbelliferae (six); there were references to between one and five species in the remaining families.

Those plant species that have been investigated are often used locally, as culinary spices or in traditional medicine, and some researchers have therefore inferred that they are safe for use as insecticides. Cross-referencing the plant species in international pharmacopoeia has shown that they may also be suitable for the treatment of many ailments, such as colds, sores, cancer and leprosy, for the induction of parturition, and for contraception. These wide-ranging medicinal uses do not, however, obviate the need for toxicological testing if materials derived from them are to be promoted for use as food protectants.

METHODS USED TO ASSESS BIOLOGICAL EFFICACY

In most of the papers reviewed, the methods used for evaluating the plant materials were questionable, particularly with respect to the amount of the commodity initially treated, and to the number of test insects in the trial. Frequently, only one, five or 10 pairs of insects were used in each replicate, and these were placed on commodities treated at various rates. Observations on the effectiveness of the plant material generally continued only during one generation of insects following application; the materials were rarely re-evaluated to assess their residual effects over time. Occasionally, trials have been described which, although lasting for several months, have only tested the protective properties of the material against adult insects; the insects usually died before laying eggs. In these cases, comparison with untreated controls offers no real indication of residual activity. In other trials, small sacks of commodity, both treated and untreated, have been left under normal storage practices in farm stores to acquire natural infestations of insects. Although this cannot quantify the persistence of a plant material, if the control and treatment are subjected to the same level of infestation pressure, the period for which the treated sacks remain relatively uninfested can, however, give some measure of efficacy and residual effectiveness.

In many of the papers, the effectiveness of a plant material or extract against a particular insect species was described giving no indication of how it worked. For example, although the failure to produce an F1 generation was frequently reported, no explanation was given as to whether this was due to adult mortality before egg-laying, egg mortality, larval mortality, or larval starvation by repellency of the treated commodity. An understanding of these factors is essential when determining the effectiveness of a particular treatment.

Although various solvents have been used for extraction, few attempts have been made to isolate the insecticidal or non-insecticidal constituents of the plant extracts. Extensive cross-referencing has, however, provided some indication of possible constituents.

Although many of the test plants can be found across a broad geographical range, only a few have been examined in more than one country. It is a well established fact of plant chemistry that different climatic, soil and seasonal conditions can affect the type and quantity of the components isolated from extracts. For example, the rhizomes of *Acorus calamus,* which is widely distributed in ponds and lakes in Asia, North America and Europe, contain a compound, β-asarone, with toxic and sterilizing properties. However, whereas the tetraploid karyotype (4n=48) found in India, East Asia and Japan contains 70-96% β-asarone, the diploid karyotype (2n=24) of North America, and the triploid karyotype (3n=36) of Central Europe, contain less than 15% (Schmidt and Streloke, 1994). Such strain variations will need to be ascertained in future evaluations of potential plant species in order to avoid using material from sources with low insecticidal activity.

The presence of so-called secondary compounds, which have no known function in photosynthesis, growth or other aspects of plant physiology, confer the anti-insect activity on the extracts. Secondary compounds include alkaloids, terpenoids, phenolics, flavonoids, chromenes and other minor chemicals. They can affect insects in several different ways, such as disrupting major metabolic pathways and causing rapid death, acting as attractants, deterrents, phagostimulants or antifeedants, or modifying oviposition. They may retard or accelerate development, or interfere with the life cycle of the insect in other ways (Bell *et al.,* 1990). Lists of the secondary metabolites found most commonly in the plant species examined have been compiled for reference (*see* Appendix 3); many of the compounds have been found in all the plants tested. Those plants which provide large or economic yields of key chemicals may offer the greatest potential as future botanical insecticides. Details of mammalian toxicity are given in Appendix 4.

The genera that have been investigated most frequently are *Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum* and *Piper.* These have many chemical constituents in common (*see* Appendix 5) and the following are found in at least three of the six genera: the five terpenoids carene, cineole, citral, eugenol and phellandrene; the alcohol linalool; and the phenol safrole. The terpenoid limonene is found in five genera and hydrocyanic acid is found in four. *Acorus,* which has not been reported to possess either of these toxicants, contains the phenyl propene, asarone (Lander and Schreier, 1990).

USE OF PLANT MATERIALS AS STORED PRODUCT PROTECTANTS

Many researchers are attempting to substantiate the efficacy of traditional storage protectants. Others are either seeking effective, readily available plant species in the local environment for farmer use at village level (Weaver *et al.,* 1991a), or plant extracts with potential for development by local pesticide industries (Kis-Tamas, 1990). Decisions on the intended users need to be made.

Whatever the intended end-use, candidate plants for pest control would need to be perennial, easy to grow, and economical to produce in terms of space, labour, water and fertilizer application; they should not show any potential to become weeds or hosts for pathogens, and if possible, they should offer complementary economic uses. In addition to the plant properties, the insecticidal component should effectively control the range of pests encountered in local storage situations, be safe to use, pose no environmental hazard, and be easy to extract, formulate and use with the skills available (Kis-Tamas, 1990). Unfortunately, in the papers examined so far, there has been little indication that any of these characteristics has been considered sufficiently.

Seed viability

The effects of the test materials on seed germination have only been examined in a few cases. Even when the effects on seed viability were investigated, tests were seldom carried out after 6-12 months, the normal period of storage for seed grain.

It has been argued that if a material is only to be used for seed treatment, investigations of its toxicological properties are not so essential. However, materials registered for seed treatment need to undergo the same stringent toxicological evaluation as for other applications, because the seed will be handled and, in times of shortage, may also be eaten.

Taint

If a synthetic insecticide is to be approved for use in grain storage, it must fulfil 10 criteria, one of which is that it must not affect the quality, flavour, smell or handling of the grain (Snelson, 1987). Unfortunately, many plant materials impart a taint to processed or unprocessed food when added directly to food commodities. The traditional practice of applying pepper, turmeric and garlic to rice or beans for the control of storage pests appears to be acceptable. However, few investigators have carried out tasting trials to ascertain whether the treated commodity is acceptable to local people when prepared in the customary manner. Unwanted plant material is often removed from the commodity by sieving or rinsing after storage.

Vegetable oils

The application of vegetable oils to beans for protection against attack by bruchid beetle has been confirmed as effective by many workers. In this review, references were found to studies on the insecticidal action of oils applied to various commodities, including rice, maize and wheat. Coconut oil was effective against *C. chinensis* and *C. maculatus* for a storage period of six months when applied to green gram at 1% (Doharey *et al.*, 1990), and it also protected rice against *R. dominica* and *S. cerealella* (Ambika Devi and Mohandas, 1982). Application of castor oil at 10 ppm to mung bean prevented damage by *C. chinensis* when the insects were introduced 18 months after treatment (Babu *et al.*, 1989). In all cases, the oil caused rapid adult mortality and prevented F1 emergence.

Vegetable oils are generally reported to exert an ovicidal action as well as causing adult mortality. Don-Pedro (1989a) applied groundnut oil to cowpea at a rate of 14 ml/kg and then infested the grains with *C. maculatus;* the carbon dioxide output of eggs laid on the treated and untreated cowpeas was observed. The pattern was similar for the first 72 h, but after that, carbon dioxide output in the untreated eggs rose six fold, while the output from the eggs laid on the treated grains remained unchanged. The post-72 h period coincides with late embryonic development and growth of the 1st instar larvae. Only 3% of the eggs examined hatched on the treated cowpeas compared to 76% on the untreated controls. It was suggested that egg mortality was caused by the physical properties of the oil coating which blocked respiration rather than by a specific chemical effect. However, the larvae hatching from eggs of *Callosobruchus* spp.

must penetrate a seed in order to survive and they are unable to do this unless the eggs are firmly attached to the seed surface. Eggs on the oil-treated seeds were found to be less firmly attached than on the controls, suggesting that the oil may inhibit larval penetration into the seed. Credland (1992) suggested that the funnel structure at the posterior pole of *Callosobruchus* eggs may be the major route for gaseous exchange and proposed that the application of oil may occlude the funnel and asphyxiate the developing larva.

Section 5

Azadirachta indica: the neem tree

DESCRIPTION

The neem tree, *Azadirachta indica*, belongs to the Meliaceae. Originally indigenous in southern and south-eastern India, it is now found in tropical and subtropical areas of Africa, America and Australia. It is evergreen, non-deciduous and fast growing, and reaches maturity within 10-15 years. It thrives in tropical climates with an average rainfall of 400-800 mm/year but can also tolerate severe drought and poor or shallow soils (Schmutterer, 1990). It has been widely planted for afforestation, shade and fuelwood, and for the production of natural pesticides. In India, neem oil extracted from the fruit is used in the manufacture of soap and as a lubricant and paint thinner. The residual neem cake is used for nematode control and as a nitrification inhibitor in fertilizer production. India produces approximately 83 000 t of neem oil and 332 000 t of neem cake each year (Saxena, 1989).

Traditional use as a grain protectant

In rural India, dried neem leaves have traditionally been placed in thick layers amongst stored grains, and neem fruits have been crushed on the inner surfaces of grain cribs, to control insect pests (Pruthi and Singh, 1944). Between 1985 and 1987, a survey of 300 farmers in seven Indian states showed that 50% of those storing foodstuffs for longer than three months mixed a handful of shade-dried neem leaves with each sack of grain (approximately 1% w/w); they had learned this technique from their elders and were satisfied with the level of control it conferred (Ahmed, 1988). However, some reports have indicated that this treatment has only a moderate or negligible effect against certain pest species (Morgan and Mandava, 1987). Other common traditional practices in India include the mixing of neem leaf paste with the mud used for making earthen containers, and the soaking of empty gunny bags in a 2-10% neem leaf decoction before drying them and filling them with grain (Saxena *et al.*, 1989). These methods have been based on the fact that neem treatment gives the grain a repellent odour and a bitter taste. The exact quantity required for optimum protection is not generally known.

Active constituents

The active constituents of neem have been identified as limonoids, a group of stereochemically homogeneous steroid-like tetranortriterpenoids. The most active constituent is azadirachtin, but the azadirachtin content of neem seed kernels varies considerably with genetic and environmental conditions. Azadirachtin shows deterrent, anti-ovipositional, antifeedant, growth-disrupting and fecundity- and fitness-reducing properties. It is formed by a group of the closely related isomers AZA, AZB, AZC, AZD, AZE, AZF and AZG. AZA is thought to be the most important compound in neem seed kernel extracts in terms of quantity, although AZE is regarded as the most effective insect growth regulator (Schmutterer, 1990). Many scientists have suggested that the complexity of neem compounds precludes their synthetic production in the near future (Saxena, 1989). Therefore, various neem derivatives have been evaluated for insecticidal activity. These include dried leaves, seed, seed kernel, oil cake, aqueous or organic solvent extracts of seed kernel, standardized neem-rich extracts, partially purified fractions and azadirachtin-rich formulations.

At least 25 other compounds have also been isolated, including β-sitosterol, fatty acids and flavonoids; nine of these, including 22-23-dihydro-23β-methoxyazadirachtin, 3-tigloylazadirachtol and 1-tigloyl-3-acetly-11-methoxyazadirachtin, have been reported to possess insect growth regulating activity. Salannin, salannol, salannolacetate, 3-deacetylsalannin, azadiradion, 14-epoxyazaradion, gedunin, nimbinen and deacetylnimbinen have been isolated from seed kernels; salannin and meliantriol are both active feeding deterrents (Schmutterer, 1990).

The effects of neem on pests of stored products

Neem oil has been found to inhibit oviposition in *C. analis* and *C. chinensis* at 10 mg/kg, and in *C. maculatus* at 30 mg/kg (Schmutterer, 1990). In some coleopteran species, neem extracts reduce adult life span, and in others they prolong it: female *C. maculatus* lived for 7 days longer on cowpea seeds treated with whole neem seed kernels, at the rate of 1-3 kernels/20 g cowpea (Schmutterer, 1990). Some insect pests of stored products are less sensitive to neem products than other, closely related species. For example, *S. zeamais* and *C. chinensis* are less sensitive than *S. oryzae* and *C. maculatus* (Morgan and Mandava, 1987). Various authors (Jotwani and Srivastava, 1981; Saxena *et al.*, 1989 and Singh, 1993) have reviewed research carried out between 1960 and 1980 on the use of neem tree parts against pests of stored products. For results of laboratory trials on neem see p.57.

Pests and diseases of neem

The neem tree is attacked by a number of pests particularly in Burma, India and Indonesia, where several insect and spider mite species have been reported to feed on different parts of the tree. Lepidoptera, Coleoptera and several species of scale insect including *Aonidiella orientalis, Coccus hesperidum, Ceroplastes* sp. and *Pulviaria* sp., have been found to attack the plant. *A. orientalis* is causing particular concern because of its rapid spread through Nigeria, Cameroon and Chad and its threat to neem, citrus and banana trees (CAB-IIBC, 1987). Seed kernels have been attacked by *Oryzaephilus surinamensis, O. acuminatus* and *Rhyzopertha dominica.* Other pests include chafers, ants, nematodes and bats.

Toxicity

Azadirachtin

In a standard Ames test, azadirachtin showed no mutagenic activity in four strains of *Staphylococcus typhimurium* (Saxena *et al.*, 1989).

AZT-VR-K

The azadirachtin-enriched formulated product, AZT-VR-K, was tested in Germany at 5000 mg/kg body weight; no acute oral toxicity in rats, or acute dermal toxicity in rabbits was observed.

Neem seed kernel extract

Methanolic neem seed kernel extract (NSKE) tested at 8750 mg/kg in rats showed no acute oral toxicity (Schmutterer, 1990). Aqueous NSKE (25 and 50 g of seed kernel/litre of water), used for a 28-day test of subacute oral toxicity in rats, proved to be non-toxic. Acute eye and dermal irritation tests of the extract (50 g seed kernel/litre of water) gave negative results. Solvent-extracted neem oil at 5000 mg/kg body weight showed no acute oral toxicity in rats (Schmutterer, 1990).

Neem oil

In subacute dermal toxicity tests, no overt signs of toxicity or abnormal behaviour were observed in albino rats when given a daily dose of Neemrich-100, a technical grade neem oil, at rates of 200, 400 and 600 mg/kg (Saxena *et al.*, 1989). Neem oil has been reported by various authors to possess strong spermicidal action *in vitro* against rhesus monkey and human spermatozoa; anti-implantation and anti-fertility effects have also been observed in female rats (Parmar, 1987). Neem seed oil administered orally to rats at a dose of 0.5 g/kg for 60 days caused a significant reduction in spermatocytes and spermatids (Purohit and Dixit, 1991).

Margosan-O

Margosan-O is a commercially produced formulation of neem. The acute oral toxicity (LD_{50}) for rats was more than 5 ml/kg and the acute dermal toxicity for albino rabbits was more than 2 ml/kg. Tests for primary skin irritation, modified eye irritation and acute inhalation, and two tests on immune response and sensitization, gave no worrying results (Larson, 1987).

On-farm trials with neem

Application of neem seed extract at a rate of 7.2 g to a jute bag of 90 kg capacity controlled 80% of the stored product pest population and prevented damage to stored wheat for 6 months. When the trial was extended to 13 months, 70% protection was reported compared to the untreated control. The neem treatment was considered to be as effective as 0.0005% pirimiphos-methyl mixed with the grain. It was subsequently tested in Sind, Pakistan, where it gave a benefit-cost ratio of 4.6, 5.6 and 7.4 for small, medium and large-scale farmers, respectively (Jilani and Amir, 1987).

A treatment of 10% neem fruit (w/w) in cowpea to protect against bruchid damage is being tested in Ghana for use by local farmers (Tanzubil, 1991).

A talc-based, 5% defatted neem kernel dust has been introduced by Tamil Nadu Agricultural University, Coimbatore, India, to protect seeds from storage pests. The formulation was used at a rate of 1 g a.i./kg seeds against *S. oryzae, R. dominica, T. castaneum* and *Callosobruchus* spp. (Anon., 1992a).

Commercial application

Margosan-O, which was the first commercial product of neem, was registered in the US in 1985 for application to horticultural crops (W.R. Grace & Co., Cambridge, MA, US). It contains 0.3% azadirachtin and has been registered by the Environmental Protection Agency (EPA) for use on ornamentals in all states of the US except California and New York. Bioneem, (developed by Ringer Corp., Minneapolis, MN, US) has EPA registration in all states of the US except Arizona, California and New York, for use on ornamentals, but is not yet registered for use on lawns, food crops or in food handling areas. Azatin, containing 3% azadirachtin, 27% other neem compounds and 70% inert ingredients, controls insects in the larval and pupal stage (Anon., 1992b).

The EPA has approved a neem-based biological pesticide developed by Tata Oil Mills Company Ltd (TOMCO) for use on a wide range of food crops. The pesticide underwent extensive field trials in the US and has been cleared for use on small fruits including raspberry, grape, kiwi, strawberry, apple, pear, peach, cherry, citrus, banana, plantain, date, coconut and nut crops. It has also been cleared for maize, rice, wheat, barley, oats, alfalfa, sesame, peanut and sunflower, for beverage crops including cocoa, coffee, tea and chicory and for leaves, stems, roots, seeds and pods of various spice crops (Anon., 1992a). Other commercial preparations include the following: Neemesis and ENI (Ringer Corp., Minneapolis, MN, US); Wellgro and RD-Repelin (ITC Ltd, Andhra Pradesh, India); Neemguard (Gharda Chemicals, Bombay, India); Neemark (West Coast Herbochem, Bombay, India) and Neemazal (Trifolio M GmBH, Lahnau, Germany). In many cases, neem seed oil is the starting material used for these insecticides (Mordue and Blackwell, 1993).

LABORATORY TRIALS ON NEEM

	Descriptors	Remarks	References
Azadirachta indica	Petroleum ether extract of leaves	680 µg/cm² applied to filter paper produced Class III (42%) repellency against *T. castaneum* 8 weeks after treatment, compared with Class V (81.5%) repellency 1 week after treatment.	Jilani and Su, 1983
	Oil	1% applied to pea seeds reduced damage by *C. chinensis* over a 3-month storage period by reducing F1 adult emergence.	Kumari *et al.*, 1990
		10 ml/kg applied to cowpeas prevented F1 adult production following repeated introduction of adult *C. maculatus* over a 6-month trial.	Daniel and Smith, 1991
		10 ml/kg applied to chickpea caused 100% mortality in adult *C. chinensis* and prevented egg laying.	Das, 1986
		1 ml of 1% oil applied to filter paper in a choice-chamber repellency test produced Class V (86%) repellency against *T. castaneum* after 4 weeks when assessed after 5 days of exposure; repellency had declined to Class III (52%) after 8 weeks.	Mohiuddin *et al.*, 1987
		0.2% (v/w) oil applied to gram prevented the emergence of F1 *C. maculatus* when adults were introduced 33 days after treatment.	Jadhav and Jadhav, 1984
		800 µg/cm² oil applied to filter paper in choice-chamber repellency tests produced 64% repellency against *R. dominica* 8 weeks after treatment, compared with 77%, 1 week after treatment.	Jilani and Saxena, 1990
		8 ml/kg applied to cowpeas almost completely prevented emergence of F1 adult *C. maculatus* following the introduction of adults 3 months after application. The oil did not increase parent mortality compared with the control treatment.	Pereira, 1983
		800 µg/cm² applied to filter paper in a choice-chamber test produced 70% repellency against *T. castaneum* 4 weeks after treatment; repellency had declined to 59%, 8 weeks after treatment.	Jilani *et al.*, 1988
		Application of 0.5% protected green gram for 3 months against damage by *C. chinensis* introduced 40 days after treatment.	Ketkar, 1987
		5 ml/kg applied to maize caused 97% mortality in *S. zeamais* and 22% mortality in *P. truncatus* when assessed after 10 days. Maize oil at 5 ml/kg caused 20% mortality in *S. zeamais* and 4% mortality in *P. truncatus* during the same period.	Maredia *et al.*, 1992

Laboratory trials on neem (*contd*)

Descriptors	Remarks	References
	0.5 ml/100 g gram seed caused 55% mortality in adult *C. chinensis* within 3 days; it significantly reduced the number of eggs laid and F1 production.	Ali *et al.*, 1983
	Application of 0.5% to black gram reduced the number of eggs laid by *C. chinensis* and prevented emergence of F1 adults.	Sujatha and Punnaiah, 1984
	Application of 0.25% to green gram reduced the number of eggs produced by *C. chinensis* and prevented emergence of F1 adults.	Sujatha and Punnaiah, 1985
	Application of 5% (v/w) protected cowpea for 4 months against damage by an initial infestation of *C. maculatus*.	Tanzubil, 1986
	1 ml/kg applied to wheat significantly reduced the amount of damage by *S. cerealella* by reducing F1 production.	Verma *et al.*, 1983
Oil seed cake	5% (w/w) admixed with maize significantly reduced damage by *S. oryzae* by inhibiting oviposition.	Bowry *et al.*, 1984
Water extract of seeds	Dipping seeds in an 80% concentration of extract significantly reduced damage by *C. maculatus* on cowpea and *S. zeamais* on maize seed when introduced at time 0 after the seeds had been stored for 5 months, by reducing egg hatch of F1.	Makanjuola, 1989
De-oiled seed kernel	0.06% (w/w) admixed with wheat prevented the development of the 1st instar larvae which hatched from eggs laid by adult *T. granarium*.	Singh and Kataria, 1984
De-oiled kernel powder	1% applied to wheat flour caused 100% mortality in 1st instar larvae of *T. granarium* within 14 days; the larvae in the untreated control survived and eventually developed into adults.	Singh and Singh, 1985
Ground seed powder	0.5 g/20 g maize caused 100% mortality in adult *S. oryzae* within 10 days, reduced egg laying and prevented F1 emergence.	Ivbijaro, 1983
	5% admixed with wheat significantly reduced damage by *S. oryzae* when repeatedly introduced to the wheat at 15-day intervals for 60 days, by reducing F1 emergence.	Rout, 1986
	3% admixed with green gram caused 100% mortality in adult *C. chinensis* within 15 days, compared to 12% in the controls; it also prevented oviposition.	Ahmed and Ahamad, 1992

Azadirachta indica (*contd*)	Seed oil	2 ml/kg cowpea did not cause a reduction in oviposition by *C. maculatus* but it significantly reduced the number of F1 adults emerging from the eggs laid.	Ivbijaro, 1990
	Seed powder	1 g/25 g dried *Tilapia* fish caused 100% mortality in adult *D. maculatus* within 14 days and prevented egg laying. 0.5 g/25 g fish significantly reduced the number of 1st instar larvae which developed into 2nd instar larvae.	Okorie *et al.*, 1990
	Extract	1% extract admixed with paddy rice, stored for 6 months and used in choice chamber trials, signifcantly reduced the percentage of damage caused by *S. cerealella* and *R. dominica*.	Ambika Devi and Mohandas, 1982
	(85% purity)	5 ppm admixed with wheat or wheat flour prevented the emergence of F1 *S. granarius* and *T. confusum* respectively, when adult insects were introduced to food media.	Smet *et al.*, 1991
Margosan-O	Extract	800 µg/cm² applied to filter paper in a choice-chamber test produced 67% repellency against *T. castaneum* 4 weeks after treatment; repellency had declined to 53% 8 weeks after treatment.	Jilani *et al.*, 1988
		800 µg/cm² applied to filter paper in a choice-chamber test produced 77% repellency against *R. dominica* 1 week after treatment; repellency had declined to 62% 8 weeks after treatment.	Jilani and Saxena, 1990
		0.2% (w/w) applied to wheat caused 50% mortality in adult *S. oryzae* and 15% mortality in *R. dominica* within 3 days; F1 emergence was reduced by 98% and 94%, respectively.	Dunkel *et al.*, 1991a

Section 6

Recommendations

Based on the evidence currently available, the most promising candidate plant species for consideration as potential grain protectants belong to the genera *Azadirachta, Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper* and *Tetradenia*; vegetable oils from various sources can also be included. However, if the use of plant materials is to be seriously considered, further information is required.

Standardized laboratory tests need to be undertaken to determine the residual effects of these materials against key insect species over a period of 6-12 months. Key insect species should include *C. chinensis* and *C. maculatus* on beans, *Sitophilus* spp. and *P. truncatus* on maize, and *Sitophilus* spp., *R. dominica* and lepidopteran species on rice and wheat. The residual effects on the stored commodities can then be critically evaluated, and the plant materials can be compared for repellent/antifeedant activity, contact adult mortality, and reduction in F1 production. Mammalian toxicity testing on the effects of the plant materials and their extracts must also be carried out, and feasibility studies are needed on the local availability of appropriate extraction and application techniques.

The plant materials indicated in the provisional list are not exclusive; others may be considered to be more effective for country-specific situations.

Appendices

APPENDIX 1: REFERENCES AND FURTHER READING

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APPENDIX 2: PLANT CLASSIFICATION OF PLANT SPECIES INCLUDED IN THE REVIEW

Acanthaceae
Adhatoda vasica
Justicia betonica

Anacardiaceae
Anacadium occidentale

Andropogonoideae
Zea mays

Annonaceae
Annona reticulata
Annona squamosa
Canangium odoratum
Monodora myristica

Apiaceae
Angelica silvestris

Apocynaceae
Catharanthus roseus
Nerium oleander

Araceae
Acorus calamus
Amoora ruhitukas

Asteraceae
Artemisia vulgaris
Blumea balsamifera
Tagetes erecta
Tridax procumbens
Tylophora asthmatica

Begoniaceae
Begonia picta

Brassicaceae
Raphanus sativus

Burseraceae
Conyza dioscoridis

Caesalpiniaceae
Erythrophleum suaveolens

Capparaceae
Boscia senegalensis

Celastraceae
Celastrus angulatus
Celastrus nocturnum

Chenopodiaceae
Anabasis setifera
Atriplex lentiformis
Chenopodium ambrosioides

Clusiaceae
Calophyllum inophyllum

Compositae
Ageratum conyzoides
Artemisia vulgaris
Blumea balsamifera
Chrysanthemum spp.
Helenium aromaticum
Helianthus annuus
Saussurea lappa
Venidium hirsutum

Convolvulaceae
Convolvulus arvensis
Ipomoea carnea

Cruciferae
Brassica juncea
Eruca vesicaria

Cucurbitaceae
Momordica charantia

Cupressaceae
Cupressus sempervirens
Juniperus virginiana

Dipterocarpaceae
Shorea robusta

Ericaceae
Gaultheria procumbens

Euphorbiaceae
Croton sparsiflorus
Jatropha curcas
Ricinus communis

Fabaceae
Arachis hypogaea
Butea frondosa
Cassia nigricans
Pongamia glabra
Tephrosia vogelii

Graminae
Cymbopogon spp.
Oryza sativa

Guttiferae
Calophyllum inophyllum

Labiatae
Coleus amboinicus
Hyptis spicigera
Lavendula spp.
Mentha spp.
Ocimum spp.
Origanum vulgare
Rosmarinus officinalis
Salvia sp.
Thymus vulgaris

Lamiaceae
Bystropogon sp.
Tetradenia riparia

Lauraceae
Cinnamomum aromaticum
Laurus nobilis

Leguminosae
Glycine max
Intsia bijuga
Lonchocarpus salvadorensis
Tephrosia vogelii
Trigonella foenum-gracum

Liliaceae
Allium sativum

Linaceae
Linum usitatissimum

Malvaceae
Gossypium spp.

Meliaceae
Azadirachta indica
Melia azadirachta

Myristicaceae
Myristica fragrans

Myrsinaceae
Embelia ribes

Myrtaceae
Eucalyptus spp.
Psidium guajava
Syzygium aromaticum

Oleaceae
Olea europaea

Palmae
Cocos nucifera
Elaeis guineensis

Pedaliaceae
Sesamum orientale

Piperaceae
Piper spp.

Pontederaceae
Eichhornia crassipes

Rutaceae
Aegele marmelos
Citrus spp.
Zanthoxylum alatum

Sapindaceae
Schleichera trijuga

Solanaceae
Capsicum annuum
Capsicum frutescens
Cestrum nocturnum
Lycopersicon esculentum
Nicotiana tabacum

Umbelliferae
Anethum graveolens
Carum carvi
Carum roxburghianum
Coriandrum sativum
Cuminum cyminum
Pimpinella anisum

Verbenaceae
Clerondendron inerme
Lantana camara
Lippia geminata
Vitex negundo

Zingiberaceae
Aframomum melegueta
Alpina galanga
Curcuma longa
Zingiber officinale

APPENDIX 3: LIST OF COMMONLY FOUND SECONDARY METABOLITES

Acids
Acetic acid
Hydrocyanic acid
Iso-butyric acid
Malic acid
Oxalic acid
Salicylic acid
Sebacic acid
Succinic acid
Valeric acid

Alcohols
Benzyl alcohol
Carvacrol
1,8-Cineol
Citronellol
Eugenol
Geraniol
Gossypol
Linalool
Menthol
Pentanol
Pyrogallol

Aldehydes
Acetaldehyde
Citral

Alkaloids
Anabasine
Capsaicin
Histamine
Methyl anthranilate
Methyl salicylate
Nicotine
Nornicotine
Piperine
Ryania
Vinblastine

Esters
Allicin
Azadirachtin
Butyric
Caprylic
Formic
Iso-valeric acid
Methyl salicylate
Pyrethrins I/II

Fatty acids
Ricinoleic acid
Saturated fatty acids
Caproic acid
Lauric acid
Myristic acid
Palmitic acid
Stearic acid
Unsaturated fatty acids
Linoleic acid
Oleic acid

Flavones
Quercetin
Rutin

Glycoside
Oleandrin
Solamine

Hydrocarbons
Camphene
Limonene
α-Pinene

Lactone
Coumarin

Nitrogen-containing compounds
Caffeine
Hydrogen cyanide
Methyl isothiocyanate
Nicotine
Sanguinarine
α-Tomatine

Phenols
Pyrogallol
Safrole

Sterol
Ergosterol

Terpenoids
Ascaridole
Azadirachtin
1-Borneol
Camphor
Carene
Carvone
1,8-Cineol
Cinnamaldehyde
Citral
Citronellol
Cumene
p-Cymene
Eugenol
Geraniol
Limonene
Meliantriol
Menthol
β-Phellandrene
α-Pinene
Pulegone
Saponin
Terpinen-4-ol
Thujone
Vinblastine

Sources: Southon and Buckingham (1988); Glasby (1982); Norris (1990); Rauffauf (1970).

APPENDIX 4: TOXICITY DATA FOR SOME CHEMICAL COMPONENTS OF DIFFERENT PLANT GENERA

Toxicity data quoted in Duke, 1985. Derived from NIOSH, 1975. Unless otherwise indicated all g, mg and µg entries are expressed as per kg body weight. ADI quoted from JECFA, 1994.

Abbreviations used:

ADI	acceptable daily intake
CNS	central nervous system
C	continuous
D	day
EC	Economic Community
frg	frog
GIT	gastrointestinal tract effects
gpg	guinea pig
hmn	human
ihl	inhalation
ipr	intraperitoneal
ivn	intravenous
LCLo	lowest published lethal concentration
LD_{50}	lethal dosage 50% kill
LDLo	lowest published lethal dose
mam	mammal
mus	mouse
NEO	neoplastic effects
scu	subcutaneous
TCLo	lowest published toxic concentration
TDLo	lowest published toxic dose
unk	unreported

Chemical	Toxicity	Plant genera
Acetaldehyde	oral rat LD_{50} 1930 mg	*Carum, Cinnamomum, Citrus, Lycopersicon, Mentha, Nicotiana, Pimpinella, Rosmarinus*
Acetic acid	oral hmn TDLo 1470 mg oral rat LD_{50} 3310 mg	Widespread, including *Gossypium*
Acetone	oral rbt LD_{50} 5300 mg	*Coriandrum, Lycopersicon, Pogostemon*
Allicin	mice LD_{50} 60 mg	*Allium*
Amyl alcohol	oral rat LD_{50} 3030 mg	*Mentha, Origanum*
Anabasine	oral rat LDLo 10 mg	*Nicotiana*
Anethole	oral rat LD_{50} 2090 mg ADI 0–0.6 mg	*Anethum, Ocimum, Pimpinella, Piper*
Apiole	scu mus LDLo 1000 mg	*Apium, Piper*
Asarone	ipr gpg LD_{50} 275 mg EC recommended limits: 0.1 mg/kg in food and beverages	*Acorus, Piper*
Ascaridole	oral LDLo 250 mg	*Chenopodium*
Azadirachta	lethal dose pig 6000 mg	*Melia*
Benzyl alcohol	oral rat LD_{50} 1230 mg ADI 0–5 mg	*Canaga, Canangium, Eugenia*
Borneol	oral rbt LDLo 2000 mg	*Angelica, Blumea, Cinnamomum, Citrus, Coriandrum, Cymbopogon, Eucalyptus, Lavendula, Myristica, Ocimum, Rosmarinus, Salvia, Thymus, Valeriana, Zingiber*
Butyraldehyde	ihl hmn TCLo 580 mg/m^2	*Artemisia, Eucalyptus, Lavendula, Raphanus*
Butyric acid	oral rat LD_{50} 2940 mg	*Eucalyptus, Gossypium, Sapindus*
iso-Butyric acid	oral rat LD_{50} 280 mg	*Artemisia, Cinnamomum, Croton, Eucalyptus, Laurus, Lavendula*

Chemical	Toxicity	Plant genera
Calamus oil	oral rat LD_{50} 777 mg	*Acorus*
d-Camphene		*Rosmarinus, Zingiber*
Camphor	ipr rat LDLo 900 mg	*Acorus, Alpina, Artemisia, Chenopodium, Chrysanthemum, Cinnamomum, Curcuma, Lavendula, Lippia, Ocimum, Rosmarinus, Salvia*
Caproic acid	oral rat LDLo 3000 mg	*Chrysanthemum, Cinnamomum, Cocos, Laurus, Lavendula, Mentha*
Caprylic acid	ivn mus LD_{50} 600 mg	*Cinnamomum, Citrus, Cocos, Cymbopogon, Mentha, Myristica*
Capsaicin	ivn cat LDLo 1600 mg	*Capsicum*
Caraway oil	oral rat LD_{50} 3500 mg	*Carum*
Carene	oral rat LD_{50} 4800 mg	*Chenopodium, Citrus, Eucalpytus, Piper*
Carvacrol	oral LD_{50} 810 mg	*Anabasis, Carum, Cinnamomum, Mentha, Ocimum, Origanum, Thymus, Zea*
Carvone	oral LD_{50} 1640 mg	*Anethum, Carum, Chrysanthemum, Citrus, Cymbopogon, Eucalpytus, Lavendula, Lippia, Mentha, Syzygium*
Cassia oil	oral rat LD_{50} 2800 mg	*Cinnamomum*
Choline	ipr rat LD_{50} 400 mg	*Acorus, Artemisia, Eupatorium, Glycine, Gossypium, Helianthus, Linum, Olea, Pimpinella, Trigonella, Valeriana*
Cineole (1-8)	oral rat LD_{50} 2480 mg	*Alpina, Artemisia, Blumea, Cinnamomum, Curcuma, Eucalyptus, Eugenia, Laurus, Lavendula, Lippia, Mentha, Ocimum, Piper, Psidium, Rosmarinus, Salvia, Syzygium, Zingiber*
Cinnamaldehyde	oral gpg LD_{50} 1160 mg	*Cassia, Cinnamomum, Lavendula, Pogostemon*
Citral	oral rat LD_{50} 4960 mg ADI 0–0.5 mg	*Citrus, Cymbopogon, Eucalyptus, Lavendula, Lippia, Ocimum, Piper, Thymus, Zingiber*
Citronella oil	oral mam LDLo 1000 mg	*Cymbopogon*
Citronellol	ims mus LD_{50} 4000 mg	*Cinnamomum, Citrus, Cymbopogon, Lippia*
Clove oil	oral rat LD_{50} 3720 mg	*Syzygium*
Coriander oil	oral rat LD_{50} 4130 mg	*Coriandrum*
Coumarin	oral rat LD_{50} 293 mg	*Ageratum, Cinnamomum, Lavendula*
Cumene	oral rat LD_{50} 1400 mg	*Cuminum*
Cumin oil	oral rat LD_{50} 2500 mg	*Cuminum*
Cuminic alcohol	oral rat LD_{50} 1020 mg	*Cinnamomum, Cuminum, Eucalyptus, Lavendula*
Cuminic aldehyde	oral rat LD_{50} 1390 mg ADI 0–0.1 mg	*Aegele, Artemisia, Cinnamomum, Cuminum, Lavendula, Zanthoxylum*
Curcumin		*Curcuma*
p-Cymene	oral hmn TDLo 86 mg CNS oral rat LD_{50} 4750 mg	*Aegele, Chenopodium, Cinnamomum, Citrus, Coriandrum, Croton, Cuminum, Cupressus, Eucalyptus, Eupatorium, Myristica, Origanum, Pimpinella, Salvia, Thymus*
Decanal	oral rat LD_{50} 3730 mg	*Cassia, Cinnamomum, Citrus, Coriandrum, Lavendula*
Ergosterol	oral dog LDLo 4 mg	*Citrus, Nicotiana*
Esdragole (estragole)	oral rat LD_{50} 1820 mg	*Artemisia, Ocimum, Pimpinella*
Ethyl alcohol	oral man LDLo 50 mg	*Citrus, Eucalyptus, Lycopersicon, Mentha, Nicotiana*
Eucalyptus oil	oral rat LD_{50} 4440 mg	*Eucalpytus*
Eugenol	oral rat LDLo 500 mg ADI 0–2.5 mg	*Acorus, Ageratum, Alpina, Cinnamomum, Citrus, Cymbopogon, Eugenia, Lantana, Laurus, Lavendula, Myristica, Nicotiana, Ocimum, Pimpinella, Piper, Pogostemon, Syzygium*
iso-Eugenol	oral LD_{50} 1560 mg	*Canaga, Canangium, Cinnamomum, Myristica*
Formic acid	oral rat LD_{50} 1210 mg ADI 0–3 mg	*Artemisia, Cinnamomum, Citrus, Mentha, Myristica, Nicotiana, Ricinus, Valeriana*
Furfural	oral rat LD_{50} 127 mg	*Angelica, Carum, Cinnamomum, Citrus, Cupressus, Cymbopogon, Gossypium, Lavendula, Mentha, Myristica, Syzygium, Zea*
Gaultheria oil	oral hmn TDLo 170 mg oral rat LD_{50} 887 mg	*Gaultheria*
Geraniol	oral LD_{50} 3600 mg	*Cinnamomum, Citrus, Eucalyptus, Eugenia, Laurus, Lavendula, Lippia, Myristica, Thymus, Zingiber*
Gossypol	oral rat LD_{50} 2315 mg	*Gossypium*

Chemical	Toxicity	Plant genera
Histamine	ivn dog LDLo 50 mg	*Chenopodium, Citrus, Lycopersicon*
Hydrocyanic acid	oral hmn LDLo 570 µg ADI not to be used	*Ageratum, Allium, Annona, Boscia, Cassia, Chenopodium, Cinnamomum, Citrus, Combretum, Crotalaria, Cymbopogon, Erythrophleum, Eucalyptus, Euphorbia, Gliricidia, Glycine, Ipomoea, Jatropha, Lantana, Linum, Nerium, Nicotiana, Ocimum, Piper, Psidium, Ricinus, Tagetes, Tephrosia*
Isovaleraldehyde		*Cinnamomum, Citrus, Cymbopogon, Eucalyptus, Glycine, Lavendula, Mentha, Raphanus*
Lauric acid	ivn mus LD_{50} 131 mg	*Cinnamomum, Citrus, Cocos, Elaeis, Laurus*
Limonene	oral rat LDLo 4600 mg ADI not specified	*Anethum, Apium, Carum, Chenopodium, Cinnamomum, Citrus, Coriandrum, Croton, Cuminum, Cymbopogon, Eucalyptus, Hyptis, Lavendula, Lippia, Mentha, Myristica, Nicotiana, Ocimum, Origanum, Pimpinella, Piper, Rosmarinus, Salvia, Syzygium, Valeriana*
Linalool	oral rat LD_{50} 2790 mg ADI 0–0.5 mg	*Artemisia, Cinnamomum, Citrus, Coriandrum, Cymbopogon, Eucalyptus, Laurus, Lavendula, Mentha, Myristica, Ocimum, Origanum, Rosmarinus, Salvia, Syzygium, Thymus, Zingiber*
Linoleic acid		*Helianthus, Ricinus*
Malic acid	oral rat LDLo 1600 mg ADI not specified	*Artemisia, Capsicum, Coriandrum, Helianthus, Juniperus, Lycopersicon, Nicotiana, Ricinus*
Menthol	oral rat LD_{50} 3180 mg ADI 0–0.2 mg	*Mentha, Thymus*
Methanol	oral hmn LDLo 340 mg	*Carum, Gossypium, Lycospericon, Mentha, Syzygium*
Methyl anthranilate	oral rat LD_{50} 2910 mg ADI 0–1.5 mg	*Cananga, Canangium, Citrus*
Methyl chavicol (esdragole) (estragole)	oral rat LD_{50} 1820 mg	*Artemisia, Ocimum, Pimpinella*
Methyl eugenol		*Syzygium*
Methyl salicylate	oral hmn LDLo 170 mg oral rat LD_{50} 887 mg ADI 0–0.5 mg	*Chenopodium, Erythroxylum, Eugenia, Gaultheria, Myristica, Syzygium, Xanthophyllum*
Myristic acid	ivn mus LD_{50} 43 mg	*Cinnamomum, Citrus, Cocos, Croton, Elaeis, Helianthus, Myristica, Pimpinella*
Myristicin	oral cat LDLo 570 mg	*Anethum, Carum, Cinnamomum, Myristica*
Neriin	scu mus LDLo 95 mg	*Nerium*
Nicotine	oral hmn LDLo 1 mg	*Erythroxylum, Nicotiana*
Nornicotine (*D* and *L*)	ipr rat 6-23.5 mg	*Nicotiana*
Noscapine	ivn mus LD_{50} 83 mg	*Lycopersicon*
Nutmeg oil (expressed)	oral rat LD_{50} 3640 mg	*Myristica*
Nutmeg oil (volatile)	oral rat LD_{50} 2620 mg	*Myristica*
Odorobioside K	ivn cat LD_{50} 2.3 mg	*Nerium*
Odoroside K	ivn cat LD_{50} 4.74 mg	*Nerium*
Oleandrin		*Nerium*
Oleic acid	ivn mus LD_{50} 230 mg	Major component of oilseeds
Origanum oil	oral rat LD_{50} 1850 mg	*Origanum*
Oxalic acid	oral hmn LDLo 700 mg	*Allium, Anacardium, Capsicum, Chenopodium, Citrus, Coriandrum, Glycine, Ipomoea, Juniperus, Lycopersicon, Mentha, Momordica, Nicotiana, Raphanus*
Palmitic acid	ivn mus LD_{50} 57 mg	Common in oilseeds, *Apium, Gossypium, Ricinus*
Pennyroyal oil	oral rat LD_{50} 400 mg	*Mentha*
Peppermint oil	oral rat LD_{50} 4441 mg	*Mentha*
Phellandrene		*Aegele, Anethum, Angelica, Artemisia, Cinnamomum, Citrus, Coriandrum, Cuminum, Curcuma, Cymbopogon, Eucalyptus, Lantana, Laurus, Lavendula, Mentha, Pimpinella, Piper, Zingiber*

Chemical	Toxicity	Plant genera
α-Pinene		*Coriandrum, Cuminum, Eucalyptus, Laurus, Myristica, Origanum, Pimpinella, Piper, Rosmarinus, Syzygium*
Pipericide		*Piper*
Propionic acid	oral rat LD_{50} 1510 mg	Widespread, including *Cinnamomum, Lavendula, Pimpinella*
Pulegone	ipr mus LD_{50} 150 mg	*Bystropogon, Mentha, Origanum*
Pyrethrin I	oral rat LD_{50} 1200 mg	*Chrysanthemum*
Pyrethrin II	oral rat LD_{50} 1200 mg	*Chrysanthemum*
Pyrethrum	oral rat LD_{50} 200 mg	*Chrysanthemum*
Pyrocatechol	oral rat LD_{50} 3890 mg	*Allium, Citrus, Eucalyptus, Psidium, Raphanus*
Pyrogallol	unk man LDLo 120 mg oral rat LD_{50} 787 mg	*Carum*
Quercitin	oral rat LD_{50} 161 mg	*Allium, Euphoria, Euphorbia, Gossypium, Psidium, Shorea, Zea*
Ricinoleic acid	scu rbt TDLo 3120 mg	*Cassia, Ricinus*
Rotenone	oral rat LD_{50} 132 mg	*Derris, Lonchocarpus, Tephrosia*
Rutin (sophorin) (vitamin P)	ivn mus LD_{50} 950 mg	Widespread, including *Artemisia, Calotropis, Eucalyptus, Gossypium, Lycopersicon, Nerium, Nicotiana, Tephrosia*
Ryania	oral rat LD_{50} 750 mg	*Ryania*
Safrole (shikimol)	oral rat LD_{50} 1950 mg No ADI allocated	*Chenopodium, Cinnamomum, Myristica, Ocimum, Pimpinella, Piper*
Sage oil	oral rat LD_{50} 2600 mg	*Salvia*
Salicylic acid	oral rat LD_{50} 891 mg No ADI allocated	*Cinnamomum, Gaultheria, Gossypium, Mentha*
Sanguinarine	ipr rat LD_{50} 18 mg	*Sapindus, Zanthoxylum*
Saponin	oral mus LDLo 3000 mg	Very widespread, including *Acorus, Aegele, Allium, Anabasis, Bassia, Cassia, Chenopodium, Citrus, Eucalyptus, Eugenia, Euphorbia, Glycine, Helianthus, Lippia, Momordica, Nicotiana, Ocimum, Olea, Raphanus, Ricinus, Salvia, Sapindus, Thymus*
Sebacic acid	ipr mus LD_{50} 500 mg	*Ipomoea*
Solanine	ipr mus LD_{50} 32 mg	*Capsicum, Lycopersicon*
Stearic acid (Octadecanoic acid)	ivn rat LD_{50} 22 mg	*Citrus, Croton*
Succinic acid	scu frg LDLo 2000 mg	*Artemisia, Gossypium, Helianthus*
Tannic acid	oral mus LDLo 2000 mg	Widespread, including *Acorus, Artemisia, Catharanthus, Cinnamomum, Coriandrum, Cuminum, Eucalyptus, Eugenia, Eupatorium, Euphoria, Helianthus, Ipomoea, Lavendula, Melia, Myristica, Pimpinella, Rosmarinus, Salvia, Syzygium*
Terpinen-4-ol	oral rat LD_{50} 4300 mg	*Artemisia, Cinnamomum, Citrus, Cuminum, Cupressus, Cymbopogon, Lantana, Laurus, Lippia, Myristica, Origanum, Pimpinella, Rosmarinus, Salvia, Thymus*
Thujone	ipr rat LDLo 120 mg	*Artemisia, Lavendula, Lippia, Salvia*
Thyme oil	oral rat LD_{50} 2840 mg	*Thymus*
Thymol	oral LD_{50} 980 mg	*Anabasis, Carum, Lavendula, Ocimum, Origanum, Thymus*
Tomatine	oral rat LDLo 800 mg	*Lycopersicon*
Trimethylamine	ipr mus LDLo 75 mg	*Acorus, Chenopodium, Gossypium, Nicotiana*
Tryptothane	oral rat TDLo 1100 mg/DC NEO	*Glycine, Helianthus, Ipomoea, Linum, Lycopersicon, Nicotiana*
Turmurone		*Curcuma*
Undecanoic acid	ivn mus LD_{50} 140 mg	*Artemisia, Cocos, Thymus*
Valeric acid	ivn mus LD_{50} 1290 mg	*Cananga, Canangium, Croton, Laurus, Lavendula, Mentha, Valeriana*
iso-Valeric acid	oral rat LDLo 3200 mg	*Artemisia, Calotropis, Cinnamomum, Citrus, Croton, Eucalyptus, Lavendula, Lippia, Mentha, Nicotiana, Rosmarinus, Valeriana*
Vinblastine	ivn mus LD_{50} 17 mg	*Catharanthus*

APPENDIX 5: LIST OF TOXINS FOUND IN THE SIX MOST FREQUENTLY EXAMINED PLANT GENERA

Acorus	Asarone, calamus oil, camphor, choline, eugenol, eugenol ethyl ether, heptanoic acid, methylamine, saponin, tannic acid, trimethylamine
Chenopodium	Ascaridole, carene, cymene, histamine, hydrocyanic acid, limonene, methyl salicylate, oxalic acid, safrole, saponin, trimethylamine
Eucalyptus	Benzaldehyde, borneol, butyraldehyde, butyric acid, carene, carvone, cineole, citral, cuminic acid, cymene, ethyl alcohol, eucalyptus oil, gallic acid, geraniol, hydrocyanic acid, isoamyl alcohol, isobutyric acid, isoprene, isovaleraldehyde, isovaleric acid, limonene, linalool, mandelonitrile, phellandrene, pyrocatechol, quercitrin, quinic acid, rutin, saponin, shikimic acid, tannic acid, valeraldehyde
Mentha	Acetaldehyde, amyl alcohol, caproic acid, caprylic acid, carvacrol, carvone, cineole, ethyl alcohol, formic acid, furfural, isoamyl alcohol, isovaleraldehyde, isovaleric acid, limonene, linalool, menthol, methanol, methylamine, nonanoic acid, oxalic acid, pennyroyal oil, peppermint oil, phellandrene, pulegone, salicylic acid, valeric acid
Ocimum	Anethole, camphor, carvacrol, cineole, citral, esdragole, eugenol, hydrocyanic acid, limonene, linalool, safrole, saponin, thymol
Piper	Anethole, apiole, asarone, carene, cineole, citral, dihydrokawain, eugenol, eugenol methyl ether, hydrocyanic acid, limonene, phellandrene, piperidine, piperonal, safrole, stearyl alcohol

APPENDIX 6: INDEX OF PLANT SPECIES

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The Bulletin series presents the results of research and practical scientific work carried out by the Natural Resources Institute. It covers a wide spectrum of topics relevant to development issues ranging from land use assessment, through agricultural production and protection, to storage and processing.

Each bulletin presents a detailed synthesis of the results and conclusions of work carried out within one specialized area, and will be of particular relevance to colleagues within that field and others working on sustainable resource management in developing countries.

The use of plant materials for the protection of stored products against insect pests is part of traditional folklore in many parts of the world. However, with the advent and widespread use of broad-spectrum synthetic pesticides the use of such materials declined. Renewed interest in their application as commodity protectants has occurred for a variety of reasons, including insect resistance, concerns over pesticide misuse, environmental contamination, insecticide residues and the increased cost of insecticide development and application. In **A Review of Plant Materials used for Controlling Insect Pests of Stored Products** the progress of research is reviewed. The insecticidal activity of over 120 plants and plant products are listed alphabetically and details of their chemical constituents and toxicology is included. Promising substances and new areas of investigation are identified. The review also provides a comprehensive bibliography covering relevant publications of the past 20 years.

This bulletin will be of special interest to workers in the field of storage entomology, research students and those involved in the control of pests of durable products in both tropical and temperate climates.