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The use of plant material to protect stored leguminous seeds against seed beetles: a review

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THE USE OF PLANT PRODUCTS TO PROTECT STORED LEGUMINOUS SEEDS AGAINST SEED BEETLES: A REVIEW

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THE USE OF PLANT PRODUCTS TO PROTECT STORED LEGUMINOUS SEEDS AGAINST SEED BEETLES: A REVIEW

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ABSTRACT

In most tropical regions beetles attack stored seeds and constitute a major cause of serious post-harvest crop losses. Beetles deposit eggs on the seed surface, the larvae develop inside the seed and leave it as adults. To protect the stored product against these insects, not only synthetic insecticides, natural enemies and physical methods can be applied, but also formulations of insecticidal or insect-repellent plants. These methods each have their advantages and their disadvantages. A considerable body of literature has accumulated on plant products as insecticides, with variable results. An overview of the available literature on plant products used against storage beetles (with a focus on Bruchidae infesting cowpea) is presented. The review is structured according to the type of formulation used to apply the plant product, i.e. powder, ash, volatile oil, non-volatile oil and extract.

For plant powders, preparation and application are easy and therefore many plants have been used as powders in pilot tests. The quantities applied vary and the results from the tests diverge considerably. Plant powders can affect all stages of the developing beetle. In most cases, the powders do not have any direct effects on the stored product.

Ash can offer an effective way to protect stored seeds against storage beetles, if it is applied in large quantities. The ash hinders adult movement and thus hampers oviposition. Disadvantages are that ash can negatively affect the appearance and germination of the stored seeds. For small quantities of seeds, ash could be a cheap and safe alternative for chemical pesticides.

Volatile oils are often effective but they quickly evaporate, unless they are applied in airtight storage structures. The oils are mainly effective against adult beetles either as repellents or as toxicants, which causes oviposition to be affected as well. Due to set-ups from which beetles cannot escape, the repellent effect is often underestimated in laboratory tests. Application of volatile oils is easy but should be repeated for long term protection. The volatile oil does not need to be in direct contact with the stored product, so the product is usually unaffected by the treatment. The yield of volatile oil from plants is generally low. Distillation equipment and a lot of plant material are needed to obtain the oil.

Non-volatile oils have mainly physical effects on the insects. Eggs are most susceptible. They are either asphyxiated or their attachment to the seed surface and subsequent penetration of the hatched larva are hampered. Non-volatile oils are difficult to apply. The seed will be protected due to this physical effect only if the oil forms a film covering its whole surface. The side effects of oils on the stored product are numerous, ranging from a change of colour to an alteration of taste and inhibition of seed germination. To obtain large enough quantities of oils large quantities of plants are needed and a lot of work. Many of the edible oils are usually for sale.

Extracts of fresh or dry plants are usually more effective than powders. They are mostly effective against adult beetles, either as repellents or as toxicants. Other developmental stages of the beetle can be susceptible as well. The effect of extracts on the stored product is usually negligible. Large quantities of plants are often needed to obtain sufficient amounts of extracts. Solvent availability can cause problems.

Many different plant species have been tested for their effect on the beetles. In this review, more than 400 species are mentioned. However, the literature available does not allow a general ranking of insecticidal or repellent efficacy. This is due to the lack of experimental detail and statistical analyses of the results in many of the cited publications. In addition, the efficacy of a plant product depends on the plant species, the individual plant, the plant part and the time and way of harvesting. In bioassays, the application mode, the quantity, the preparation of the plant material, the state of the product to store (e.g. intactness of the seed skin and/or pod) and storage conditions (e.g. humidity, rate of infestation) as well as the beetle species tested are important for the outcome of the tests. The mere fact that natural products are used implies that considerable variation is to be expected in bioassay outcomes. Indeed, literature results are often contradictory, notwithstanding the fact that many plant species do show useful effects against seed beetles. The most effective plants or methods of application are not yet known, but results are promising and plant products can be an effective replacement for chemical insecticides in the battle against seed beetles.

1 INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important crop in tropical regions, particularly in West and Central Africa. The green parts of the plant are used as a vegetable or as fodder for cattle. The seeds contain a high amount of protein and B-vitamins (238) and help to prevent starvation among low resource farmers and the poor urban population (80; 156; 243). The plant, in symbiosis with root nodule bacteria of the *Rhizobium* genus, can fix nitrogen (225) and does not need extra nitrogen or fertilisers to provide good harvests (15). For many varieties, the need for water is limited so the plant can grow on poor and dry soils of, for example, the Sahelian region. The spreading growth form of the plant covers the soil making it a good competitor against weeds in single or inter-cropping systems (92).

Many diseases, viruses and insect pests (41; 126) attack the plant in the field, but once the cowpea has been harvested the problems are not over. After harvest, the beans can be either sold immediately for a relatively low price or they can be stored before use or trading. At the end of the storage season, just before the new harvest, the market price will be much higher than immediately after harvest (305). However, by that time the stored product can be damaged not only by fungi and rodents but also by insects, if nothing is done to prevent this.

In the field, several beetle species lay their eggs on the surface of the maturing pod or directly on the testa of the ripening seed and can thus be brought to the storage room with the harvested beans (161; 343). The larvae of these beetles develop inside the bean, destroying its contents. After a few weeks, new adults emerge, leaving the bean a perforated seed with a low probability of germination (38; 307). These new adults oviposit on the available beans again. Most of the beetle species with such a life cycle have only few generations inside the storage structures before they develop into a diapausing (101) or non-reproducing flying form, which leaves the storage room (104). However, one beetle species, the cowpea weevil, *Callosobruchus maculatus* Fabricius (Coleoptera: Bruchidae) is capable of developing inside cowpea storehouses for many generations before going into diapause. This beetle will not develop into the flying form to leave the storage structure until all beans are hollow or pulverised. The eggs are taken from the cowpea field (105; 241) into the storage room with the harvested beans. Females of the reproductively active, flightless form can lay up to 120 eggs during the 3-15 days of their adult life. The eggs hatch after 3-8 days and the larvae develop in 9-19 days inside the bean to the pupal stage of 5-11 days. The whole life cycle, from adult to adult, takes 21 to 40 days, depending on the temperature, humidity, host plant, etc. (88; 112; 197; 221; 313). This beetle is known to infest 100% of a cowpea harvest within 3 to 5 months of storage (300) and it is responsible for over 90% of all insect damage to cowpea seeds (44).

Due to insect infestation, the germination of the seeds decreases, (31; 147) and incidence of fungal infection increases (46). Insect infestation causes the uric acid content (310) and the contents of anti-nutritional factors, such as phytic acid, trypsin inhibitor activity and saponin of the beans to increase (193), while the weight of the stored product decreases (192). The contents of vitamins of the B complex (thiamine, riboflavin and niacin) (190) and of starch, energy and non-reducing sugars decrease for stored seeds with increasing infestation, while contents of crude fibre, cellulose, hemicellulose and lignin increase (189). The protein quality changes with infestation, with probably a decrease in methionine content and an increase of non-protein nitrogen. Insect-infested legumes become unhygienic due to presence of high amounts of uric acids and are not suitable for human consumption (84; 191).

Control measures against storage beetles

There are many methods known to prevent or reduce damage done by the cowpea weevil. The most common control measures taken against storage beetles are:

- **Synthetic pesticides**. Some chemicals have proven to be very effective against bruchid damage if they are used at the right time, in the right quantities, with the right application method, etc. For low resource families in villages, however, the availability and costs of such chemicals can bring about great problems whereas a lack of knowledge about the application may reduce the efficacy of the pesticide and can be a hazard to consumers of the beans. Moreover, resistance of the beetles to some pesticides has already been reported (28; 90; 292). Other disadvantages are the fact that some of these products have a severe negative effect on seed viability (254) and that they kill all insects, including beneficial ones such as the natural enemies of the beetles.
- **Hermetic storage**. Storage beetles can penetrate plastics up to 0.18 mm thick (297) but thick plastic bags can be used to store beans (301) especially if they are used with a cotton inner lining (43). Oil drums with well-fitted lids (286) are also practicable to store seeds if they are filled completely, with as little air left as possible. The developing beetles will then use up the available oxygen (304) within a short time (ca. 2 weeks) and thus suffocate before their development can cause serious damage (43; 289). However, any tiny hole in the bag or drum through which a flow of air can pass will nullify the effect, so bags should be protected against rodents, vessels should be protected from rust and the structures should be treated with care to avoid damage.
- **Natural enemies**. Developing bruchid beetles can be parasitised by egg parasites such as *Uscana lariophaga* or by the larval or pupal parasites such as *Dinarmus basalis* and *Eupelmus vuilleti*. Under optimised laboratory conditions, parasitization can control the bruchid infestation up to 70% (107) or even up to 82% (53). In the field, the parasitoids also suppress the build up of beetle populations (43; 269; 273; 335; 337), but the control is never 100%. For an overview, see Gahukar (95).
- **Inert materials**. Sand or ash can be mixed with stored beans to make an effective barrier against the beetles which prevents the emerged adults from finding each other for mating or from reaching a next bean to oviposit on. Fine ash or sand can effectively suffocate the adults, larvae and possibly eggs (49). The large quantities of inert material needed make this method of protection less practical, especially for considerable quantities of stored beans.

Physical methods. In a (solar) heater, or in plastic bags exposed to the sun (48), where a temperature of at least 57 °C can be reached for more than one hour, all stages of the bruchid are killed whereas the cooking properties and germination of the beans are not negatively influenced (152). At 51.5 °C for 15 minutes or at 47.5 °C for four hours all adult female beetles are killed (122). Young developmental stages of the beetles are most susceptible to such a heat treatment (150). This treatment inhibits the transformation from pupa to adults and induces adult mortality (276). Cold treatment or freezing the beans kills all developmental stages. Seeds can also be preserved by hanging them in the smoke of a cooking fire (153). If care is taken to prevent re-infestation, these could be useful options to prevent damage. Sieving the beans will remove many of the adult beetles and thus prevents severe attack (309).

Gamma radiation is lethal to bruchids. Eggs and young larvae are especially sensitive to this treatment (102) and females appear to be more sensitive to it than males (82).

Treatment with biogas (196; 326) low oxygen and high carbon dioxide kills adult storage beetles and, less effectively, eggs, larvae and pupae (115; 220) with pupae being least susceptible (179). An anoxic atmosphere with 100% carbon dioxide is more toxic to eggs, larvae and pupae than atmospheres containing low levels of oxygen (177).

- **Plant material.** Many plants are known to repel insects and to produce compounds toxic to non-specialised insects. If products of such plants, fresh or dried material, extracts or oils are applied to stored beans, they have been shown to effectively protect stored cowpeas against bruchid infestation.

Plant products could offer a solution for the problems of availability, health risks, costs, and resistance in the case of synthetic pesticides, and for the lack of equipment for hermetic storage, gamma irradiation and controlled atmospheres. They could be compatible with natural enemies to reduce the pest population in the seeds or they could replace space-consuming inert materials. In the ideal situation, plant products could be readily available for everybody without costs, easily and safely applicable and toxic or repellent only to the target organism. Especially the low resource farmers in the tropics, who can not afford chemical insecticides, will profit from cheap ways to protect their stored seeds.
The effect and the efficacy of the plant materials depend on their mode of application. The materials can be added to the beans as fresh whole plants, or other methods can be used to make them more effective.
Up until now, much research has been done to test many plant species for their efficacy as seed protectants. However, no general test protocols have been used and the applied quantities vary greatly. Many authors have tested plant materials and have reported their experiences, but no overview exists of the ranking for insecticidal properties of plants.

Apart from cowpea, many other seed crops such as maize, cereals, peanuts, grams and beans, are also damaged during storage, by beetle species with life histories similar to that of the cowpea beetle. The methods used against these insects are generally comparable to those employed against *Callosobruchus maculatus*. In this paper knowledge of control measures using plant products against the storage beetle species mentioned in table 1, is reviewed in general, with a focus on beetles of the family Bruchidae. The abbreviations given in this table are used throughout the paper. Per application mode a list of plants is given, ordered per plant family, and discussed with respect to possible correspondence or discrepancies. In this discussion, the differences in set-ups of the tests as they are used in different publications could mostly not be taken into account.

Table 1: Names, families, descriptors and common names of the beetle species mentioned in this article (After Couilloud 54).

	Beetle species	Author(s)	Beetle family	Common name	Abbreviation
1	*Acanthoscelides obtectus*	Say	Bruchidae	Bean bruchid	*Ao*
2	*Attagenus megatoma*	Piceus (Olivier)	Dermestidae	Black carpet beetle	*Am*
3	*Bruchidius atrolineatus*	Piceus	Bruchidae	Pulse beetle	*Ba*
4	*Callosobruchus analis*	Fabricius	Bruchidae		*Ca*
5	*Callosobruchus chinensis*	Linnaeus	Bruchidae	Adzuki bean beetle	*Cc*
6	*Callosobruchus maculatus*	Fabricius	Bruchidae	Cowpea beetle	*Cm*
7	*Callosobruchus phaseoli*	Gyllenhal	Bruchidae	Bean weevil	*Cph*
8	*Callosobruchus rhodesianus*	Piceus	Bruchidae		*Cr*
9	*Callosobruchus subinnotatus*	Piceus	Bruchidae		*Csu*
10	*Caryedon serratus*	Olivier	Bruchidae	Groundnut seed beetle	*Cse*
11	*Cylas puncticollis*	Boheman	Apionidae	Sweet potato weevil	*Cpu*
12	*Dermestes maculatus*	De Geer	Dermestidae	Common hide beetle	*Dm*
13	*Lasioderma serricorne*	Fabricius	Anobiidae	Cigarette beetle	*Ls*
14	*Oryzaephilus surinamensis*	Linnaeus	Silvanidae	Saw toothed grain beetle	*Os*
15	*Prostephanus truncatus*	Horn	Bostrichidae	Greater/larger grain borer	*Pt*
16	*Rhyzopertha dominica*	Fabricius	Bostrichidae	Australian wheat weevil	*Rd*
17	*Sitophilus granarius*	Linnaeus	Curculionidae	Grain weevil	*Sg*
18	*Sitophilus oryzae*	Linnaeus	Curculionidae	Rice weevil	*So*
19	*Sitophilus zeamais*	Motschulsky	Curculionidae	Maize weevil	*Sz*
20	*Tribolium castaneum*	Herbst	Tenebrionidae	Red flour beetle	*Tca*
21	*Tribolium confusum*	Jaquelin du Val	Tenebrionidae	Confused flour beetle	*Tco*
22	*Trogoderma granarium*	Everts	Dermestidae	Khapra beetle	*Tg*
23	*Zabrotes subfasciatus*	Boheman	Bruchidae	Mexican bean beetle	*Zs*

2 POWDERS OR FRESH APPLICATION

The simplest way to apply plants to a stock of seeds is harvesting the plant and adding it to the seeds. As the stored seeds should be dry to prevent moulds and germination, the plants are often pre-dried. To attain a finer and more even distribution, these dry plants can than be ground to powder before application. Many plants have been tested in the laboratory as powders to estimate their possible effects. The modes of action of these powders vary, but with low to moderate dosages, the effect is always repellent or toxic, never mechanical. All plants discussed in this chapter and in Table 2 were dried, ground and used as powders, unless stated otherwise.

Table 2: Plants used against storage insects, the quantity and the used plant part.

Plant (sub-) family	**Plant species**	**Plant part $**	**Quantity ~**	**Beetle species ^**	**Affected stage #**							**Reference**
					A	**O**	**E**	**H**	**L**	**M**	**P**	
Acanthaceae	*Adhatoda* spp.	L	8%	*Cm*							**	111
Acanthaceae	*Adhatoda vascia*	L	5-20	*Cc*				*!		**		1
		L	5-20	*Cc*							**	228
Amaranthaceae	*Achyranthes aspera*	--	5-20	*Cc*		*!				*!		50
Amaryllidaceae	*Crinum defixum*	--	5-20	*Cc*		*!				*!		50
Anacardiaceae	*Anacardium occidentale*	Nut shell liquid	4 perforated nuts/kg	*Cm*		*!				!!	*!	81
		Gum exudate	5-60%	*Cm*		*!			*!	*!		174
Anacardiaceae	*Sclerocarya birrea*	Bs	100-300	*Cm*							*!	93
Annonaceae	*Annona reticulata*	L	0.1-0.4 g/ 50 seeds	*Cm*	**			*!		*!		248
Annonaceae	*Annona senegalensis*	L po/wh	1/10 pods	*Ba, Cm*	**	**	**			**		15
		Bs	100-300	*Cm*							**	93
Annonaceae	*Annona* spp.	S	0.5-2%	*Cm*							*!	111
Annonaceae	*Annona squamosa*	S	50	*Ca*	!!	!!					!!	135
		S	5-100	*Ca*	*!	*!						139
		S	10-50	*Cc*		*!				*!	*!	296
Annonaceae	*Dennettia tripetala*	F	4-120	*Cm, Sz*	!!					!!		215
Annonaceae	*Monodora myristica*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
		F	4-60	*Cm, Sz*	*!					!!		215
Annonaceae	*Xylopia aethiopica*	F	2 g/500 seeds	*Cm*		**		**				209
		F	4-60	*Cm, Sz*	*!					*!		215
Apiaceae	*Anethum graveolens*	S	5-20	*Cm, Ls, So, Tco*	*!							319

Plant Family	**Plant species**	**Plant part**	**Quantity**	**Beetle**	**A**	**O**	**E**	**H**	**L**	**M**	**P**	**Ref.**
Apocynaceae	*Nerium oleander*	L	60	*Cm*		*!				*!	**	131
		L, T	40	*Cm*							*!	341
Apocynaceae	*Thevetia peruviana*	F	5-20	*Cc*							*!	228
		F	1-2%	*Cm*							*!	111
Araceae	*Acorus calamus*	--	5-20	*Cc*		!!				*!		50
		R	5-20	*Cc*							*!	228
		R	10-50	*Cc*		*!				*!	*!	296
		T	0.5-5%	*Cc, Sg, So*	*!							121
		R	1-2%	*Cm*							*!	111
Asteraceae	*Ageratum conyzoides*	T	2 g/500 seeds	*Cm*		**		**				209
Asteraceae	*Artemisia tridentata*	L, T	1-30	*So, Zs*		*!		*!		*!		348
Asteraceae	*Aspilia africana*	T	2 g/500 seeds	*Cm*		**		**				209
Asteraceae	*Balsamorhiza sagittata*	L, T	1-30	*So, Zs*		**		*!		*!		348
Asteraceae	*Chromolaena odorata*	L	0.5-4 g/50 seeds	*Cm*		**				**		2
		L	12.5-75	*Cm*						*!		12
		L	2 g/500 seeds	*Cm*		**		**				209
		G	25	*Cse*	**	*!			*!			67
Asteraceae	*Emilia sonchifolia*	L	2 g/500 seeds	*Cm*		**		**				209
Asteraceae	*Eupatorium* spp.	Wh	100	*Ao*							**	30
Asteraceae	*Sphaeranthus indicus*	L po/wh	50	*Cc*						*!		325
Cactaceae	*Opuntia burrageana*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
Capparaceae	*Boscia senegalensis*	L po/wh	Layers	*Ba, Cm*	*!		*!				*!	13
		L po/wh	3/10 pods	*Ba, Cm*	*!	**	*!			*!		15
		T wh	Layers	*Cm*	**							59
		--	25	*Cm*	*!	**			**			60
		F, L fr/d	0.5-32%	*Cm*	!!					!!	!!	288
		F fr	1.2-4.8 g/l	*Cm*						!!		289
		F, L fr	20-40	*Cm, Cse, Pt, Sz, Tca*	*!					*!	*!	180
Chenopodiaceae	*Chenopodium ambrosioides*	G	25	*Cse*	*!	!!			*!			67

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Combretaceae	*Combretum apiculatum*	B, L	60	*Cm*		*!				*!	**	131
Combretaceae	*Combretum imberbe*	Wood	60	*Cm*		*!				*!	**	131
Combretaceae	*Terminalia sericea*	B, L	60	*Cm*		*!				*!	**	131
Convolvulaceae	*Ipomoea carnea*	L	5-20	*Cc*							*!	228
		L	8%	*Cm*							*!	111
Convolvulaceae	*Ipomoea mauritiana*	L	10-50	*Cm*		**			**			69
Cucurbitaceae	*Momordica* spp.	L	2 g/500 seeds	*Cm*		**		**				209
Dilleniaceae	*Dillenia retusa*	L	0.1-0.4 g / 50 seeds	*Cm*	*!			*!		*!		248
Ericaceae	*Ledum palustre*	T	0.5-5%	*Cc, Sg, So*	*!							121
Euphorbiaceae	*Bridelia ferruginea*	B	2 g/500 seeds	*Cm*		**		**				209
Euphorbiaceae	*Croton gratissimus*	L	60	*Cm*		*!				*!	**	131
Euphorbiaceae	*Euphorbia tirucalli*	T	40	*Cm*							*!	341
Euphorbiaceae	*Jatropha indica*	L	20	*Cm, Sz*							**	22
Euphorbiaceae	*Ricinus communis*	L	3.3-16.7	*Cm*	!!					*!	*!	214
Euphorbiaceae	*Spirostachys africana*	B	60	*Cm*		*!				*!	**	131
Geraniaceae	*Geranium viscosissimum*	L, T	1-30	*So, Zs*		*!		*!		*!		348
Juglandaceae	*Juglans* spp.	Nut shell	1 g/60 insects	*Ao*	**							51
Lamiaceae	*Hyptis spicigera*	Wh	0.3-30	*Ao*		**				*!		162
		wh fr	3-5 cm layers	*Ba, Cm*							**	58
		L	Layers	*Cm*	**	**		**		**		59
		--	25	*Cm*	*!	**			**			60
		L, T	33.3	*Cm, Rd, So, Tca, Tg*							*!	8
Lamiaceae	*Hyptis suaveolens*	Shoot	100-300	*Cm*							*!	93
		T	25	*Cm, Rd, So, Tca, Tg*							**	8
Lamiaceae	*Lavandula angustifolia*	--	1-7.4	*Ao, Sg*	*!							138
Lamiaceae	*Mentha piperita*	Wh	1 g/6 beans	*Ao*	*!	**		**		**		261
		L	50	*Ca*	!!	!!					!!	135
Lamiaceae	*Mentha spicata*	L	10%	*Ca*		*!					*!	100

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Lamiaceae	*Monarda fistulosa*	L, T	1-30	*So, Zs*		*!		*!		*!		348
Lamiaceae	*Ocimum basilicum*	L	1 g	*Ao, Zs*	!!							344
		L	10-50	*Cc*		**				**	**	296
		Wh	Layers	*Cm*	**							59
		--	25	*Cm*	*!	**			**			60
		G	25	*Cse*	**	**			**			67
		L	5-50	*Zs*	*!	!!		*!		*!		346
Lamiaceae	*Ocimum gratissimum*	Wh	Layers	*Cm*	**							59
		--	25	*Cm*	*!	**			**			60
		T	2 g/500 seeds	*Cm*		*!		*!				209
Lamiaceae	*Ocimum sanctum*	L	0.1-0.4 g / 50 seeds	*Cm*	*!			*!		*!		248
Lamiaceae	*Origanum vulgare*	--	1-7.4	*Ao, Sg*	*!							138
Lamiaceae	*Rosmarinus officinalis*	Wh	1 g/6 beans	*Ao*	*!	*!		*!		*!		261
		--	1-7.4	*Ao, Sg*	*!							138
Lamiaceae	*Satureja hortensis*	wh	1 g/6 beans	*Ao*	*!	*!		*!		*!		261
Lamiaceae	*Tetradenia riparia*	L	1-100	*Ao, Zs*		*!		*!		*!		345
Lamiaceae	*Thymus serpyllum*	wh	1 g/6 beans	*Ao*	*!	*!		*!		*!		261
Lamiaceae	*Thymus vulgaris*	wh	1 g/6 beans	*Ao*	*!	*!		*!		*!		261
		--	1-7.4	*Ao, Sg*	*!							138
Lauraceae	*Cinnamomum camphora*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
		L	10-50	*Cm*		**			**			69
Lauraceae	*Laurus nobilis*	wh	1 g/6 beans	*Ao*	**	**		*!		**		261
		--	1-7.4	*Ao, Sg*	*!							138
Lecythidaceae	*Napoleona imperialis*	L	5-37.5	*Cm, Csu, Sz*	**	**				**		176
Leguminosae-Caesalpinioideae	*Chamaecrista nigricans*	--	0.003	*Ao*				*!				66
		wh	0.3-30	*Ao*		**				*!		162
		L	2g/20seeds	*Cm*	**	*!		**		**		59
		--	25	*Cm*	*!	*!			**			60
		--	10 ml/kg	*Cm*							**	61
		L, P	50 ml/l	*Cm, Tco*							*!	354
Leguminosae-Caesalpinioideae	*Erythrophleum suaveolens*	B	2 g/500 seeds	*Cm*		*!		*!				209
Leguminosae-Caesalpinioideae	*Peltophorum africanum*	B	60	*Cm*		*!				**	**	131

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Leguminosae-Caesalpinioideae	*Senna occidentalis*	L, S	100	*Cm*		**				**		165
Leguminosae-Caesalpinioideae	*Tamarindus indica*	L	10-50	*Cm*		*!			*!			69
Leguminosae-Mimosoideae	*Acacia concinna*	Pod	5-10	*Cc*				*!		**		1
Leguminosae-Mimosoideae	*Acacia sinuata*	L, S	10%	*Ca*		**					**	100
		S	10-50	*Cc*		**				**	**	296
Leguminosae-Mimosoideae	*Entada africana*	L	100-300	*Cm*							**	93
Leguminosae-Mimosoideae	*Parkia biglobosa*	Bs	100-300	*Cm*							**	93
Leguminosae-Mimosoideae	*Prosopis africana*	Bs	100-300	*Cm*							*!	93
Leguminosae-Papilionoideae	*Derris inudata*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
Leguminosae-Papilionoideae	*Derris* spp.	--	3%	*Cc, Sz*	*!							200
Leguminosae-Papilionoideae	*Myroxylon balsamum*	L	10-50	*Cm*		**			**			69
Leguminosae-Papilionoideae	*Phaseolus vulgaris*	Beans' phytohemag glutinin	0.1-5%	*Cm*					*!			130
Leguminosae-Papilionoideae	*Pongamia pinnata*	S	10-50	*Cc*		**				**	**	296
		L po/wh	50	*Cc*						*!		325
Leguminosae-Papilionoideae	*Tephrosia vogelii*	G	25	*Cse*	*!	!!			!!			67
		L	0.8-80	*So, Zs*							*!	207
Leguminosae-Papilionoideae	*Trigonella foenum-graecum*	L, S	100-400	*Ao, Tca*	*!	*!		*!		*!		234
Liliaceae	*Allium sativum*	Cloves fr	1 g/6 beans	*Ao*	**	**		**		**		261
		Bu	20	*Cm*		**					**	132
Liliaceae	*Aloe marlothii*	L	60	*Cm*		*!				*!	**	131
Malvaceae	*Sida acuta*	T	2 g/500 seeds	*Cm*		**		**				209
Meliaceae	*Aphanamixis polystachya*	B, L, S	25	*Cc*	*!	*!	**			*!	*!	330

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Meliaceae	*Azadirachta indica*	L	0.25-1 l/l	*Ao, Zs*						*!		49
		L po/wh	1/10 pods	*Ba, Cm*	**	**	**			**		15
		K, L	10%	*Ca*		**					**	100
		S	50	*Ca*	!!	!!					!!	135
		K, L	5-20	*Cc*				*!		*!		1
		L, S	1-3%	*Cc*	!!	!!	!!					4
		K	3%	*Cc*							**	40
		--	5-20	*Cc*		*!				*!	!!	50
		L	2-8	*Cc*							*!	226
		B	2-8	*Cc*	*!							227
		L	20-80	*Cc*		*!				*!		267
		S	10-50	*Cc*		*!				*!	*!	296
		--	2-8	*Cc*							*!	302
		W	2-8	*Cc*							*!	308
		L po/wh	50	*Cc*						*!		325
		K, L po/wh	0.5-15%	*Cc, Cm, Rd, Sg, So, Sz, Tca, Tco, Tg*	*!	*!				*!	*!	275
		K, L	0.5-5%	*Cc, Sg, So*	*!							121
		K, L	50	*Cm*							*!	10
		F	12.5-75	*Cm*						*!		12
		L	2g/20seeds	*Cm*	**	**		**		**		59
		K, L	25	*Cm*	*!	**			**			60
		S	10 ml/kg	*Cm*		**					**	61
		F	5	*Cm*		*!				*!	*!	81
		L, K, S	10-20, 0.5-12%	*Cm*	*!						*!	111
		K	50-150	*Cm*	**	*!				!!	!!	123
		K	5-20	*Cm*							!!	134
		S	6.4-38.4	*Cm*		*!				*!		161
		S	0.5-5%	*Cm*	!!	*!		*!		*!		169
		L	0.5-3%	*Cm*	!!	*!		!!		!!		170
		S	25	*Cm*	*!						*!	211
		S	6.25-150	*Cm*	*!	*!				!!		212
		L, S	10-30	*Cm*	*!							285
		L, S	10-30	*Cm*	*!	**					*!	287
		K	0.5-2%	*Cm*						*!	*!	311
		L	20	*Cm, Sz*							!!	22

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Meliaceae	*Khaya senegalensis*	B	2g/20seeds	*Cm*	**	**		**		**		59
		Bs	100-300	*Cm*							**	93
Meliaceae	*Melia azedarach*	--	50	*Cm*							*!	10
		F	1-8%	*Cm*	*!						*!	85
		F, B	60	*Cm*		*!				*!	**	131
Moraceae	*Ficus exasperata*	L	2 g/500 seeds	*Cm*		**		**				209
Myrtaceae	*Eucalyptus citriodora*	L po/wh	20-80	*Cc*						!!		325
Myrtaceae	*Eucalyptus globulus*	L po/wh	1 g/6 beans	*Ao*	**	*!		*!		*!		261
Myrtaceae	*Eucalyptus* spp.	L	10-50	*Cc*		**				**	**	296
		L po/wh	50	*Cc*						*!		325
		F, L	60	*Cm*		*!				*!	**	131
		L	20	*Cm, Sz*							**	22
Myrtaceae	*Eugenia aromatica*	Fl	20	*Cm*		!!					!!	132
Myrtaceae	*Eugenia uniflora*	L	0.5-4 g/50 seeds	*Cm*		*!				*!		2
Piperaceae	*Piper guineense*	F po/wh	25-75	*Cm*	*!	*!				*!		125
		S	12.5-37.5	*Cm*	*!	!!				!!		178
		F	53-420	*Cm*		*!				*!		216
		F	5-37.5	*Cm, Csu, Sz*	*!	*!				*!		176
		F	4-120	*Cm, Sz*	!!					!!		215
Piperaceae	*Piper nigrum*	--	0.012	*Ao*							*!	30
		S	2.8-11.1	*Ao*							*!	163
		S	0.03-0.12%	*Ao, Cc*	*!					*!	!!	199
		S	50	*Ca*	!!	!!					!!	135
		--	0.05%	*Ca, Cc*							**	149
		--	0.25-0.5%	*Cc*							!!	111
		--	0.12%	*Cc*	*!							198
		S	10-50	*Cc*		*!				*!	*!	296
		F	20	*Cm*		*!					*!	132
		L	0.10 g/50 seeds	*Cm*	*!							247
		L	0.1-0.4 g/ 50 seeds	*Cm*	*!			*!		*!		248
		F	20	*Cm*							*!	341
		F	0.063-0.5%	*Cm, So*	*!					*!		315
		--	10 g	*Cm, Sz*							*!	22

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Poaceae	*Cymbopogon citratus*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
		L	0.5-4 g/50 seeds	*Cm*		**				**		2
		L	10-50	*Cm*		**			**			69
		L	2 g/500 seeds	*Cm*		**		*!				209
		L, T	40	*Cm*							**	341
Poaceae	*Cymbopogon nardus*	wh	1 g/6 beans	*Ao*	**	*!		*!		*!		261
Poaceae	*Cymbopogon schoenanthus*	B	2g/20 seeds	*Cm*	**	*!		**		**		59
		L	25	*Cm*	*!	**			**			60
Polygalaceae	*Polygala butyracea*	Seed coat	250 ml/l	*Cm, Tco*							*!	354
Polygalaceae	*Securidaca longepedunculata*	L, Br	50-100	*Cm, Sz, Tca*	*!					*!	*!	180
Polygonaceae	*Polygonum hydropiper*	L	20-80	*Cc*		*!				*!		267
Rubiaceae	*Diodia sarmentosa*	Fl	5-37.5	*Cm, Csu, Sz*	**	**				**		176
Rubiaceae	*Mitracarpus scaber*	Shoots	100-300	*Cm*							**	93
		Fl	5-37.5	*Cm, Csu, Sz*	**	**				**		176
Rutaceae	*Citrus aurantifolia*	L	100-300	*Cc, Cm, Cr*		**		**				251
		P	50-100	*Cm*	**	**				*!		219
Rutaceae	*Citrus crematifolia*	P	0.20 g/50 seeds	*Cm*		*!						247
		P	0.1-0.4 g/ 50 seeds	*Cm*	**			*!		*!		248
Rutaceae	*Citrus grandis*	P	40	*Cm*							*!	341
Rutaceae	*Citrus limon*	L	100-300	*Cc, Cm, Cr*		**		**				251
		P	50-100	*Cm*	**	**				**		219
		L, P	20	*Cm*							*!	341
Rutaceae	*Citrus paradisi*	P	1-100	*Cm*	!!	*!				!!		9
		P	50-100	*Cm*	*!	*!				*!		219
		P	25-180	*Cm, Dm*	*!							73
Rutaceae	*Citrus reticulata*	P	50	*Ca*	!!	!!					!!	135
		P	40	*Cm*							**	341

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Rutaceae	*Citrus sinensis*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
		P	1-100	*Cm*	*!	*!				*!		9
		P	12.5-75	*Cm*						*!		12
		P	2-4	*Cm*							**	37
		L	10-50	*Cm*		**			**			69
		P	50-100	*Cm*	**	**				**		219
		P	25-180	*Cm, Dm*	*!					*!		73
		P	20	*Cm, Sz*							**	22
Rutaceae	*Citrus* spp.	F wh	1/5 kg	*Ao*							**	30
Rutaceae	*Zanthoxylum zanthoxyloides*	Br, S	25	*Cm*	*!						*!	211
		Br	6.25-150	*Cm*	*!	*!				!!		212
		Br	25	*Cm*	*!							213
Sapindaceae	*Sapindus saponaria*	Pod	5-20	*Cc*				*!		**		1
Solanaceae	*Capsicum annuum*	--	0.12%	*Cc*	**							198
		F po/wh	25-75	*Cm*	*!	*!				*!		125
		F	10-20	*Cm*		*!						218
		F	2.5	*Cm*	*!						*!	357
		--	10 g	*Cm, Sz*							**	22
Solanaceae	*Capsicum chinense*	F	10-20	*Cm*		!!						218
Solanaceae	*Capsicum frutescens*	F	0.03-0.12%	*Ao, Cc*	*!					*!	!!	199
		F	2g/20seeds	*Cm*	**	**		**		**		59
		F po/wh	25-75	*Cm*	**	*!				*!		125
		F	20	*Cm*		**					**	132
		F	--	*Cm*		*!				*!		160
		F	10-20	*Cm*		!!				*!		218
		F	30	*Cm, Rd, So, Tca, Tg*							*!	8
		--	80 ml/l	*Cm, Tco*							**	354
Solanaceae	*Capsicum* spp.	--	25	*Cm*	*!	**			**			60
Solanaceae	*Nicotiana tabacum*	G	25	*Cse*	**	**			**			67
		L	2 g/500 seeds	*Cm*		*!		*!				209
		L	2	*Cc, Cm*	**	*!	**		**	*!		245
Solanaceae	*Solanum incanum*	--	50	*Cm*							*!	10
Sphenocleacea	*Sphenoclea zeylanica*	Shoot	100-300	*Cm*							*!	93
Tiliaceae	*Tilia cordata*	--	1 g/6 beans	*Ao*	*!	**		**		**		261

Plant Family	Plant species	Plant part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Verbenaceae	*Lantana camara*	--	5-20	*Cc*		*!				*!		50
		L po/wh	50	*Cc*						*!		325
		L	0.5-4 g/50 seeds	*Cm*		**				**		2
		L	10-50	*Cm*		**			**			69
Verbenaceae	*Lippia adoensis*	L	0.5-4 g/50 seeds	*Cm*		*!				*!		2
Verbenaceae	*Lippia chevalieri*	wh	Layers	*Cm*	**							59
Verbenaceae	*Lippia multiflora*	G	25	*Cse*	**	*!			*!			67
Verbenaceae	*Vitex altissima*	L	10-50	*Cm*		*!			**			69
Verbenaceae	*Vitex negundo*	L wh	5-30	*Cc*		*!				*!		240
		L	20-80	*Cc*		*!				*!		267
Verbenaceae	*Vitex* spp.	L	10	*Ca*	**	**						139
Zingiberaceae	*Aframomum melegueta*	S	2 g/ 500 seeds	*Cm*		**		**				209
Zingiberaceae	*Alpinia galanga*	--	0.25-3%	*Cc*	!!	!!	*!					4
		R	40	*Cm*							**	341
Zingiberaceae	*Curcuma amada*	--	0.25-3%	*Cc*	!!	!!	*!					4
Zingiberaceae	*Curcuma longa*	--	1-3%	*Cc*	!!	!!	!!					4
		R	10-20	*Cc*		*!				*!	*!	296
		R	20	*Cm*		*!					**	132
Zingiberaceae	*Curcuma zedoaria*	--	0.25-3%	*Cc*	!!	!!	*!					4
Zingiberaceae	*Zingiber officinale*	--	1-3%	*Cc*	!!	*!	**					4
		R	5	*Cm*		*!				*!	*!	81
		R	20	*Cm*		**					**	132
		R	2 g/500 seeds	*Cm*		**		**				209
Zingiberaceae	*Zingiber spectabile*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
Zingiberaceae	*Zingiber zerumbet*	L	100-300	*Cc, Cm, Cr*		*!		*!				251
Zygophyllaceae	*Balanites aegyptiaca*	R	100-300	*Cm*							*!	93

$: B = bark, Br = root bark, Bs = stem bark, Bu = bulb, F = fruits, Fl = flowers, G = green parts, K= kernels, L = leaves, P = peels, R = rhizomes, roots, S = seeds, T = twigs, Tu = tuber, W = wood; d = among others used dry, fr = fresh, po = among others used as a powder, wh = whole un-ground material used.
~: in g plant material/kg stored product, unless stated otherwise.
^: See table 1
#: A= adult longevity & fecundity, O = oviposition, E = survival of eggs & embryos on the seed surface, H = hatching, L= survival of larvae and pupae inside the seed, M = emergence, P = population numbers & effect on the stored product; ** = Measured, but no statistically significant results were found or presented, *! = Significant decrease, !! = Total inhibition.

2.1 DEVELOPMENTAL STAGE AFFECTED

The efficacy of plant powders as insecticides depends on the plant (species, used parts, harvest time, storage method etc.), the size of the powder particles (51) and on the applied quantity.

2.1.1 EFFECTS ON ADULTS

Toxicity, either through fumigation or through direct contact, is usually the major action of plant powders against adult insects in laboratory tests. In the literature, toxicity levels vary widely, from slight toxicity to induction of complete mortality of all adult insects. *Chenopodium ambrosioides* and *Tephrosia vogelii* affected adult survival of *Cse* (67). Leaves and kernels of *Azadirachta indica* slightly increased adult mortality of *Cm* (287). Fresh and dry whole leaves of *Boscia senegalensis* caused mortality (288) and root bark of *Zanthoxylum zanthoxyloides* showed high contact toxicity to adults of *Cm* (212). The gum exudate of *Anacardium occidentale* mixed with cowpea flour in artificial seeds reduced the number of surviving adults of *Cm* (174). Leaves of *Piper nigrum* caused adult mortality for *Cm* (248) and were highly toxic to *So* adults. The toxicity was attributable to the presence of piperine (315). *Piper guineense* seeds caused adult mortality in *Cm, Csu* and *Sz* (176). *Dennettia tripetala* achieved complete adult mortality for *Sz* (215) whereas *Alpinia galanga, Curcuma amada* and *Curcuma zedoaria* did so for *Cc* (4) and *Ricinus communis* for *Cm* (214).

On the other hand, repellence accounts for a large part of the effect of powders of Apiaceae, Lamiaceae and Rutaceae on storage beetles. The effect of *Hyptis spicigera, Lippia chevalieri, Ocimum basilicum* and *Ocimum gratissimum,* applied as layers of powder between layers of cowpea pods, could be due to an insect repellent effect (59). *Anethum graveolens* repelled *So, Cm* and *Ls* (319).

However, in laboratory tests, the repellent effect can only be measured if the test insects are given the choice to escape from the treated areas. In other cases, the toxic effects of plant powders are measured, where the effect would be repellent if the insect could get away. Leaves of *Ocimum basilicum* caused complete mortality and showed fumigant toxicity against adults of *Zs* (346), but were found to have a repellent effect in other situations (59).

Sometimes both repellent and lethal effects are found. Peels of *Citrus sinensis* and *Citrus paradisi* were all both toxic and repellent to adults of *Cm* (73) but *Citrus sinensis* was more effective than *Citrus paradisi* (9).

2.1.2 EFFECTS ON OVIPOSITION

If plant powders reduce adult longevity and fitness, the numbers of eggs laid will often be lower as well. Moreover, the mechanical effect of large quantities of powders themselves could have an effect on oviposition. In most papers, results are given without an explanation. All plant powders tested by Javaid and Mpotokwane (131) were effective against oviposition of *Cm*. *Capsicum frutescens, Capsicum annuum* and *Capsicum chinense* effectively reduced oviposition of *Cm* (218), but seeds of *Piper guineense* (216) were more effective than the first two species (125). The gum exudate of *Anacardium occidentale* mixed with cowpea flour in artificial seeds prevented oviposition of *Cm* (174). Peels of *Citrus paradisi, Citrus aurantifolia* (219) and *Citrus crematifolia* (248), root bark of *Zanthoxylum zanthoxyloides* (212), fruits of *Curcuma longa* and *Eugenia aromatica* (132), *Azadirachta indica, Anacardium occidentale* and *Zingiber officinale* all decreased the number of eggs laid by *Cm* (81). *Mitracarpus scaber, Napoleona imperialis* and *Diodia sarmentosa* decreased the

number of eggs laid by *Cm* and *Sz* (176). Leaves, bark and seeds of *Aphanamixis polystachya* deterred oviposition of *Cc* to some extent (330). *Eucalyptus citriodora* was effective against oviposition of *Cc* (325). *Chenopodium ambrosioides* and *Tephrosia vogelii* affected oviposition of *Cse* (67). Leaves of *Ocimum basilicum* suppressed oviposition of *Zs* completely, but when large quantities of whole intact leaves were applied, oviposition was enhanced (346).
Plant powders can have an effect on the reproduction of stored product beetles without affecting the longevity of parent or F1 adults. Seeds of *Azadirachta indica* did not impair adult longevity of *Cm* females, but they did reduce their fecundity (123). Oviposition of *Cc* and *Cm* was decreased by leaf dust of *Nicotiana tabacum* but the eggs that were laid developed normally (245).

2.1.3 EFFECTS ON EGGS AND LARVAE

Effects of plant powders on eggs are not often found. *Curcuma longa* exhibited an ovicidal effect on *Cc* (4).
Larvae of seed beetles, protected by the testa and the seed contents, are not very susceptible to the effects of plant powders either. Leaves, bark and seeds of *Aphanamixis polystachya* decreased larval survival and seed damage by *Cc* (330). *Piper nigrum* and *Capsicum frutescens* had an effect on larval development of *Ao* and *Cc* (199).
Plant powders often prevent or reduce the emergence of adult beetles from the seed. However, it is not clear if this effect is caused by larval mortality, or by the fact that the emerging adults contact the plant powder while gnawing their way out of the seed. All plants tested by Javaid and Mpotokwane (131) were effective against emergence of *Cm* but none of them decreased the seed weight loss. In this case, the seed weight loss was said to imply that the larvae did develop completely. Based on the data provided in most publications, it is not possible to unequivocally determine the stage of the beetle that was affected. *Anacardium occidentale, Zingiber officinale* and *Azadirachta indica* (81) and peels of *Citrus paradisi* and *Citrus aurantifolia* significantly decreased infestation and emergence of *Cm* (219). Seeds of *Azadirachta indica* had the same effects and they prolonged the developmental period of the beetle as well (123). *Piper guineense* reduced adult emergence in *Cm* (216). *Dennettia tripetala* and *Piper guineense* inhibited emergence of *Cm* and *Sz* completely (215). *Eucalyptus citriodora* (325) and leaves of *Vitex negundo* (240) were effective against emergence of *Cc*. Seed treatment with whole plants of *Chamaecrista nigricans* and with some ecotypes of *Hyptis spicigera* decreased emergence of *Ao* (162).
In some cases, the protecting effect of plant powders against insects is mentioned without any indication of the susceptible developmental stage. Whole leaves of *Boscia senegalensis* caused a reduction of progeny numbers and a decrease in seed damage by *Cm* (288). *Capsicum frutescens* effectively controlled *Rd* (8). Leaves of *Azadirachta indica* had antifeedant properties and an inhibiting effect on the growth and reproduction of storage insects (119). *Trigonella foenum-graecum* inhibited larval penetration of *Ao* and was moderately toxic to larvae of *Tca* (234).
Sometimes plant powders are found to have an effect opposite of what was aimed for. High concentrations of intact leaves of *Ocimum basilicum* increased hatching and progeny emergence (346).

2.2 COMPARISON OF BEETLE SPECIES

Not all storage pest insects are equally susceptible to the effect of plant powders. *Capsicum frutescens* and *Hyptis spicigera* effectively controlled *Rd* but were not effective against *Cm, So, Tca* and *Tg* (8). *Citrus sinensis* and *Citrus paradisi* peels were more toxic to *Cm* than to *Dm* adults (73). *Mitracarpus scaber*, *Napoleona imperialis* and *Diodia sarmentosa* prevented oviposition of *Cm* and *Sz* but not of *Csu* (176).
The test conditions can influence the outcome of experiments. In laboratory tests, *Ao* was most effectively controlled by an oil extract of *Lavandula angustifolia* and for the control of *Sg*, dried dust of *Laurus nobilis* was most effective. However, under storehouse conditions, the best insecticidal efficacy against *Sg* in milling wheat was shown by dust of *Rosmarinus officinalis*, whereas in seed wheat an oil extract of *Laurus nobilis* was best (138).

2.3 COMPARISON OF PLANT SPECIES

Results of tests with neem, *Azadirachta indica* are sometimes ambiguous. Usually neem is very effective against insects. The seeds were more insecticidally effective than *Citrus chinensis* and *Eupatorium odoratum* (12). But not always is *Azadirachta indica* among the most effective plants. *Azadirachta indica, Zingiber officinale* and *Curcuma longa* were less effective than *Alpinia galanga, Curcuma amada* and *Curcuma zedoaria* against *Cc* (4). *Anacardium occidentale* protected cowpea better against *Cm* than *Zingiber officinale* and/or *Azadirachta indica* did (81). Moreover, some contradicting results have also been found in the screened literature. According to Chiranjeevi and Sudhakar (50), *Azadirachta indica* completely inhibited the development of *Cc* whereas *Acorus calamus* did so only slightly. However, *Azadirachta indica* was less effective against *Cc* than *Acorus calamus* kernel (258) and less repellent than twigs of *Acorus calamus* and *Ledum palustre* (121). *Acorus calamus, Thevetia peruviana* and *Ipomoea carnea* effectively protected seeds against *Cc* (228). *Azadirachta indica* and *Zanthoxylum zanthoxyloides* were both as effective as pirimiphos-methyl and permethrin in reducing bruchid damage (211), but Ogunwolu and Odunlami (212) found *Zanthoxylum zanthoxyloides* to be significantly more effective against *Cm* than *Azadirachta indica.*
Pepper species, *Capsicum* and *Piper*, are traditionally often used. When compared to other plants they are often, but not always highly effective. Here again, contradictory results have been found. Of six plants, *Capsicum annuum* was the only one that effectively controlled *Cm* and *Sz* (22). *Capsicum annuum, Capsicum chinense* and *Capsicum frutescens* in particular were effective in reducing damage to cowpea by *Cm* (218). The insecticidal properties of *Capsicum frutescens* were better than carbon-bisulphite and pyrethrum (339). However, according to Zehrer (354), *Capsicum frutescens* was ineffective against *Cm* and *Tco* and the results did not differ from the untreated control. Besides, Morallo-Rejesus *et al.* (199) found that *Piper nigrum* showed more contact toxicity against *Ao* and *Cc* than *Capsicum frutescens*. *Piper nigrum* reduced damage by *Cm*, whereas *Capsicum frutescens, Zingiber officinale* and *Allium sativum* were not effective (132). *Piper guineense* enhanced mortality in *Cm* (178) more than *Capsicum annuum* and *Capsicum frutescens* (125) and it caused mortality in *Csu* and *Sz* adults (176). However, *Dennettia tripetala* was more effective than *Piper guineense, Monodora myristica* and *Xylopia aethiopica* against *Sz* (215).
For plants of the Lamiaceae, the results of laboratory tests vary greatly. Dry *Hyptis spicigera* and *Chamaecrista nigricans* did not decrease oviposition of *Ao*, but some

ecotypes did decrease emergence (162). These powders reduced infestation by *Cm* considerably (339) and *Hyptis spicigera* effectively controlled *Rd* but it was not effective against other seed beetles. *Hyptis suaveolens* was not effective against any of the insect species tested, including *Cm* (8), but of ten plants tested, *Hyptis suaveolens* and *Sphenoclea zeylanica* showed the best protectant effects against *Cm* (93). *Ocimum basilicum* and *Lippia multiflora, Eupatorium odoratum* and *Nicotiana tabacum* had little or no effect on *Cse* (67). *Rosmarinus officinalis, Origanum vulgare, Thymus vulgaris* and *Laurus nobilis* were only slightly effective against *Ao* but under storehouse conditions, *Rosmarinus officinalis* showed the highest insecticidal efficacy against *Sg* (138). *Mentha spicata* was as effective as two chemical pesticides against *Ca* (100). Of *Mentha piperata, Rosmarinus officinalis, Thymus serpyllum, Thymus vulgaris, Allium sativum, Cymbopogon nardus, Eucalyptus globulus, Laurus nobilis* and *Satureja hortensis,* the first five, all Lamiaceae, provided the best insecticidal effect against *Ao* and among them, *Thymus serpyllum* was the most efficient (261).

Plants from other families can also show differing rates of efficacy. *Thevetia peruviana* and *Ipomoea carnea* effectively protected seeds from damage by *Cc*, whereas *Adhatoda vascia* leaves proved to be ineffective (228). *Eugenia aromatica* reduced damage by *Cm* completely whereas *Curcuma longa* reduced only oviposition (132). Leaves of *Eugenia uniflora* and *Lippia adoensis* were effective against *Cm,* but *Lantana camara* and *Cymbopogon citratus* were not (2). Dry and fresh leaves, and whole and ground seeds of *Senna occidentalis* did not show contact toxicity to *Cm* and did not protect stored seeds (165). None of the plant powders tested by Javaid and Mpotokwane (131) decreased the seed weight loss due to *Cm* infestation. *Annona senegalensis, Entada africana, Khaya senegalensis* and *Parkia biglobosa* were ineffective or even increased the number of damaged seeds (93). All plant powders tested by Javaid and Mpotokwane (131) were effective against *Cm,* but *Terminalia sericea* and *Peltophorum africanum* were the only ones inhibiting adult emergence. *Citrus sinensis* was more effective than *Citrus paradisi* as a repellent and a toxicant against adults of *Cm* (9; 73).

The plant part and its preparation used in experiments can influence the results. Seeds of *Aphanamixis polystachya* were more effective against *Cc* than the leaves and bark of this plant (330). Fresh ground leaves of *Boscia senegalensis* were more effective than fresh entire leaves or dry leaf powder against *Cm* (288). At low dosages, kernels of *Azadirachta indica* were more effective against *Cm* than leaves (287). Bruchid mortality was highest for ground fruits of *Capsicum annuum,* lower for sliced fruits and lowest for whole fruits (357).

2.4 DURATION OF THE EFFECTS

The persistence of powders or fresh plants is usually better than for instance that of volatile oils (chapter 4). In most studies, the short-term effect is less important than the overall long-term effect on the beetle population. *Ricinus communis* leaves (214), *Capsicum annuum* (22) and *Dennettia tripetala, Piper guineense, Monodora myristica* and *Xylopia aethiopica* (215) offered seed protection for 3 months. *Hyptis suaveolens* and *Sphenoclea zeylanica* still showed protectant effects after 4 months (93). Grain treatment with *Piper nigrum* seeds caused a reduction damage by *Ao* after 4 months (163). *Thevetia peruviana, Acorus calamus* and *Ipomoea carnea* effectively protected seeds from damage by *Cc,* for at least 135 days (228). The effect of *Zanthoxylum zanthoxyloides* and *Azadirachta indica* against *Cm* lasted for nearly 5 months (212). Residual toxicity of *Piper nigrum* and *Capsicum frutescens* lasted for 6 months (199) and *Capsicum annuum* effectively controlled *Sz* up to the sixth month (22). Kernels of *Azadirachta indica* protected cowpea against *Cm* satisfactorily up until 8 months (311). *Vitex negundo* reduced oviposition and adult emergence of *Cc* up until 9 months (240). *Azadirachta indica* kernel powder protected stored seeds for up to 11 months against *Cm* (134). Leaves of *Cissus quadrangularis* protected cowpea from insect pests for 1-2 years, whereas *Swartzia madagascariensis* did so for 1 year, *Prosopis africana* for 3-5 years and *Pterocarpus santalinus* and *Maerua angolensis* for up to 7 years, and the latter did not show any effect on germination (153).

2.5 EFFECTS ON THE STORED PRODUCT

Powders may have an effect on the seeds they are supposed to protect. Seeds treated with *Monodora myristica* changed colour (215) and powdered fruits of *Capsicum annuum* left a red colour on the seeds (357). Stored grain, treated with *Azadirachta indica* seed powder, was spoiled due to growth of the neem seed-borne fungus of the *Aspergillus* family (236).

However, powders do not usually have these adverse effects. In most experiments, the seeds retain their viability and culinary properties. No adverse effect on seed germination was found after treatment with *Origanum vulgare*, *Laurus nobilis*, *Thymus vulgaris*, *Rosmarinus officinalis* (138), *Thevetia peruviana*, *Adhatoda vascia*, *Acorus calamus*, *Ipomoea carnea* (228) and *Maerua angolensis* (153). Seed quality and viability were not affected by treatment with peels of *Citrus paradisi* and *Citrus aurantifolia* (219) or by *Capsicum annuum*, *Capsicum chinense* and *Capsicum frutescens* (218). Neither of the treatments with *Piper guineense*, *Capsicum annuum* or *Capsicum frutescens* affected seed viability or cooking properties (125). Seed germination and taste were preserved quite well after treatment with root bark of *Zanthoxylum zanthoxyloides* (212) and these properties were not impaired by treatment with *Azadirachta indica* kernel powder either (134). Seeds remained viable and their texture, colour and overall attractiveness remained unaffected after treatment with seeds of *Azadirachta indica* (123).

2.6 CONCLUSIONS

For powders, hardly any general rule is to be found. There is no ranking order for efficacy of the plants and the best mode of application is unknown. The preparation and application are easy and therefore many plants have been used as powders in pilot tests. Applied quantities and results from tests vary greatly. If the right plant is chosen, all stages of the developing beetle can be affected. If an effect is found, it usually lasts for a few months. There are usually no effects on the stored product.

3 ASH

Whereas the effect of powders is mainly toxic or repellent, the effect of ash mixed with the stored seeds, a traditional means of protection, is mainly physical. Ashes of different plant species can have different effects on insects due to their structure and particle size or to components of the ash that still have toxic effects on the beetles. Generally, the finer the particles are and/or the greater the applied quantity, the more effective this method will be. The quantities of ash needed to effectively protect stored products are large. The treatment will occupy much of the storage room and would therefore be useful for small quantities of cowpea only (59). The plants used as ashes and their effects on storage beetles are summarised in table 3.

Table 3: Incinerated material used against storage insects, the quantity and its effect.

Plant (sub-) family	Plant species	Quantity ~	Beetle species ^	Affected stage #							Reference
				A	O	E	H	L	M	P	
Bombacaceae	*Ceiba pentandra*	1000 ml/l	*Cm*						*!	*!	349
Casuarinaceae	*Casuarina indica*	10-20	*Cc*		*!				*!		50
Combretaceae	*Combretum imberbe*	60	*Cm*		*!				*!	*!	131
		20	*Cm*		*!					*!	132
		100-1000	*Cm*		*!				*!	*!	133
Leguminosae-Caesalpinioideae	*Afzelia africana*	2g/20 grains	*Cm*	**	*!		**		**		59
		2:3-1:1 v:v	*Cm*	*!	*!			**			60
		1000 ml/l	*Cm*						*!	*!	349
Leguminosae-Caesalpinioideae	*Tamarindus indica*	20-25	*Cm, Rd, So, Tca, Tg*							*!	8
Leguminosae-Mimosoideae	*Acacia nilotica*	10-20	*Cc*		*!				*!		50
Leguminosae-Mimosoideae	*Acacia* spp.	50	*Cm*							*!	10
Leguminosae-Mimosoideae	*Parkia biglobosa*	1000 ml/l	*Cm*						*!	*!	349
Leguminosae-Papilionoideae	*Phaseolus* spp.	50-300	*Cm*		*!				*!	*!	140
Leguminosae-Papilionoideae	*Pterocarpus erinaceus*	2g/20 grains	*Cm*	**	*!		**		**		59
		2:3-1:1 v:v	*Cm*	*!	*!			**			60
Meliaceae	*Azadirachta indica*	10-20	*Cc*		*!				*!		50
		20	*Cm, Sz*							**	22
Poaceae	*Cymbopogon nardus*	5-100	*Ca*	*!	*!						139
Poaceae	*Oryza sativa*	40	*Cm*							*!	247

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Poaceae	*Pennisetum* spp.	2g/20 grains	*Cm*	**	*!		**		**		59
		2:3-1:1 v:v	*Cm*	*!	*!			**			60
Poaceae	*Sorghum bicolor*	1000 ml/l	*Cm*						*!	*!	349
Rubiaceae	*Coffea arabica*	33-66	*Ao*							*!	338
Sapotaceae	*Vitellaria paradoxa*	2g/20 grains	*Cm*	**	*!		**		**		59
		2:3-1:1 v:v	*Cm*	*!	*!			**			60
		1000 ml/l	*Cm*						*!	*!	349
	Cattle dung	10-20	*Cc*		!!				*!		50
		25-1000	*Cm*		*!				*!	*!	133
	Wood (kitchen stove)	200	*Ao*							*!	30
		33-66	*Ao*							*!	338
		0.25-1.00 l/l	*Ao, Zs*						*!	*!	49
		50	*Ao, Zs*						**	**	309
		10%	*Ca*		**					*!	100
		2g/20 grains	*Cm*	**	*!		**		**		59
		500 ml/l	*Cm*	*!							66
		10-40	*Cm*						!!	!!	341
		1000 ml/l	*Cm*						*!	*!	349
		0.125-1.0 l/l, mix & layer	*Cm*		!!				**		350
		20	*Cm, Sz*							**	22

~: Quantity in g ash/kg stored product, unless stated otherwise
^: See table 1
#: A= adult longevity & fecundity, O = oviposition, E = survival of eggs & embryos on the seed surface, H = hatching, L= survival of larvae and pupae inside the seed, M = emergence, P = population numbers & effect on the stored product; ** = Measured, but no statistically significant results were found or presented, *! = Significant decrease, !! = Total inhibition.

3.1 DEVELOPMENTAL STAGE AFFECTED

3.1.1 EFFECTS ON ADULTS

Most of the effect of ashes is caused by a mechanical rather than by a chemical action. Immobilisation of the adult insects plays an important role. Adult beetles use the inter-granular space to infest the stored product. Obstruction of inter-granular spaces hinders movement of the adult beetles and thus leads to less or shallower infestation (110). Since the movement of the adults is hampered (66; 140) their latitude of movement and of meeting conspecifics is limited (339) and their rate of multiplication will thus be lower. The evolution of the infestation in ash-treated stored seeds is slower than in untreated control samples. The bruchids go to the surface when they can and lay their eggs on seeds sticking out of the ash (60). Accordingly, any dry, powdery substance, such as fine sand (66), filling the inter-granular space might serve as a good protective medium for stored seeds. However, the relatively heavy sand particles, and powders of irregular size cannot be evenly mixed with the beans and are therefore less effective than fine ash (49).

The applied ash does not only hamper beetle movement, but it can also do physical damage to the adult beetles. If the adult insects move over or through the ash, their bodies (22; 65), especially the layer of chitin on the adults' abdomen are grazed (339). Clogging of insect spiracles and tracheae (350) or blocking of the lateral stigmates, all essential for respiration, cause suffocation of the adult and enhance mortality (66). Toxicity and/or repellence by (components of) the ashes could also be important in the effects against insects. In this case, it does matter which material is incinerated to use against bruchid infestation. Remains of toxic compounds in ashes of specially selected plants might have extra effects on the beetles. Millet ash was said to be effective, because it contains acidic components that repel the beetles. Farmers recommended ashes of *Pterocarpus erinaceus, Vitellaria paradoxa, Pennisetum* spp. and *Afzelia africana* for their specific essence (59; 60).

Katanga Apuuli and Villet (140) found that the use of moist materials could induce premature germination or mould of the stored seeds. This is, however, inconsistent with the finding that ash can protect stored seeds from mould (153), and with the experience that the layer of ash covering the contents of storage structures is sometimes drenched with water to close it better and to make it more airtight (66).

3.1.2 EFFECTS ON OVIPOSITION

If applied in large enough quantities, the effect of ash on oviposition can be important. Wood ash failed to prevent oviposition of *Ca* (100), but *Cm* laid fewer eggs on beans treated with ash (350) of *Combretum imberbe* (131; 132) or of cow dung than on untreated control beans (133). Decreased oviposition could be caused by the restriction of movement of the beetles among the seeds, thus diminishing the possibility to oviposit directly onto the seed (140). Ash was also reported to obstruct the adhesion of the egg to the grain, just as non-volatile oils did (119), but the effect on oviposition could also just be attributed to the shorter lifetime of the females (59).

3.1.3 EFFECTS ON EGGS AND LARVAE

Suffocation could be a mechanism of the effect of ash on eggs, adults and larvae. Thick layers of ash reduce the available oxygen (339) and could interfere with the respiratory ability of eggs, larvae and adult bruchids (140).

However, the mechanism of the effect of ash is not always clearly stated. Ash of cow dung (133) and of *Combretum imberbe* significantly reduced adult emergence of *Cm* (131), as did ordinary wood ash (208). Larval and pupal mortality of *Cm* were higher in beans treated with ash than in untreated controls (350). Ash was more effective than sand and millet husks preventing adult emergence of *Zs* and *Ao* (49).

3.2 COMPARISON OF BEETLE SPECIES

Since the effect of ashes on storage beetles is mostly mechanical, the differences in susceptibility between different beetle species depend mostly on the differences in their life cycle. *Ba* leaves the store after a few generations, whereas *Cm* stays inside (119). Therefore, it could be that the latter species is more heavily affected by treatments with ash. *Sz* was more affected and thus caused less damage to seeds treated with ash than *Cm* (22). *Ao* was more affected by ash than *Zs* (49).

The differences in efficacy can depend on the product that is treated rather than on the differences in susceptibility between beetle species. *Azadirachta indica* ash and ordinary wood ash did not control *Cm*. The smooth surface of the cowpea prevented adherence of the applied ash to the seed, whereas on the rougher seed-surface of maize, used for tests with *Sz*, the ash adhered better (22).

3.3 COMPARISON OF PLANT SPECIES

Significant differences in weight loss and in numbers of beetles were noted for different ashes. *Parkia biglobosa* and *Afzelia africana* were more effective than *Vitellaria paradoxa, Ceiba pentandra, Sorghum vulgare*, or mixtures of these ashes. Chemical analyses of these ashes could not prove the presence of heavy metals or alkaline salts as insecticidal components. However, tests with sand of the same particle size as the ashes did not give similar results, so the mere presence of inert particles of different sizes could not be the (only) cause for the differences in the results (349). Cow dung ash was more effective than *Combretum imberbe* ash (133). However, Javaid & Mpotokwane (131) found that the ash of *Combretum imberbe* could easily and maybe effectively be used if it were integrated with insecticidal plant products or with resistant seeds.
The results are often given without explanations of the possible mechanisms of action. Ash of *Phaseolus* spp. harvest-remains protected cowpea. A mixture of ash and beans gave very satisfactory protection, with fewer offspring than there were parents (140). Wood ash was found to be more effective than onion scale leaves and dry chilli pepper fruits (208).

3.4 DURATION OF THE EFFECTS

Ash seems to be appropriate for storage periods of intermediate lengths. A top (a middle) and a bottom layer will be enough to prevent (new) infestation. Wolfson *et al.* (350) suggested a 1:1 (by volume) ratio of ash with a layer on top to protect the cowpeas for at least one generation of beetles. *Azadirachta indica* wood ash and ordinary wood ash controlled *Sz* up to five and six months respectively (22). Ash would be appropriate for a three to six months' storage period (208) and kitchen ash caused bruchid damage to remain below the economic threshold for at least 9 months (30). This is in contrast with findings from another study in which, after four months of storage, the application of wood ash did not result in fewer beans to be damaged and there were not significantly fewer beetles than in the untreated control experiment (309).

3.5 EFFECTS ON THE STORED PRODUCT

There are a few clear disadvantages associated with the use of ash for protection of stored products. Due to the ash treatment, the appearance of the beans can change. Ash of *Sorghum vulgare* changed the colour of the beans, whereas other ashes did not do so (349). Farmers have reported that wood ash affected the marketability of the stored product (309) because it made the beans appear old and dirty. Ash could also have a negative effect on germination of the stored seeds (31), although George and Patel (100) found that the percentage of germination of green gram treated with ash was higher than for the untreated control. Anyhow, the applied ash should be well dried to prevent the induction of premature germination or moulding, but then, due to the dehydrating action of the ash, beans can become very hard and therefore incookable and inedible (140).

3.6 CONCLUSION

Ash can provide an effective, simple, cheap and clean way of protection of stored seeds against storage beetles, if it is applied in large enough quantities. Care should be taken that both the beans and the ash are very dry from the beginning of the storage on, to prevent moulding. For small quantities of beans, this method could be useful, but the quantities of ash and storage space, needed to protect large quantities of cowpea, are not easily available.

4 VOLATILE OILS

From some aromatic plants volatile oils can be extracted. These oils can be applied to stored seeds as protectants against storage insect pests. The yield of oil is usually low, but due to repellence or toxicity, even small amounts of the concentrated essential extract can be very effective in airtight or hermetic storage structures. A major advantage of volatile insecticides is that they do not need to be mixed with the seeds. No physical contact is needed between seeds and protectant. The effect of these volatile oils is usually reached through fumigation. All plants discussed in this chapter and in table 4 are used as volatile oils, unless stated otherwise.

Table 4: Plants of which the volatile oil is used against storage insects, the quantity of oil used and its effect.

Plant (sub-) family	Plant species	Quantity ~	Beetle species ^	Affected stage #							Reference
				A	O	E	H	L	M	P	
Annonaceae	*Dennettia tripetala*	3 ml/kg	*Cm, Sz*	!!						**	215
Annonaceae	*Monodora myristica*	3 ml/kg	*Cm, Sz*	**						**	215
Annonaceae	*Xylopia aethiopica*	3 ml/kg	*Cm, Sz*	**						**	215
Apiaceae	*Anethum graveolens*	5-10 g/kg	*Ao*					**	!!		262
Apiaceae	*Apium graveolens*	5-10 g/kg	*Ao*					*!	!!		262
Apiaceae	*Coriandrum sativum*	5-10 g/kg	*Ao*					*!	*!		262
		10-50 μg/insect	*Cm, Ls, So, Tco*	*!							320
Apiaceae	*Cuminum cyminum*	5-10 g/kg	*Ao*					*!	!!		262
Apiaceae	*Diplolophium africanum*	6.7-33.3	*Cm*	*!	*!				!!		106
		6.7-33.3	*Cm*	**	*!						143
		44.8 mg/l	*Cm, Csu*		!!				!!		154
Apiaceae	*Petroselinum crispum*	5-10 g/kg	*Ao*					*!	!!		262
Araceae	*Acorus calamus*	2-4%	*Cc*	*!							111
		1-7 μl/insect	*Cc*	*!							332
		10-50 μl	*Cc, Rd, Sg, So, Tco*	*!							87
		2.5-125	*Cc, Rd, Sg, So, Tco*	*!		*!					278
		10 μl	*Cc, Sg, So*	*!		*!					280
		10-50 μl	*Cc, Sg, So, Tco*			*!		**	**		264
		25-125	*Cc, Sg, So, Tco*	*!					*!		279
		12.5-25	*Cph*	!!	*!	*!			*!		246
Asteraceae	*Ageratum conyzoides*	0.1-2 g/kg	*Ao, Cc*	!!	!!						199
Asteraceae	*Blumea balsamifera*	0.1-2 g/kg	*Ao, Cc*	!!	!!						199
Asteraceae	*Chromolaena odorata*	0.5-30 μl/50 seeds	*Cm*		**				**		2
		5-20 μl/50 seeds	*Cm*		*!				*!		99
Asteraceae	*Chrysanthemum indicum*	0.1-2 g/kg	*Ao, Cc*	!!	!!						199
Asteraceae	*Eupatorium capillifolium*	20-120	*Cm*	*!							25

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Asteraceae	*Tagetes minuta*	4-37.5 µl/insect	*Cm*	*!	*!		!!		!!		141
Geraniaceae	*Pelargonium* spp.	1-10% dip	*Cc*	*!	*!		!!		!!		263
Lamiaceae	*Coleus amboinicus*	0.1-2 g/kg	*Ao, Cc*	!!	!!						199
Lamiaceae	*Hyptis spicigera*	0.2-0.35 µl/insect	*Cm*	*!							72
Lamiaceae	*Hyptis suaveolens*	0.7-2.2 µl/insect	*Cm*	*!							72
		4-37.5 µl/insect	*Cm*	**	*!		!!		!!		141
Lamiaceae	*Lavandula angustifolia*	0.1-0.74 ml/kg	*Ao, Sg*	*!							138
		5-10 g/kg	*Ao*					**	!!		262
Lamiaceae	*Lavandula* spp.	6.7-33.3	*Cm*	*!	*!				!!		106
		6.6-33.3	*Cm*				!!	!!			142
Lamiaceae	*Mentha citrata*	5.5-174	*Cc*	*!					!!		185
Lamiaceae	*Mentha piperita*	5.5-174	*Cc*	*!					!!		185
		5-10 g/kg	*Ao*					**	**		262
Lamiaceae	*Mentha spicata*	5.5-174	*Cc*	*!					!!		185
Lamiaceae	*Ocimum basilicum*	5-10 g/kg	*Ao*					**	!!		262
		1-10% dip	*Cc*	*!	*!		!!		!!		263
		0.05-0.17µl/insect	*Cm*	*!							72
		1-37.5 µl/insect	*Cm*	*!	*!		**		*!		141
		0.2-2 ml/kg	*Cm, So*	*!							96
Lamiaceae	*Origanum majorana*	5-10 g/kg	*Ao*					**	!!		262
Lamiaceae	*Origanum vulgare*	5-10 g/kg	*Ao*					*!	!!		262
		0.1-0.74 ml/kg	*Ao, Sg*	*!							138
Lamiaceae	*Rosmarinus officinalis*	5-10 g/kg	*Ao*					*!	!!		262
		0.1-0.74 ml/kg	*Ao, Sg*	*!							138
Lamiaceae	*Salvia officinalis*	5-10 g/kg	*Ao*					**	!!		262
Lamiaceae	*Satureja hortensis*	5-10 g/kg	*Ao*					*!	!!		262
Lamiaceae	*Thymus serpyllum*	5-10 g/kg	*Ao*					*!	!!		262
Lamiaceae	*Thymus vulgaris*	5-10 g/kg	*Ao*					**	!!		262
		0.1-0.74 ml/kg	*Ao, Sg*	*!							138
Lauraceae	*Cinnamomum mercadoi*	10-50 mg	*Cc*	*!							98
Lauraceae	*Cinnamomum verum*	5-10 g/kg	*Ao*					*!	!!		262
Lauraceae	*Laurus nobilis*	5-10 g/kg	*Ao*					**	**		262
		0.1-0.74 ml/kg	*Ao, Sg*	*!							138
Leguminosae-Papilionoideae	*Galega* spp.	1-10% dip	*Cc*	*!	*!		*!		*!		263

Plant family	**Plant species**	**Quantity**	**Beetle**	**A**	**O**	**E**	**H**	**L**	**M**	**P**	**Ref.**
Myristicaceae	*Myristica fragrans*	5-10 g/kg	*Ao*					**	!!		262
Myrtaceae	*Callistemon citrinus*	20-120	*Cm*	*!							25
Myrtaceae	*Eucalyptus citriodora*	6.7-33.3	*Cm*	*!	*!				*!		106
		6.6-33.3	*Cm*				!!!	!!			142
		6.7-33.3	*Cm*	**	*!						143
		0.2-2 ml/kg	*Cm, So*	!!							96
Myrtaceae	*Eucalyptus globulus*	5-10 g/kg	*Ao*					**	**		262
Myrtaceae	*Eucalyptus* spp.	1-10% dip	*Cc*	**	*!		*!		*!		263
Myrtaceae	*Eucalyptus tereticornis*	0.2-2 ml/kg	*Cm, So*	**							96
Myrtaceae	*Eugenia aromatica*	0.75-1% w:w	*Cc*	!!							111
		1-3	*Cm*	**	**		**		**		129
		12.5-100 mg/kg	*Cm*	*!	**				**		158
Myrtaceae	*Eugenia uniflora*	0.5-30 µl/50 seeds	*Cm*		*!				*!		2
		5-50 µl/50 seeds	*Cm*		*!				*!		99
Pinaceae	*Cedrus deodara*	1-3%	*Cc*	!!	**						244
Pinaceae	*Cedrus* spp.	6.7-33.3	*Cm*	*!	*!				*!		106
Pinaceae	*Pinus* spp.	3%	*Cc, Sz*	*!							200
Piperaceae	*Piper acutifolium*	66.7-133.3	*Cm*	**	*!						166
Piperaceae	*Piper guineense*	2-3	*Cm*	!!	*!				!!		124
		4-37.5 µl/insect	*Cm*	*!	*!		*!		!!		141
		0.002-0.8%	*Cm*		!!				!!		216
		3 ml/kg	*Cm, Sz*	!!						**	215
Piperaceae	*Piper nigrum*	0.2-0.8%	*Cm*	*!	!!						249
Poaceae	*Cymbopogon citratus*	1-10% dip	*Cc*	*!	*!		*!		*!		263
		0.5-30 µl/50 seeds	*Cm*		!!				!!		2
		2-8 g/kg	*Cm*		*!						36
		5-40 µl/50 seeds	*Cm*		!!				*!		99
		6.7-33.3	*Cm*	*!	*!				!!		106
		6.6-33.3	*Cm*				!!	!!			142
		6.7-33.3	*Cm*	**	*!						143
		4-8 g/kg	*Cr*		*!						250

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Poaceae	*Cymbopogon nardus*	5-10 g/kg	*Ao*					**	!!		262
		1-10% dip	*Cc*	*!	*!		*!		*!		263
		2-8 g/kg	*Cm*		*!						36
		6.7-33.3	*Cm*	*!	*!				!!		106
		6.6-33.3	*Cm*				!!	!!			142
		6.7-33.3	*Cm*	*!	*!						143
		25-200 mg/kg	*Cm*	*!	**				**		158
Poaceae	*Cymbopogon schoenanthus*	6.7-33.3	*Cm*	*!	*!				!!		106
		6.6-33.3	*Cm*				!!	!!			142
		6.7-33.3	*Cm*	*!	*!						143
Rutaceae	*Citrus aurantifolia*	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	!!							324
		2.5-10 g/kg	*Cm*		*!	*!			!!		323
		3.5-14 ml/kg	*Cm, Dm, Sz*	*!	!!				!!		77
		2-20	*Cm, Dm, Sz*	*!							78
		4-40	*Cm, Dm, Sz*	*!				*!			79
Rutaceae	*Citrus limon*	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	!!							324
		5-10 g/kg	*Ao*					**	*!		262
		1-10% dip	*Cc*	**	*!		**		*!		263
		0.1125-0.9 g/kg	*Cm*	*!	**				**		158
		50 g/l, 0.5 μl/insect	*Cm*	!!							314
		2.5-10 g/kg	*Cm*		!!	!!			!!		323
		4-40	*Cm, Dm, Sz*	*!				*!			79
Rutaceae	*Citrus paradisi*	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	!!							324
		2.5-10 g/kg	*Cm*		*!		!!		!!		89
		2.5-10 g/kg	*Cm*		*!	*!			!!		323
		3.5-14 ml/kg	*Cm, Dm, Sz*	*!	*!				*!		77
		4-40	*Cm, Dm, Sz*	*!				*!			79
Rutaceae	*Citrus reticulata*	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	**							324
		2.5-10 g/kg	*Cm*		*!	!!			!!		323
		3.5-14 ml/kg	*Cm, Dm, Sz*	*!	*!				*!		77
		4-40	*Cm, Dm, Sz*	*!				*!			79

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Rutaceae	*Citrus sinensis*	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	**							324
		2.5-10 g/kg	*Cm*		*!		*!		*!		89
		2.5-10 g/kg	*Cm*		*!	!!			!!		323
		4-40	*Cm, Dm, Sz*	*!				*!			79
		0.2-2 ml/kg	*Cm, So*	**							96
Rutaceae	*Citrus X tangelo*	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	**							324
		2.5-10 g/kg	*Cm*		*!	*!			*!		323
Rutaceae	*Fortunella* spp.	1.6-50 μg/insect	*Am, Cm, Ls, So, Tca, Tco*	*!							324
		2.5-10 g/kg	*Cm*		*!	!!			!!		323
Rutaceae	*Murraya koenigii*	3.4-3400 ppm	*Cc*	!!	!!				*!		232
Verbenaceae	*Lantana camara*	0.5-30 μl/50 seeds	*Cm*		*!				*!		2
		5-40 μl/50 seeds	*Cm*		*!				**		99
Verbenaceae	*Lippia adoensis*	0.5-30 μl/50 seeds	*Cm*		!!				!!		2
		5-15 μl/50 seeds	*Cm*		!!				!!		99
Verbenaceae	*Lippia multiflora*	6.7-33.3	*Cm*	*!	*!				!!		106
		6.6-33.3	*Cm*				!!	!!			142
		6.7-33.3	*Cm*	**	*!						143
		6.28-12.56 mg/l	*Cm*	*!	!!				!!		155
Verbenaceae	*Verbena officinalis*	5-10 g/kg	*Ao*					**	*!		262
Verbenaceae	*Vitex negundo*	0.1-2 g/kg	*Ao, Cc*	!!	!!						199

~: Quantities in μl oil/l of air unless stated otherwise
^: See table 1
#: A= adult longevity & fecundity, O = oviposition, E = survival of eggs & embryos on the seed surface, H = hatching, L= survival of larvae and pupae inside the seed, M = emergence, P = population numbers & effect on the stored product; ** = Measured, but no statistically significant results were found or presented, *! = Significant decrease, !! = Total inhibition.

4.1 DEVELOPMENTAL STAGE AFFECTED

4.1.1 EFFECTS ON ADULTS

Volatile oils mostly affect adult beetles. The vapours usually have a repellent effect, causing the beetles to flee from the store, or not to invade it at all. In most laboratory set-ups, however, the beetles cannot escape from the test arena. This could be a cause for the frequent findings of toxic action of volatile oils against adult beetles. Formulations of *Acorus calamus* all showed an excellent knockdown effect on *Cc* and a long lasting residual effect (351). *Dennettia tripetala* and *Piper guineense* achieved complete adult mortality for *Cm* and *Sz* (215). *Lippia multiflora* was toxic to adults of *Cm* (155).

Fumigation often leads to repellence or toxicity. As fumigants in relatively enclosed or airtight systems, essential citrus oils could be efficient to control insects. Their contact toxicity is not important for the effect (77). Adults of *Cc* were susceptible to vapours of *Acorus calamus* (278). In fumigation experiments, *Cymbopogon schoenanthus* and *Lavandula* spp. were very toxic to *Cm* adults (106).
However, contact toxicity has been found to also play an important role against beetles. Topical application of eight lyophilised citrus peel oils showed high toxicity to *Cm* adults (324). *Ageratum conyzoides, Blumea balsamifera, Chrysanthemum indicum, Coleus amboinicus* and *Vitex negundo* exhibited contact toxicity to the same beetle species, and the oils were even more effective when mixed with the seeds (199). Significant mortality of *Cm* adults occurred in fumigation bioassays with *Callistemon citrinus* and *Eupatorium capillifolium* (25). From lemon peel oil three fractions were isolated that were more toxic to *Cm* adults than the crude oil, upon topical application (314).

4.1.2 EFFECTS ON OVIPOSITION
The number of eggs laid is often reduced after treatment with volatile oils. This effect on oviposition can be caused, among others, by the reduced longevity of the adult insects. Citrus peels reduced oviposition through adult mortality, but had no residual activity on the eggs or larvae produced by surviving adults (77). *Ocimum basilicum* and *Pelargonium* spp. caused a reduction of oviposition and of adult longevity (263).
However, the effect is not always due to a reduction of adult longevity. For *Cm, Piper acutifolium* had no effect on adult mortality, but it did cause a decrease in oviposition (166). The effect of oils on female fecundity has been studied in detail. For *Cc, Acorus calamus* induced infertility and regression in the terminal follicles of the vitellarium initially, and later a shift to regression of the upper parts of the ovary. Derailment of follicular epithelium was also observed, which resulted into the irreversible atrophy of the follicles (332).
In most cases, a reduction of oviposition is mentioned, without the possible cause. *Cymbopogon citratus, Eugenia uniflora, Lantana camara* and *Lippia adoensis* completely inhibited oviposition and adult emergence of *Cm* (2). *Piper guineense* (216), *Cymbopogon citratus, Cymbopogon nardus* (36) and *Lippia adoensis* completely inhibited oviposition of *Cm* whereas *Eugenia uniflora, Lantana camara* and *Eupatorium odoratum* did so partly (99). Seed treatment with *Ageratum conyzoides, Blumea balsamifera, Chrysanthemum indicum, Coleus amboinicus* and *Vitex negundo* inhibited oviposition (199). *Diplolophium africanum* prevented oviposition by *Cm* and *Csu* (154). *Piper guineense* strongly reduced oviposition, and completely prevented reproduction of *Cm* (124).
Enhancing effects of volatile oils on oviposition have also been found: median- and sub-lethal doses of *Eugenia aromatica, Cymbopogon nardus* and *Citrus limon* caused oviposition to be enhanced for *Cm*. Hormoligosis, the stimulatory effect of harmful agents when applied at sub-harmful doses, could account at least in part for this improved fecundity (158).

4.1.3 EFFECTS ON EGGS AND LARVAE

The juvenile stages of the storage insects are generally less affected by volatile oils than the adult beetles, but they are usually not completely tolerant to the treatments. Eggs of *Cc* were susceptible to vapours of *Acorus calamus*. The younger embryonic stages were more susceptible than the later stages (278) but the oil did not affect larvae and pupae (264). For *Cm*, the fertility of eggs was heavily affected by treatment with *Cymbopogon schoenanthus* and *Lavandula* spp. (106). *Ocimum basilicum* and *Pelargonium* spp. showed highest effect on reduction of egg hatching and on adult emergence for *Cc* (263). *Piper guineense* prevented adult emergence of *Cm* completely (216). Peel oils of eight citrus species all showed a decrease in numbers of progeny of *Cm* from treated beans (323). Numbers of offspring of *Sg*, *So* and *Cc* emerging from seeds treated with *Acorus calamus* oil vapours were considerably lower than in the controls. The response was correlated to increase of exposure time rather than to increase in dose (279).

4.2 COMPARISON OF BEETLE SPECIES

Beetle species differ in susceptibility to volatile oils. The vapours of *Acorus calamus* were more effective against *Cc* than against *Sg* and *So*. Adults of both *Tco* and *Rd* were completely tolerant (87; 264; 278). *Eucalyptus citriodora* and *Ocimum basilicum* were not toxic to *So* but were potent against *Cm* (96). *Coriandrum sativum* was topically non-toxic to *Cm*, *Ls* and *Tco*, but the oil was repellent and moderately toxic to *So* and repellent to *Tco* (320). Citrus peel oils showed more effect against adults of *Cm* than against adults of *Dm* and *Sz* (79). Topical application of eight lyophilised citrus peel oils was highly toxic to *Cm* and moderately toxic to *So* adults (324).

4.3 COMPARISON OF PLANT SPECIES

Not all volatile plant oils are equally effective as protectants of stored products. In the reviewed articles, the most effective plants found in comparisons are often of the family of the Lamiaceae. *Coleus amboinicus* was more effective as a contact toxicant against *Ao* and *Cc* than *Ageratum conyzoides*, *Blumea balsamifera*, *Chrysanthemum indicum*, and *Vitex negundo* (199). All oils of Lamiaceae tested by Djibo *et al.* (72) were toxic to adults of *Cm*; *Ocimum basilicum* was three times more toxic than *Hyptis spicigera* and fourteen times more toxic than *Hyptis suaveolens*. *Ocimum basilicum* was more toxic than *Tagetes minuta* and *Piper nigrum* to eggs and adults of *Cm* (141).

For *Cymbopogon*, a ranking in the degree of effectiveness is not evident. Bhaduri *et al.* (36) showed that *Cymbopogon citratus* and *Cymbopogon nardus* were more effective than seven non-volatile oils against oviposition of *Cm*. Adebayo and Gbolade (2) found that *Cymbopogon citratus*, *Eugenia uniflora*, *Lantana camara* and *Lippia adoensis* completely inhibited oviposition and adult emergence of *Cm*, whereas *Eupatorium odoratum* was less effective. *Cymbopogon schoenanthus* and *Lavandula* spp. were very toxic to *Cm*, causing paralysis and death at low dosages, whereas, on the other hand *Cymbopogon citratus*, *Cymbopogon nardus*, *Cedrus* spp., *Diplolophium africanum*, *Eucalyptus citriodora* and *Lippia multiflora* were less toxic (106). Richa *et al.* (263) found that *Ocimum basilicum* and *Pelargonium* spp. were more effective in causing adult mortality of *Cc* than *Cymbopogon citratus*, *Cymbopogon nardus* and *Galega* spp. whereas *Citrus limon* and *Eucalyptus* spp. were not effective at all.

For the family of the Rutaceae, some contradicting results have been found. *Citrus aurantifolia*, *Citrus limon*, *Citrus paradisi* and *Citrus reticulata* caused complete adult mortality for *Cm*, whereas *Citrus sinensis* and *Citrus X tangelo* were not toxic (324).

Citrus paradisi completely inhibited egg hatch of *Cm* while *Citrus sinensis* was less effective (89). However, Don-Pedro (73) found that *Citrus sinensis* was more effective against *Cm* and *Dm* adults than *Citrus paradisi* and Richa *et al.* found that *Citrus limon* had no effect on mortality of *Cc* (263).
Acorus calamus is often tested, but never compared to other oils. *Acorus calamus* oils from three origins differed in efficacy, but at high doses they were all completely toxic to adults of *Cph* (246).

4.4 DURATION OF THE EFFECTS

Contradictory results have been found for the duration of the effect of volatile oils. The oils are often found effective for only a short time, with no residual action. Citrus peel oil treatment caused 100% mortality of *Cm* and *Dm* adults at one hour after application, but the oil lost all activity within 24 hours and did not show any residual activity on eggs or larvae. The activity of lime-peel oil was dependent on the time interval between application of the oil and the start of the bioassay (77). *Dennettia tripetala* and *Piper guineense* achieved complete adult mortality within one week but these and other (*Xylopia aethiopica* and *Monodora myristica*) volatile oils were not effective as grain protectants because they did allow the development of an F1 generation (215).
However, for some volatile oils a longer lasting effect has been found. *Piper guineense* (216) *Cymbopogon citratus* and *Cymbopogon nardus* were effective against *Cm* for up to 90 days (36). *Citrus paradisi* and *Citrus sinensis* retained their effect up to 150 days after treatment (89). *Acorus calamus* showed a long lasting residual effect and could ensure the storage room to be free from pulse beetles for many months (351).
Emergence of *Cm* from seeds treated with peel oils of eight citrus species was low until 312 days after treatment (323).
Generally, the duration of exposure of the beetles to the oil is more important than the applied dosage of the oil as a factor affecting the efficiency (87). The response after treatment with *Acorus calamus* was correlated to an increase of the exposure time rather than to an increase in dose (279). This was indicated by the increase of beetle mortality after an increasing period of exposure at a certain dosage (278). The LC_{50} for *Callistemon citrinus* and *Eupatorium capillifolium* for adults of *Cm* decreased with exposure time (25).

4.5 EFFECTS ON THE STORED PRODUCT

The effects of volatile oils on stored seeds are minimal because the oils usually do not need to make contact with the seeds to be effective. None of the investigated preparations of plant origin had a negative influence on wheat seed germination (138). Formulations of *Acorus calamus* were non-hazardous and did not impair seed germination (351). Edible volatile oils could be very useful on farm level in developing countries as potential control agents against storage beetles. They could play an important role in stored-grain protection, reducing the need for, and risk associated with, the use of insecticides (293).

4.6 CONCLUSION

Volatile oils are effective against storage beetles but their period of action is usually not long because they quickly evaporate unless airtight structures are used for storage. Volatile oils mainly affect adult beetles. The effect can be either repellent or toxic, but due to laboratory set-ups the toxic effect is often overestimated. Through the adults, oviposition is affected and oil vapours can affect larvae and eggs.
Application is easy, but should be repeated for-long term protection. The insecticide does not usually need to touch the stored product, so the product is mostly unaffected by the treatment. To obtain large enough quantities of volatile oil, large quantities of plants, distillation equipment and a lot of work are needed.

5 NON-VOLATILE OILS

Non-volatile oil, used as a coating for seeds, can effectively protect these seeds against insect pests during storage. The film of oil prevents the attachment of the egg to the seed coat and plugs the respiratory systems of eggs and adult beetles. Oils can be extracted mechanically or by hand from seeds cheaper than the stored product or from seeds of non-crop plants. To obtain enough oil for treatment, large quantities of plant material are needed and the extraction and application of non-volatile oils are not easily done. However, most of the oils are very effective and retain their effectiveness over a long period. All plants discussed in this chapter and listed in table 5 are used for their non-volatile oil unless stated otherwise.

Table 5: Plants of which the non-volatile oil is used against storage insects, the quantity of oil used and its effect.

Plant (sub-) family	Plant species	Quantity ~	Beetle species ^	Affected stage #							Refe-rence
				A	O	E	H	L	M	P	
Arecaceae	*Cocos nucifera*	1-20	*Ao, Cc*	*!	*!						199
		10	*Ao, Cm*	!!	!!					**	271
		1-4	*Ca*		*!				*!	*!	157
		5-10	*Cc*	!!	!!	!!		!!	!!		11
		3	*Cc*	**	*!	*!					32
		0.5-3	*Cc*							*!	33
		10	*Cc*	!!							127
		10	*Cc*	*!							128
		0.5%	*Cc*							*!	190
		50 g/kg	*Cc*							*!	193
		0.5-5	*Cc*						*!		201
		1-4	*Cc*							*!	294
		2-4	*Cc*		*!					*!	295
		5-7.5	*Cc*							*!	298
		1-5	*Cc*		*!				*!	*!	299
		1-3	*Cc*		*!				*!		306
		1-8, 3 g/kg	*Cc, Cm*							*!	111
		150 µg/bean	*Cc, Cm*				*!				352
		1-10 g/kg	*Cc, So*	*!	*!	*!			*!		292
		3%	*Cc, Sz*	*!							200
		2-8 g/kg	*Cm*		*!						36
		3.5-14	*Cm*	**	*!	*!					74
		1.75-14	*Cm*			*!	*!				75
		Dipped	*Cm*	**	**	*!					76
		5	*Cm*		*!	*!		*!	*!		181
		2.5-10	*Cm*		**		**		*!		203
		2.5-10	*Cm*						**	**	204

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Arecaceae	*Cocos nucifera*	1.5 g/kg	*Cm*		*!		*!				256
	Continued	0.4-2.5 g/kg	*Cm*		*!		!!		!!		290
		1-8	*Cm*						*!	*!	305
		5-10	*Cm*							*!	341
		4-8 g/kg	*Cr*		*!						250
		1-5	*Zs*						*!		283
Arecaceae	*Elaeis guineensis*	5-10	*Cc*	!!	!!	*!		*!	!!		11
		10	*Cc*	*!							128
		5-10	*Cc*		*!		**				136
		5-10	*Cc*						*!	*!	144
		5-10	*Cc*	**	**						145
		10	*Cc*		*!						146
		2-4	*Cc*		**					*!	295
		2-8	*Cc*		**		!!		!!		342
		150 µg/bean	*Cc, Cm*				*!				352
		1-10 g/kg	*Cc, Cm, So*	*!	**	*!			*!		292
		1-8	*Cm*							*!	111
		2.5-10	*Cm*		**		**		*!		203
		2.5-10	*Cm*						*!	**	204
		0.25-8	*Cm*		*!		*!		**		235
		5	*Cm*							*!	268
		0.4-2.5 g/kg	*Cm*		*!		!!		!!		290
		1.5-3 g/kg	*Cm*							*!	293
		1-8	*Cm*						*!	*!	305
		2.5-30	*Cm*	*!	*!				*!		334
		5	*Cm*							*!	341
		6	*Cm, Rd, So, Tca, Tg*						*!		8
		1	*Zs*	*!	*!				*!		118
		1-5	*Zs*	!!			!!		!!		283
Asteraceae	*Carthamus tinctorius*	5-40 ml/l	*Cc*		*!				*!		5
		5-10	*Cc*		*!		*!				136
		5-10	*Cc*						*!	*!	144
		5-10	*Cc*	**	**						145
		10	*Cc*		*!						146
		2.5-10	*Cc*		**	*!			*!		272
		1-3	*Cc*		*!				*!		306
		1-10 g/kg	*Cc, So*	*!	**	*!			*!		292
		5	*Cm*		*!	*!		*!	*!		181

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Asteraceae	*Carthamus tinctorius*	2.5-10	*Cm*		**		**		*!		203
	continued	2.5-10	*Cm*						**	**	204
		0.4-2.5 g/kg	*Cm*		*!		!!		!!		290
Asteraceae	*Guizotia abyssinica*	2.5-10	*Cm*		**		*!		*!		203
		2.5-10	*Cm*						*!	**	204
Asteraceae	*Helianthus annuus*	5	*Ao*							*!	338
		1-4	*Ca*		**				**	**	157
		5-40 ml/l	*Cc*		*!				*!		5
		5-10	*Cc*		*!		*!				136
		5-10	*Cc*						*!	*!	144
		5-10	*Cc*	**	**						145
		10	*Cc*		*!						146
		0.5-5	*Cc*						**		201
		2.5-10	*Cc*		**	*!			!!		272
		2-4	*Cc*		*!					*!	295
		1-3	*Cc*		*!				*!		306
		5-10	*Cc, Cm, Cr*	*!	*!						251
		1-10 g/kg	*Cc, So*	*!	*!	*!			*!		292
		3 g/kg	*Cm*							*!	111
		2-30	*Cm*						*!		255
		0.4-2.5 g/kg	*Cm*		**		*!		*!		290
Bombacaceae	*Ceiba pentandra*	1-10 g/kg	*Cc, So*	**	**	*!			*!		292
		0.4-2.5 g/kg	*Cm*		**		!!		!!		290
Brassicaceae	*Brassica juncea*	1-4	*Ca*		**				**	**	157
		5-10	*Cc*	*!	**	*!		*!	*!		11
		5-10	*Cc*						*!	*!	144
		1-4	*Cc*							*!	294
		2-4	*Cc*		**					*!	295
		1-5	*Cc*		**				*!	*!	299
		1-3	*Cc*		*!				!!		306
		2-8	*Cc*		**		!!		!!		342
		150 µg/bean	*Cc, Cm*				!!				352
Brassicaceae	*Brassica* spp.	1-4	*Ca*		**				**	**	157
		5-10	*Cc*	*!	**	!!		*!	*!		11
		3	*Cc*	*!	*!	*!					32
		0.5-3	*Cc*							*!	33
		5-10	*Cc*		*!		*!				136

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Brassicaceae	*Brassica* spp.	5-10	*Cc*	**	**						145
	continued	10	*Cc*		*!						146
		5-10	*Cc*						!!	!!	148
		0.5%	*Cc*							*!	190
		50 g/kg	*Cc*							!!	193
		0.5-5	*Cc*						*!		201
		0.25-1%	*Cc*		*!				*!	*!	231
		2.5-10	*Cc*			*!					260
		2.5-10	*Cc*		*!	*!			!!		272
		1-4	*Cc*							*!	294
		2-4	*Cc*		**					*!	295
		5-7.5	*Cc*							*!	298
		1-5	*Cc*		*!				*!	*!	299
		15	*Cm*						!!		6
		2-8 g/kg	*Cm*		*!						36
		2.5, 3 g/kg	*Cm*							*!	111
		2.5-10	*Cm*		**		*!		*!		203
		2.5-10	*Cm*						*!	**	204
		2-30	*Cm*						!!		255
Brassicaceae	*Eruca vesicaria*	2-4	*Cc*		*!					*!	295
		1-3	*Cc*		*!				!!		306
Brassicaceae	*Raphanus sativus*	1-3	*Cc*		**				*!		306
Clusiaceae	*Calophyllum inophyllum*	1-3	*Cm*	**	*!		!!		!!		129
		2.5-10	*Cm*		**		*!		!!		203
		2.5-10	*Cm*						*!	**	204
Dipterocarpaceae	*Shorea robusta*	3-5 g/kg	*Cm*							*!	111
		3-5	*Cm*							**	229
Euphorbiaceae	*Jatropha curcas*	1-3	*Cm*	**	*!		!!		!!		129
Euphorbiaceae	*Jatropha indica*	10	*Cm, Sz*							!!	22
Euphorbiaceae	*Ricinus communis*	10	*Ao, Cm*	!!	!!					**	271
		5-10	*Cc*		*!		!!				136
		5-10	*Cc*						!!	*!	144
		5-10	*Cc*	**	*!						145
		10	*Cc*		*!						146
		0.5-5	*Cc*						*!		201
		2.5-10	*Cc*			*!					260
		2.5-10	*Cc*		*!	*!			!!		272

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Euphorbiaceae	*Ricinus communis*	1-3	*Cc*		*!				!!		306
	continued	5-15	*Cc*	!!	!!		*!		!!		355
		2-8 g/kg	*Cm*		*!						36
		1-8	*Cm*							*!	111
		2.5-10	*Cm*		**		*!		!!		203
		2.5-10	*Cm*						*!	**	204
		1-8	*Cm*						*!	*!	305
		5-10	*Cm, Cph*		*!				!!		222
		4-8 g/kg	*Cr*		*!						250
Leguminosae-Caesalpinioideae	*Senna occidentalis*	10	*Cm*			*!		*!	*!		165
		10	*Cm*			*!		*!			180
Leguminosae-Papilionoideae	*Arachis hypogaea*	10	*Ao, Cm*	!!	!!					**	271
		5-10	*Ba, Cm*	*!		*!					171
		1-4	*Ca*		*!				*!	*!	157
		3	*Cc*	**	*!	*!					32
		0.5-3	*Cc*							*!	33
		5-10	*Cc*		*!		!!				136
		5-10	*Cc*						*!	*!	144
		5-10	*Cc*	**	**						145
		10	*Cc*		*!						146
		0.5%	*Cc*							*!	190
		50 g/kg	*Cc*							!!	193
		0.5-5	*Cc*						*!		201
		2.5-10	*Cc*			**					260
		1-4	*Cc*							*!	294
		2-4	*Cc*		**					*!	295
		5-7.5	*Cc*							*!	298
		1-5	*Cc*		*!				*!	*!	299
		1-3	*Cc*		*!				*!		306
		2-8	*Cc*		**		!!		!!		342
		1-10, 3 g/kg	*Cc, Cm*		*!					!!	111
		150 µg/bean	*Cc, Cm*				*!				352
		5-10	*Cc, Cm, Cr*	**	*!						251
		1-10 g/kg	*Cc, So*	**	*!	*!			*!		292
		5-10	*Cm*			!!					17
		5	*Cm*							*!	20
		2-8 g/kg	*Cm*		*!						36
		Flour pellets	*Cm*	*!	*!			!!	*!		42

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Leguminosae-Papilionoideae	*Arachis hypogaea* continued	5	*Cm*							*!	52
		10 25 g/kg	*Cm*	*!	*!		*!		*!		60
		10	*Cm*		*!				*!	*!	61
		3.5-14	*Cm*	**	*!	*!					74
		1.75-14	*Cm*			*!	*!				75
		Dipped	*Cm*	**	**	*!					76
		7	*Cm*	**	*!				*!		77
		1-5	*Cm*		*!	*!		*!	*!		181
		2.5-10	*Cm*		**		**		*!		203
		2.5-10	*Cm*						**	**	204
		5-6	*Cm*	!!							217
		0.25-8	*Cm*		*!		*!		**		235
		5	*Cm*							*!	239
		2-30	*Cm*						*!		255
		0.4-0.8 g/kg	*Cm*		**		*!		*!		290
		1-8	*Cm*						!!	*!	305
		2.5-30	*Cm*	*!	*!				!!		334
		1-5	*Cm*							*!	341
		5 ml/l	*Cm, Tco*							*!	354
		10	*Cm, Sz*							!!	22
		4-8 g/kg	*Cr*		*!						250
Leguminosae-Papilionoideae	*Glycine max*	5	*Ao*							*!	30
		10	*Ao, Cm*	!!	!!					**	271
		1-4	*Ca*		**				**	**	157
		3	*Cc*	**	*!	*!					32
		0.5-3	*Cc*							*!	33
		5-15	*Cc*							!!	57
		0.25-1%	*Cc*		*!				*!	*!	231
		1-4	*Cc*	*!		*!			**		265
		2-4	*Cc*		**					*!	295
		1-5	*Cc*		*!				*!	*!	299
		1-5	*Cc*							*!	303
		1-3	*Cc*		**				!!		306
		2-8	*Cc*		**		!!		!!		342
		150 µg/bean	*Cc, Cm*				**				352
		1-10 g/kg	*Cc, So*	*!	**	*!			*!		292
		2.5-10	*Cm*		**		*!		*!		203
		2.5-10	*Cm*						**	**	204

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Leguminosae-Papilionoideae	*Glycine max* continued	2-30	*Cm*						*!		255
		0.4-2.5 g/kg	*Cm*		**		!!		!!		290
		5-10	*Cm, Cph*		*!				!!		222
		4-8 g/kg	*Cr*		*!						250
		1-5	*Zs*	*!	*!				*!		283
Leguminosae-Papilionoideae	*Pongamia pinnata*	5-10	*Cc*		*!		!!				136
		5-10	*Cc*						!!	*!	144
		5-10	*Cc*	**	*!						145
		10	*Cc*		*!						146
		10-200	*Cc*		*!				*!		206
		2.5-10	*Cc*			*!					260
		2.5-10	*Cc*		*!	*!			!!		272
		2-8 g/kg	*Cm*		!!						36
		2.5-10	*Cm*		**		**		!!		203
		2.5-10	*Cm*						!!	**	204
Linaceae	*Linum usitatissimum*	1-4	*Ca*		**				**	**	157
		5-40 ml/l	*Cc*		*!				*!		5
		10	*Cc*							**	111
		0.5-2 ml	*Cc*		**						184
		1-3	*Cc*		**				*!		306
		10	*Cc, Cm*	*!	*!	*!		*!	*!	*!	245
Malvaceae	*Gossypium hirsutum*	1-4	*Ca*		*!				*!	*!	157
		2.5-10	*Cc*		*!	*!			!!		272
		1-4	*Cc*							*!	294
		2-8	*Cc*		*!		!!		!!		342
		5-15	*Cc*	!!	*!		**		*!		355
		150 µg/bean	*Cc, Cm*				*!				352
		1-10 g/kg	*Cc, So*	*!	**	*!			*!		292
		10	*Cm*	*!	*!		*!		*!		60
		10	*Cm*		**				*!		61
		3-5 g/kg	*Cm*							*!	111
		2.5-10	*Cm*		**		**		*!		203
		2.5-10	*Cm*						**	**	204
		3-5	*Cm*							*!	229
		2-30	*Cm*						*!		255
		0.4-2.5 g/kg	*Cm*		**		!!		!!		290

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Malvaceae	*Gossypium hirsutum*	1	*Zs*	*!	*!				*!		118
	continued	1-5	*Zs*	!!			*!		!!		283
Meliaceae	*Azadirachta indica*	5-100 g/l	*Ao, Cc*	*!	*!						199
		2.5-7.5	*Ao, Zs*	!!							47
		1-3	*Ca, Cc, Cm*	**	*!						282
		1-10	*Ca, Cc, Cm, Rd, Sz, Tca, Tco*	*!	*!		*!				275
		5-40 ml/l	*Cc*		*!				!!		5
		5-10	*Cc*	!!	!!	!!		!!	!!		11
		10	*Cc*							!!	64
		10	*Cc*	*!							128
		5-10	*Cc*		!!		!!				136
		5-10	*Cc*						!!	*!	144
		5-10	*Cc*	**	*!						145
		10	*Cc*		*!						146
		0.5-2 ml	*Cc*		*!						184
		10-50 g/kg	*Cc*							*!	228
		1-3%	*Cc*	*!	**						244
		2.5-10	*Cc*			**					260
		2.5-10	*Cc*		*!	*!			!!		272
		10	*Cc, Cm*	!!	*!	*!		!!	!!	*!	245
		3%	*Cc, Sz*	*!							200
		2-8 g/kg	*Cm*		*!						36
		25 g/kg	*Cm*	*!	*!				*!		60
		1-10	*Cm*		!!		!!		!!		63
		1-3%	*Cm*							*!	111
		2-3	*Cm*	*!	*!				*!		124
		1-3	*Cm*	**	*!		!!		!!		129
		2.5-20 g/kg	*Cm*		!!				!!		161
		2.5-10	*Cm*		**		*!		!!		203
		2.5-10	*Cm*						!!	**	204
		0.25-8	*Cm*		!!		*!		*!		235
		2%	*Cm*							**	255
		1.5 g/kg	*Cm*		*!		*!				256
		10	*Cm, Sz*							!!	22
		5 ml/l	*Cm, Tco*		*!				*!	*!	354
		4-8 g/kg	*Cr*		*!						250
Meliaceae	*Melia azedarach*	2-8	*Cc*		*!				*!		356

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Oleaceae	*Olea europaea*	10	*Ao, Cm*	!!	!!					**	271
		5-15	*Cc*	!!	*!		*!		!!		355
		150 µg/bean	*Cc, Cm*				*!				352
		1-10 g/kg	*Cc, So*	*!	*!	*!			*!		292
		15	*Cm*						*!		6
		0.4-2.5 g/kg	*Cm*		**		!!		!!		290
		2.5-30	*Cm*	**							334
		10	*Cm*							*!	341
Pedaliaceae	*Sesamum indicum*	10	*Ao, Cm*	!!	!!					**	271
		1-4	*Ca*		*!				*!	**	157
		5-40 ml/l	*Cc*		*!				*!		5
		5-10	*Cc*	!!	!!	!!		*!	!!		11
		10, 3 g/kg	*Cc*							*!	111
		10	*Cc*	*!							128
		5-10	*Cc*		*!		*!				136
		5-10	*Cc*						*!	*!	144
		5-10	*Cc*	**	**						145
		10	*Cc*		*!						146
		0.5-2 ml	*Cc*		**						184
		0.5-5	*Cc*						*!		201
		0.25-1%	*Cc*		*!				*!	*!	231
		1-4	*Cc*							*!	294
		2-4	*Cc*		*!					*!	295
		1-5	*Cc*		*!				*!	*!	299
		1-3	*Cc*		**				*!		306
		5-15	*Cc*	!!	*!		*!		!!		355
		150 µg/bean	*Cc, Cm*				*!				352
		5-10	*Cc, Cm, Cr*	**	*!						251
		2.5-10	*Cm*		**		*!		*!		203
		2.5-10	*Cm*						**	**	204
		15-20	*Cm*							*!	341
Poaceae	*Oryza sativa*	1-5	*Cc*							!!	45
		1-3	*Cc*		*!				*!		306
		1-8	*Cc*	*!			!!				353
		150 µg/bean	*Cc, Cm*				*!				352
		1-10 g/kg	*Cc, Cm, So*	**	*!	!!			!!		292
		3-5 g/kg	*Cm*							*!	111

Plant family	Plant species	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Poaceae	*Oryza sativa*	3-5 mg/kg	*Cm*							*!	229
	continued	0.4-0.8 g/kg	*Cm*		**		!!		!!		290
		5	*Cm*							*!	341
		1.5-10 g/kg	*Cm, Sz*							*!	293
Poaceae	*Zea mays*	5	*Ao*							*!	338
		5	*Ao, Zs*						*!	*!	309
		5-10	*Cc*							*!	57
		5-10	*Cc*		*!		*!				136
		7.5-12.5	*Cc*						*!	*!	144
		5-10	*Cc*	**	**						145
		10	*Cc*		*!						146
		5-15	*Cc*	!!	!!		!!		!!		355
		5-10	*Cc, Cm, Cr*	**	*!						251
		1-10 g/kg	*Cc, So*	*!	*!	*!			*!		292
		0.4-2.5 g/kg	*Cm*		**		!!		!!		290
		1-5	*Zs*	*!	*!				*!		283
Sapotaceae	*Madhuca longifolia*	5-10	*Cc*	!!	*!	!!		**	!!		11
		2.5-10	*Cc*		*!	*!			!!		272
		2-8 g/kg	*Cm*		*!						36
		1-3	*Cm*	**	**		*!		!!		129
		5	*Cm*		*!	*!					247
		1.5 g/kg	*Cm*		*!		*!				256
		4-8 g/kg	*Cr*		*!						250
Sapotaceae	*Vitellaria paradoxa*	10	*Cm*	*!	*!		*!		*!		60
		10	*Cm*		**					*!	61
		0.25-8	*Cm*		*!		*!		**		235
	Dalda	5-10	*Cc*	*!	*!	*!		*!	!!		11

~: Quantities in ml oil/kg stored product, unless stated otherwise
^: See table 1
#: A= adult longevity & fecundity, O = oviposition, E = survival of eggs & embryos on the seed surface, H = hatching, L= survival of larvae and pupae inside the seed, M = emergence, P = population numbers & effect on the stored product; ** = Measured, but no statistically significant results were found or presented, *! = Significant decrease, !! = Total inhibition.

5.1 DEVELOPMENTAL STAGE AFFECTED

5.1.1 EFFECTS ON ADULTS

Non-volatile oils can have negative effects on adult beetles, either through contact toxicity or through deterrence. All oils tested by Salas and Hernández (271) caused complete adult mortality for *Ao* and *Cm*. *Arachis hypogaea* caused high adult mortality for *Cm* (217). *Arachis hypogaea* and *Elaeis guineensis* decreased adult longevity of *Cm*

(334). *Elaeis guineensis* increased adult mortality and reduced reproduction of *Zs*. The insecticidal effectiveness was determined by the triglyceride component of the oil (118). *Cocos nucifera* (127), *Madhuca longifolia, Sesamum indicum, Azadirachta indica,* and *Elaeis guineensis* inflicted complete adult mortality for *Cc* (11). *Glycine max* showed high efficacy against eggs and adult stages of *Cc* (265). All oils tested by Zewar (355) caused mortality of *Cc* adults.

5.1.2 EFFECTS ON OVIPOSITION

Oviposition can be influenced by treatment of the stored product with non-volatile oil. The decrease in the number of eggs could be due to other causes than just the effect on the longevity of the adult beetle. *Ricinus communis, Arachis hypogaea, Pongamia pinnata* and *Azadirachta indica* affected oviposition and induced egg mortality for *Cc* (136). Seed treatment with *Azadirachta indica* (64), *Cocos nucifera* (199), *Madhuca longifolia, Sesamum indicum* and *Elaeis guineensis* prevented adults of *Cc* from laying eggs (11). *Zea mays, Arachis hypogaea, Helianthus annuus* and *Sesamum indicum* reduced oviposition of *Cm, Cc* and *Cr* (251). All oils tested by Sangappa (272) and by Singal and Singh (299) reduced oviposition of *Cc* significantly and the oils tested by Singh *et al.* (306) did the same for *Cm*. On bambara groundnut, *Azadirachta indica, Elaeis guineensis, Arachis hypogaea* and *Vitellaria paradoxa* had a decreasing effect on oviposition of *Cm* (235). *Azadirachta indica* (161), *Cocos nucifera* and *Madhuca longifolia* deterred oviposition of *Cm* (256). *Jatropha curcas, Azadirachta indica, Calophyllum inophyllum* and *Madhuca longifolia* all partly prevented oviposition (129). Oviposition of *Cm* was completely inhibited after seed treatment with *Pongamia pinnata* (36).

5.1.3 EFFECTS ON EGGS AND LARVAE

Most of the efficacy of non-volatile oils can be attributed to the effect on eggs and their attachment to the seed coat. The effect of the oils is at least partly based on mechanical action. Due to the oil layer around treated seeds, eggs cannot be attached effectively to the seed surface. Hatching of first instar larvae is prevented because penetration is more difficult if egg attachment is less secure (75). For *Cm*, the funnel through which the larvae should hatch into the seed, is clogged by the oil so the larva cannot hatch and dies in the egg stage (55). If the egg had already been laid before treatment of the seed, the oil will plug its micropyle, which causes the embryo inside the egg to die from oxygen starvation (202). The oil could also penetrate the chorion of the egg via the micropyle and cause death of the developing embryo through asphyxiation (161). *Arachis hypogaea* had an ovicidal and suffocating effect on bruchids, with eggs and young larvae being more sensitive than older larvae and nymphs (171). Eggs of one or two days old were killed immediately, whereas in three to five day old eggs death of the developing larvae occurred in minutes (17).

In addition to the mechanical effect, a combination of mechanical and toxic effects could occur. The ovicidal effect of oils of *Arachis hypogaea* and *Cocos nucifera* could be caused by a direct toxic action after penetration of the oil into the egg. However, the effect could also be caused by the reduction of respiratory activity of the egg and by accumulation of toxic metabolites inside it as a result of the oil barrier effect (75). Effects being solely toxic have also been found. *Oryza sativa, Shorea robusta* and *Gossypium hirsutum* entered the egg through the micropyles, and the toxic components of the oils destroyed the yolk (229).

However, the way in which the effect is accomplished has not always been elucidated. The insecticidal activity of non-volatile, edible oils and of the active fatty acids extracted from them, depended mainly on their ovicidal effect (74; 76). For *Cm*, *Carthamus tinctorius, Cocos nucifera* and *Arachis hypogaea* caused high mortality of eggs and larvae on the seed surface, but had no effect on individuals that successfully entered the seed. The lack of oil-specific activity indicated the effect to be physical rather than chemical (181). *Azadirachta indica* and its extract effectively reduced egg hatching of *Cm* (203). For *Cc, Ricinus communis, Arachis hypogaea, Pongamia pinnata* and *Azadirachta indica* completely prevented hatching of the eggs (136). *Jatropha curcas, Azadirachta indica, Calophyllum inophyllum* and *Madhuca longifolia* prevented egg hatching and emergence (129).

5.2 COMPARISONS OF BEETLE SPECIES

The effects of different oils can vary when they are tested on different beetle species. *Oryza sativa, Glycine max, Gossypium hirsutum* and *Elaeis guineensis*, were potential control agents against *Cm*, but they were less effective against *Sz* and *So* (293). *Zea mays, Helianthus annuus, Arachis hypogaea,* and *Sesamum indicum* significantly reduced adult longevity of *Cm* and *Cc*, whereas only the latter two oils affected *Cr* (251). *So* was best controlled with refined *Elaeis guineensis*, whereas *Tca* and *Tg* were most sensitive to fresh *Elaeis guineensis* and *Cm* was susceptible to both (8). For effective control of *So* and *Sz,* dosages of oil needed are higher than for the control of *Cm* (292).

5.3 COMPARISON OF PLANT SPECIES

If different oils are compared, a few general conclusions can be drawn.

- Crude oils are more effective than refined ones from the same plant. Fresh oil of *Elaeis guineensis* was more effective than bleached and refined oil (8). Against *Cc,* purified *Gossypium hirsutum* was not effective (355). Crude oils of *Gossypium hirsutum, Glycine max* and *Cocos nucifera* were more effective than refined ones (283). Crude oils tested by Shaaya and Kostjukovsky (292) mostly resulted in fewer eggs laid and fewer emerged adults of *Cc* than after treatment with refined or distilled products made of these oils.
- Non-edible oils seem to be generally more effective than edible oils (203). *Ricinus communis* was more effective than *Glycine max* against *Cm* and *Cph* (222). Among the non-edible oils, *Azadirachta indica* oil is often one of the most effective ones. *Azadirachta indica* was most toxic to adults of *Cc* when compared with *Cocos nucifera* (199) or *Linum usitatissimum* (245). *Azadirachta indica* gave complete protection against *Cc* (64) and of all tested oils, *Azadirachta indica* was the only one that completely prevented oviposition of *Cm* on cowpea (235). *Azadirachta indica* and its extract were more effective than *Ricinus communis, Pongamia pinnata* and *Calophyllum inophyllum,* which themselves were more effective than the edible oils of *Sesamum indicum, Brassica* spp., *Guizotia abyssinica, Gossypium hirsutum, Elaeis guineensis, Arachis hypogaea, Cocos nucifera, Carthamus tinctorius* and *Glycine max* (203).

Different mechanisms seem to be involved. *Helianthus annuus* was effective against oviposition of *Cc,* whereas *Glycine max, Brassica juncea, Arachis hypogaea* and *Oryza sativa* protected against adult emergence and *Eruca vesicaria, Cocos nucifera, Carthamus tinctorius* and *Ricinus communis* were effective against both (306).

- When edible oils are compared, crude cotton (*Gossypium hirsutum*), and Brassicaceae are usually among the most effective ones. *Gossypium hirsutum* was more effective against *Cm* than *Oryza sativa* and *Shorea robusta* (229). *Brassica* spp. was more effective than *Olea europaea* (6). *Arachis hypogaea, Cocos nucifera, Brassica* spp., *Sesamum indicum, Glycine max* and *Brassica juncea* were all effective against *Cc*. *Brassica* spp. was most effective (299). *Arachis hypogaea* and *Brassica* spp. were more persistent than *Cocos nucifera* (193).

For a few oils, contradictory results have been reported. Both fresh and refined oils of *Elaeis guineensis* were effective against *Cm* and *Rd* (8). *Elaeis guineensis* was the most effective crude oil (283), more effective than *Zea mays* and *Arachis hypogaea* (151). However, *Elaeis guineensis* was found to be the least effective of 10 oils tested by Khaire *et al.* (144), in this article it was found to be less effective than, among others, *Zea mays*. Emergence was prevented, in decreasing order of effectiveness by (non-edible) *Azadirachta indica, Pongamia pinnata, Ricinus communis*, and seven edible oils (144). However, in other experiments *Pongamia pinnata* was more effective than *Azadirachta indica* (272), *Ricinus communis* and four edible oils (36). According to Singh (305), *Arachis hypogaea* completely prevented emergence of *Cm* whereas *Ricinus communis, Cocos nucifera* and *Elaeis guineensis* only caused partial reduction but Pierrard (239) found that *Arachis hypogaea* failed to completely control *Cm*.

5.4 DURATION OF THE EFFECTS

The time scale of the effect aimed for is not the same in every article. Some authors aim for a protection mechanism that works immediately, whereas others intend to keep the level of damage in the stored product below a certain threshold for as long a period as possible. For the immediate knockdown effect on adult beetles, non-volatile oils are usually less suitable.

Non-volatile oils seem to be most effective for intermediate periods of protection, weeks to a few months. In the Sahel, oils diminished infestation only temporarily, whereas in other, more humid regions the method appeared to be effective (20). The protection offered by oils of *Azadirachta indica* and *Pongamia pinnata* lasted almost twice as long as that of edible oils (204). *Pongamia pinnata* completely inhibited oviposition, but its efficacy sharply deteriorated at later stages (>30 days) (36). *Ricinus communis, Pongamia pinnata* and *Azadirachta indica* completely protected stored seeds against *Cc* for 33 days and partly up until 100 days. *Arachis hypogaea* prevented egg hatching beyond 33 days (136). *Linum usitatissimum* and *Azadirachta indica* were effective for three and four months respectively (245). The toxic effect of *Cocos nucifera* against *Cc* lasted for at least 10 weeks (127). The effect of *Arachis hypogaea* against *Cm* persisted for 3 months (217). *Oryza sativa* gave complete protection against *Cc* for up to 135 days (45). *Azadirachta indica* effectively protected gram seeds against bruchid damage for at least 135 days (228). If the treatment was repeated after 12 days and after 4 months of storage, *Vitellaria paradoxa* was able to effectively protect seeds stored in jars or sacks (153).

Other authors waited longer and found the effects to last even longer. *Ricinus communis* protected stored cowpea for up to 150 days. *Glycine max* reduced the population build up for up to 90 days (222). With *Gossypium hirsutum*, infestation started at the same time as with *Oryza sativa* and *Shorea robusta*, but it remained almost negligible up until 5 months (229). *Cocos nucifera* protected beans for 4 months against insect infestation and *Arachis hypogaea* and *Brassica* spp. did so for 6 months (190; 193). *Azadirachta indica* gave complete protection against *Cc* for at least 5 months (64). *Azadirachta indica* (63), *Jatropha indica* and *Arachis hypogaea* completely controlled *Cm* and *Sz* for 6 months (22). Seeds treated with *Arachis hypogaea* could be stored for 6 to 12 months without beetle attack (171). *Glycine max* caused damage to remain below the economic threshold for 8 months (30). *Pongamia pinnata* protected stored red gram for 319 days and remained active afterwards (272).

5.5 EFFECTS ON THE STORED PRODUCT

Disadvantages exist if oils are used for long-term storage of seeds. *Zea mays* caused a change of colour in the seeds (309). Products of *Vitellaria paradoxa* became rancid and could therefore be used for sowing seeds only (66). *Azadirachta indica* and *Ricinus communis* had a negative influence on the taste of the beans. *Azadirachta indica* and *Guizotia abyssinica* had a negative effect on seed germination after 6 months of storage (204). Seeds treated with *Cocos nucifera* or with *Arachis hypogaea* failed to germinate (334). Water absorption by stored seeds was affected after oil treatment (355) and the cooking time of oil-treated seeds was prolonged (231).
Another disadvantage is the difficulty of applying non-volatile oils especially for greater quantities of beans. If the film around the bean does not completely cover the surface, the efficacy of the oil treatment will be much lower since the mechanical effect of oils is usually the key to their efficacy. A complete film over the seed surface is vital for the success of non-volatile oils as protective agents of stored products (75). A uniform spread of the oil on all grain would maximise the effect (74).
Advantageous effects were reported as well. No effect on seed germination was found after treatment with either *Glycine max* or *Zea mays* for 8 months (57) or with *Helianthus annuus* for six months (338), and the palatability and appearance of the beans improved due to their shiny coating.

5.6 CONCLUSION

Non-volatile oils have mainly physical effects. They are most effective if they completely cover the surface of the stored seeds and therefore care should be taken to apply them properly. The mechanical action seems to be most effective against eggs, whereas adults are more affected by the chemical action. Larvae and pupae, as they are inside the bean, are generally less sensitive to the effects of oils. The effects of oils on the stored product are numerous, ranging from a slight change of colour to a severe change of taste and inhibition of seed germination. To obtain large enough quantities of oil, great quantities of plant material are needed and lots of work. From one kilo of dry *Azadirachta indica* kernels 75-100 ml of oil can be obtained by hand (21). Most of the edible oils are usually for sale.

6 EXTRACTS

Extracting plant material with an appropriate solvent generally results in concentration of active ingredients. Such extracts are therefore often more effective against storage beetles than powders or fresh plants. Usually, the extract is mixed with the beans as a liquid, and the solvent evaporates before the beans are stored. Disadvantages that have been mentioned are that extracts are mostly difficult or laborious to make and yields are usually low. The solvents are mostly not available for low resource farmers and large quantities of plant material are needed. All plants mentioned in this chapter and in table 6 were used as extracts unless stated otherwise.

Table 6: Plants of which extracts are used as protective agents against storage beetles, the solvent, the extracted plant part, the quantity and the effect.

Plant (sub-) family	Plant species	Solvent *	Plant part $	Quantity ~	Beetle species ^	Affected stage #							Reference
						A	O	E	H	L	M	P	
Acanthaceae	*Adhatoda vascia*	B, Et, PE	--	40 g/kg	*Cm*		**				**	**	111
Acanthaceae	*Andrographis paniculata*	Et	W	Soaked in 0.125-20%	*Cc*		*!						117
Annonaceae	*Annona glabra*	--	S	0.5%	*Cm*		*!						242
Annonaceae	*Annona muricata*	--	S	0.5%	*Cm*		*!						242
Annonaceae	*Annona squamosa*	--	S	0.5%	*Cm*		*!						242
Annonaceae	*Monodora myristica*	EE	S	Rubbed with crude extract	*Cm*		!!	!!		*!		!!	210
Annonaceae	*Stelechocarpus cauliflorus*	--	S	0.5%	*Cm*		*!						242
Apiaceae	*Anethum graveolens*	Ac	S	10-50 µg/insect	*Cm, Ls, So, Tco*	*!							319
Apiaceae	*Carum roxburghianum*	PE	S	1-5	*Cc*							!!	45
Apiaceae	*Coriandrum sativum*	Ac	S	10-50 µg/insect	*Cm, So*	*!							320
Apocynaceae	*Nerium oleander*	PE	L	0.1-5% w:v	*Cc*	*!	!!				!!		83
Apocynaceae	*Rhazya stricta*	Aq	L	0.1%	*Cm*		*!				*!	*!	84
Apocynaceae	*Strophantus hispidus*	Et	L	10 g/l	*Ao, Pt, So*	*!							331
Apocynaceae	*Thevetia peruviana*	PEB	L, T	1 g/ml, 5-15 ml/l	*Cc*		**					**	230
Arecaceae	*Cocos nucifera*	PE	Nut shell	1-3	*Cm*	**	**		**		*!		129
Asteraceae	*Ageratum conyzoides*	PEB	buds, Fl, L	1 g/ml, 5-15 ml/l	*Cc*		**					**	230
Asteraceae	*Artemisia absinthium*	Et	L	0.5-1.0%	*Ao*					**		*!	175

Plant family	Plant species	Solvent	Part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Asteraceae	*Artemisia dracunculus*	--	--	2-8%	*Ao*	*!						*!	253
Asteraceae	*Chamomilla recutita*	--	--	2-8%	*Ao*							*!	253
Asteraceae	*Chromolaena odorata*	Et	L	10 g/l	*Ao, Pt, So*	*!							331
Asteraceae	*Chrysanthemum* spp.	--	Fl	5-100 g/kg	*Ca*	*!							139
Asteraceae	*Eclipta prostrata*	--	--	10-50%	*Cc*			*!			*!		111
Asteraceae	*Parthenium hysterophorus*	B, Et, PE	--	40 g/kg	*Cm*		**				**	**	111
Asteraceae	*Saussurea lappa*	PE	R, Rh	1-5	*Cc*							!!	45
Asteraceae	*Sphaeranthus indicus*	PE	L, T	0.001-0.05	*Cc*	*!							29
Asteraceae	*Tagetes minuta*	Aq	R, Fl, L	0-1000 μg/cm²	*Zs*	*!							347
Asteraceae	*Tridax precombens*	B, Et, PE	--	40 g/kg	*Cm*		*!				*!	*!	111
Boraginaceae	*Heliotropium bacciferum*	Aq	T	0.1%	*Cm*		*!				*!	*!	84
Brassicaceae	*Lepidium aucheri*	Aq	S	0.1%	*Cm*		*!				*!	*!	84
Capparaceae	*Boscia senegalensis*	Ac	Fr	1000 g/l, 5ml	*Cm, Pt, Sz, Tca*	*!							288
Chenopodiaceae	*Atriplex lentiformis*	PE	L	0.1-5% w:v	*Cc*	*!	*!				!!		83
Convolvulaceae	*Ipomoea carnea*	PEB	L	1 g/ml, 5-15 ml/l	*Cc*		!!					!!	230
		B, Et, PE	--	40 g/kg	*Cm*		**				**	**	111
Convolvulaceae	*Ipomoea palmata*	PE	L	0.1-5% w:v	*Cc*	!!	*!				!!		83
Cupressaceae	*Thujopsis dolabrata*	Aq	Sd	1.5-5 mg	*Cc, Ls, So*	*!							7
Cyperaceae	*Cyperus rotundus*	Et	R	100, 1.25-10%	*Cm*	*!	*!						3
Euphorbiaceae	*Ricinus communis*	Et	L	0.5-1.0%	*Ao*					*!		*!	175
		Et	S	10 g/l	*Ao, Pt, So*	*!							331
Lamiaceae	*Hyptis spicigera*	Aq, E, Et, Me	W	1 g/ml, 0.3-30	*Ao*		*!		*!				162
Lamiaceae	*Hyptis suaveolens*	Et	L	100, 1.25-10%	*Cm*	**	*!						3
Lamiaceae	*Mentha piperita*	--	--	2-8%	*Ao*	*!						*!	253
Lamiaceae	*Ocimum basilicum*	Es	L	2-10 g/kg	*Cm, So*	*!							97

Plant family	Plant species	Solvent	Part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Lamiaceae	*Salvia officinalis*	Aq	T	0.1%	*Cm*		*!				*!	*!	84
Lamiaceae	*Thymus serpyllum*	--	--	2-8%	*Ao*							*!	253
Lamiaceae	*Thymus vulgaris*	--	--	2-8%	*Ao*							*!	253
Lecythidaceae	*Napoleona imperialis*	PE-Me	L	5 g/kg	*Cm, Csu, Sz*	**	**				**		176
Leguminosae-Caesalpinioideae	*Caesalpinia bonduc*	PE	Fr	1-5	*Cc*							!!	45
Leguminosae-Caesalpinioideae	*Chamaecrista nigricans*	Aq, E, Et, Me	W	1 g/ml, 0.3-14	*Ao*		*!		*!				162
Leguminosae-Caesalpinioideae	*Erythrophleum suaveolens*	Et	L	10 g/l	*Ao, Pt, So*	*!							331
		Et	Bark	100, 1.25-10%	*Cm*	*!	*!						3
Leguminosae-Caesalpinioideae	*Senna occidentalis*	E	S (oil)	10	*Cm*		**			**	*!		165
Leguminosae-Mimosoideae	*Tetrapleura tetraptera*	Es	Fr	2-10 g/kg	*Cm, So*	*!							97
Leguminosae-Papilionideae	*Lonchocarpus salvadorensis*	EtO2, CH2Cl2	S	0.001-0.5%	*Cm*						*!		39
Leguminosae-Papilionideae	*Melilotus officinalis*	--	--	2-8%	*Ao*							*!	253
Leguminosae-Papilionoideae	*Pachyrhizus erosus*	--	S	5-100 g/kg	*Ca*	*!	*!						139
Leguminosae-Papilionoideae	*Phaseolus vulgaris*	Aq	S peels	Bean equivalent	*Cc, Cm*		**						108
Leguminosae-Papilionoideae	*Pongamia pinnata*	--	--	2%	*Cc*		*!						137
Leguminosae-Papilionoideae	*Psoralea corylifolia*	PE	S	1-5	*Cc*							!!	45
Leguminosae-Papilionoideae	*Trigonella foenum-graecum*	Ac, He, Me	L, S	6-30 μg/insect, 130 μg/bean	*Ao, Tca*	*!	*!						234
Leguminosae-Papilionoideae	*Vigna angularis*	Aq	S peels	Bean equivalent	*Cc, Cm*		**						108
Leguminosae-Papilionoideae	*Vigna unguiculata*	Aq	S peels	Bean equivalent	*Cc, Cm*		**						108

Plant family	Plant species	Solvent	Part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Liliaceae	*Allium cepa*	PE	B	10-50 g/kg	*Cc*							**	228
		Et	Scale L	100, 1.25-10%	*Cm*	**	*!						3
		PE	--	5%	*Cm*							**	111
Liliaceae	*Allium sativum*	PE	B	10-50 g/kg	*Cc*							*!	228
		PE	--	1-3%	*Cm*							*!	111
Liliaceae	*Gloriosa superba*	--	R	10g/kg	*Ca*	**	**						139
Malvaceae	*Sida acuta*	Et	L	10 g/l	*Ao, Pt, So*	*!							331
Meliaceae	*Aglaia elliptica*	--	S	0.5%	*Cm*		*!						242
Meliaceae	*Aphanamixis polystachya*	PE	S	10-100 µg/insect	*Cc*	*!							330
		Ac, Et, PE	S	0.123 g/l	*Cc, So, Tca*	*!							329
Meliaceae	*Azadirachta indica*	Et	--	0.3-30	*Ao*		*!				*!		162
		--	--	3-15	*Ao*							*!	237
		Et	S	10 g/l	*Ao, Pt, So*	*!							331
		--	K	10%	*Ca*	*!	**					**	100
		--	--	1%	*Cc*		*!						137
		PEB	L, twigs	1 g/ml, 5-15	*Cc*		*!					*!	230
		Aq	K, L	0.1%	*Cm*		*!				*!	*!	84
		Aq, Et, Me	S	0.02-1%	*Cm*	!!	!!		!!		!!		169
		Ac, Aq, Cf, Et	L	0.5-3.0%	*Cm*	!!	!!		!!		!!		170
		He	K	5-200 µl	*Cm*	!!			!!	!!	!!		259
		Aq	L, Fr	Dipped 25-60 g/l	*Cm*	*!	*!				*!		287
		Aq	L, K	Soaked in fatty residue	*Cm, Cpu, So*		*!		*!		*!		172
		Ac, Aq, Et, PE	Fl, L, S	1-3%	*Cm, Rd, So, Tca, Tg*	*!							275
Meliaceae	*Dysoxylum cauliflorum*	--	S	0.5%	*Cm*		*!						242
Meliaceae	*Khaya senegalensis*	Et	W	0.3-30	*Ao*		**				**		162
Meliaceae	*Melia azedarach*	Ac, PE	Fr	1,25-10%	*Cm*	*!						!!	85
Menispermaceae	*Cissampelos owariensis*	Et	L, R	10 g/l	*Ao, Pt, So*	*!							331

Plant family	Plant species	Solvent	Part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Myrsinaceae	*Embelia ribes*	PE	S	1-5	*Cc*							!!	45
		B, Et, PE	--	40 g/kg	*Cm*		**				**	**	111
Myrtaceae	*Eucalyptus citriodora*	Es	L	2-10 g/kg	*Cm, So*	*!							97
Myrtaceae	*Eucalyptus tereticornis*	Es	L	2-10 g/kg	*Cm, So*	**							97
Myrtaceae	*Eugenia aromatica*	Et	Fl	100, 1.25-10%	*Cm*	*!	*!						3
		Aq	Fl	0.1%	*Cm*		*!				*!	*!	84
Piperaceae	*Lepianthes peltata*	Et	S	100, 1.25-10%	*Cm*	*!	*!						3
Piperaceae	*Piper guineense*	Et	S	12.5-37.5 g/kg	*Cm*	*!	!!				!!		178
		PE-Me	Fr	5 g/kg	*Cm, Csu, Sz*	*!	*!				*!		176
		He	Fr	5-40 g/l, 0.5 µl	*Cm, Ls, So, Tco*	*!					*!		317
		Es	Fr	2-10 g/kg	*Cm, So*	**							97
Piperaceae	*Piper nigrum*	--	--	0.25-0.5%	*Cc*							!!	111
		MC	Fr	0.15-20 µg/insect	*Cc*	*!							188
		Aq	S	0.1%	*Cm*		*!				*!	*!	84
		Ac	Fr	140 g, 11.3% yield	*Cm*	*!							321
		Ac	Corns	50 g/l, 0.5 µl	*Cm, Ls, So*	*!					!!		316
		Ac	Fr	5-40 g/l, 0.5 µl	*Cm, Ls, So, Tco*	*!					*!		317
		Et	Fr	3.13-25 µg/insect	*Cm, So*	!!							315
Poaceae	*Cymbopogon nardus*	--	--	3.5%	*Ao*	*!	*!						327
Poaceae	*Cymbopogon* spp.	Et	--	0.3-30	*Ao*		*!				*!		162
Pontederiaceae	*Eichhornia crassipes*	PE	L	100-400 g/ml	*Cc*	!!							257
		Es	L	2-10 g/kg	*Cm, So*	**							97
Rubiaceae	*Coffea arabica*	Et	S	Soaked	*Cc*	*!	*!						266
Rubiaceae	*Diodia sarmentosa*	PE-Me	Fl	5 g/kg	*Cm, Csu, Sz*	**	**				**		176
Rubiaceae	*Mitracarpus scaber*	PE-Me	Fl	5 g/kg	*Cm, Csu, Sz*	**	**				**		176
Rutaceae	*Citrus limon*	He	P	15-35 µg/insect	*Cm, So*	*!							322

Plant family	Plant species	Solvent	Part	Quantity	Beetle	A	O	E	H	L	M	P	Ref.
Rutaceae	*Citrus sinensis*	Es	P	2-10 g/kg	*Cm, So*	**							97
Rutaceae	*Citrus* spp.	Aq	P	0.1%	*Cm*		*!				*!	*!	84
Rutaceae	*Zanthoxylum alatum*	Ac	Pericarp	10-50 μg/insect	*Cm, Ls, So, Tco*	*!							318
Rutaceae	*Zanthoxylum zanthoxyloides*	Ac, Aq	R	50	*Cc*		*!				*!		213
Sapindaceae	*Dodonaea viscosa*	PE	--	1-3	*Cm*	**	*!		*!		!!		129
Solanaceae	*Capsicum annuum*	Ac	Fr	1.25-10%, 200	*Cm*		*!				**		159
Solanaceae	*Capsicum frutescens*	Ac	Fr	1.25-10%, 200	*Cm*		*!				*!		159
		Es	Fr	2-10 g/kg	*Cm, So*	*!							97
Solanaceae	*Cestrum nocturnum*	PE	L	1-5	*Cc*							*!	45
Solanaceae	*Datura metel*	Et	S	10 g/l	*Ao, Pt, So*	*!							331
Solanaceae	*Datura stramonium*	Et	S	10 g/l	*Ao, Pt, So*	*!							331
		Ac, PE, Et	L	5-10%	*Cm*	**					*!		195
Solanaceae	*Solanum nigrum*	Et	L	10 g/l	*Ao, Pt, So*	*!							331
Solanaceae	*Withania somnifera*	PE	R, Rh	1-5	*Cc*							*!	45
Tiliaceae	*Grewia carpinifolia*	Et	L	10 g/l	*Ao, Pt, So*	*!							331
Verbenaceae	*Clerodendrum inerme*	PE	L	1-5	*Cc*							*!	45
		PE	L	0.1-5% w:v	*Cc*	*!	*!				!!		83
Verbenaceae	*Lantana camara*	PEB	L, Fl	5-15 g/l	*Cc*		!!					!!	230
		Me, PE	L, T	1-5% crude	*Cc*	*!	!!						277
		--	L	10	*Cc, Cm*	**	*!	**		**	*!		245
		Es	L	2-10 g/kg	*Cm, So*	**							97
Verbenaceae	*Vitex negundo*	PE	--	1-3	*Cm*	**	*!		**		*!		129
Zingiberaceae	*Aframomum melegueta*	Et	S	100, 1.25-10%	*Cm*	**	*!						3

*: Ac = acetone, Aq = aqueous, B = benzene, Cf = chloroform, E = ether, EE = ethyl ether, Es = ester, Et = ethanol, He = hexane, MC = methylene chloride, Me = methanol, PE = petroleum ether, PEB = petroleum ether, diluted with benzene
$: B = bulbs, Fl = flowers, Fr = fruits, K = kernels, L = leaves, R = roots, Rh = rhizomes, P = peels, S = seeds, Sd = saw dust, T = twigs, W = whole plant
^: See table 1
~: in ml extract/kg stored product unless stated otherwise
#: A= adult longevity & fecundity, O = oviposition, E = survival of eggs & embryos on the seed surface, H = hatching, L= survival of larvae and pupae inside the seed, M = emergence, P = population numbers & effect on the stored product; ** = Measured, but no statistically significant results were found or presented, *! = Significant decrease, !! = Total inhibition.

6.1 DEVELOPMENTAL STAGE AFFECTED

6.1.1 EFFECTS ON ADULTS

Extracts often have an effect on adults, either acting as a repellent, a toxicant, or a combination of these two actions. *Lantana camara* showed a feeding deterrent action and was slightly toxic to *Cc*, showing a loss of fecundity at higher doses (277). *Piper guineense* also caused adult mortality of *Cm, Csu* and *Sz* (176) whereas *Piper nigrum* showed contact and oral toxicity against *Cm, Ls* and *So* (316). For *Cc, Eichhornia crassipes* caused attraction and mortality of adults (257), whereas *Aphanamixis polystachya* was slightly repellent and quite toxic to the beetles (330). Seeds coated with *Ocimum basilicum, Piper guineense, Eucalyptus citriodora, Capsicum frutescens* and *Tetrapleura tetraptera* caused adult mortality for *Cm* (97). *Azadirachta indica* seeds and leaves effectively caused adult mortality of *Cm* (169; 170) and ripe kernels also reduced fecundity (287), with adults being more susceptible than eggs and larvae (259). *Boscia senegalensis* caused mortality of *Cm, Pt, Sz* and *Tca* (288) whereas *Anethum graveolens* effectively repelled *So* and *Tco* (319). *Ricinus communis, Solanum nigrum, Cissampelos owariensis,* and *Erythrophleum suaveolens* were all toxic to *Ao, Pt* and *So* (331). *Trigonella foenum-graecum* reduced longevity and fecundity of *Ao* and affected the fertility of both sexes of *Tca* (234). *Zanthoxylum zanthoxyloides* disturbed mating behaviour of *Cm* (213). The insecticidal action of *Thujopsis dolabrata* against *Ls, Cc* and *So* was attributable to fumigant action (7). Roots of *Tagetes minuta* were more active against *Zs* than flowers and leaves (347).

Single components from extracts can differ in efficacy from the complete extract. Components isolated from *Citrus limon* showed weak toxicity to *So* and *Cm* but were less effective than the complete extract (322). The compound, 1,3,7-tritrimethylxanthine, isolated from *Coffea arabica,* effectively caused sterility (266) and pipericide, an amide from *Piper nigrum,* was highly toxic to *Cc* (188). Piperine in *Piper nigrum* was highly toxic to adults of *So* (315). The complete extract of *Piper guineense* (178) and three amides isolated from *Piper nigrum* showed toxicity to *Cm* (321), whereas *Piper guineense* and *Piper nigrum* showed contact toxicity to *Cm* and *So* (317).

6.1.2 EFFECTS ON OVIPOSITION

The effects on adults cause effects on oviposition, numbers of offspring etc. In some cases, the eggs that have been laid are affected as well. *Lantana camara* (277) and high concentrations of *Andrographis paniculata* (117) reduced the number of eggs laid by *Cc*. *Azadirachta indica, Lantana camara, Ageratum conyzoides, Thevetia peruviana* and *Ipomoea carnea,* diluted with benzene all repelled adult *Cc* beetles and prevented oviposition (230). *Azadirachta indica* kernels (170; 287), *Piper guineense* (178), *Monodora myristica* (210) and *Zanthoxylum zanthoxyloides* (213) inhibited oviposition by *Cm*. *Lantana camara* had an effect on oviposition of *Cc* and *Cm,* but the eggs that were laid developed normally and the grains were destroyed with a little retardation only (245). Extracts of *Lonchocarpus salvadorensis*, mixed with cowpea flour in artificial seeds, reduced oviposition of *Cm* (39). *Capsicum frutescens* was effective in reducing female fecundity and oviposition of *Cm* (159). *Dodonaea viscosa* (129) and *Azadirachta indica* were effective against oviposition, hatching and emergence of *Cm* (172). *Piper guineense* was effective in preventing oviposition of *Cm, Csu* and *Sz* (176). *Chamaecrista nigricans* and *Hyptis spicigera* caused a reduction of oviposition and hatching for *Ao* (162) whereas *Trigonella foenum-graecum* only inhibited oviposition (234).

6.1.3 EFFECTS ON EGGS AND LARVAE

Eggs and young larvae can be affected by extracts whereas older larvae are usually less susceptible. *Piper guineense* caused egg mortality of *Cm, Csu* and *Sz* (176). *Capsicum frutescens* (159) and *Zanthoxylum zanthoxyloides* reduced adult emergence of *Cm* (213). *Monodora myristica* had ovicidal and larvicidal effects on *Cm* (210), whereas eggs were not affected by *Lonchocarpus salvadorensis*, but for this plant, larval mortality was complete and no adults emerged from treated seeds (39). Eggs, young and old larvae of *Cm* were susceptible to *Azadirachta indica.* Eggs failed to hatch, but larvae were more susceptible (259). *Azadirachta indica* prevented adult emergence (170; 287) and hatching of *Cm* and was effective against adult emergence of *So* (172). *Dodonaea viscosa* was effective against hatching and emergence of *Cm* (129). The majority of the larvae of *Ao* were not capable of gnawing or hatching after seed treatment with *Ricinus communis* and *Artemisia absinthium. Ricinus communis* contains a compound that locks the normal metabolism in newly hatched larvae (175) and hatching was also reduced with *Hyptis spicigera* (162).

6.2 COMPARISON OF BEETLE SPECIES

Not all beetle species are equally sensitive to the extracts. *Ao* was more sensitive to *Ricinus communis* and *Solanum nigrum* than *So* and *Pt* were (331). When applied topically *Coriandrum sativum* seed was slightly toxic to *Tco* and *Ls* adults, but it showed only little toxic effect to *So* and it was topically non-toxic to *Cm* (320). *Ocimum basilicum, Piper guineense, Eucalyptus citriodora, Capsicum frutescens*, and *Tetrapleura tetraptera* were toxic to *Cm,* whereas *So* was slightly less sensitive (97). However, *So* was more susceptible to *Piper nigrum* than *Cm* (315) and one compound extracted from *Citrus lemon* was non-toxic to *Cm*, but slightly toxic to *So* (322). Extracts of different plant parts of *Azadirachta indica* had an effect on oviposition, hatching and emergence for *Cm*, on emergence of *So* but they had no effect on *Cpu* (172). Pericarp of *Zanthoxylum alatum* showed no oral toxicity to *Cm* larvae or *So* adults, very little contact toxicity to *Cm* and *Tco* adults, but it was topically slightly toxic to *So* and *Ls* adults (318). *Ls* was less sensitive to various *Piper nigrum* varieties than *So* and *Cm* were (316). *Anethum graveolens* was non-toxic to *Cm*, not very toxic to *Ls* and *Tco,* but it was toxic to *So* upon topical application (319). *Acorus calamus* was toxic to *So* adults, but not to *Tca* adults (233). *Aphanamixis polystachya* had a strong repellent effect on *Tca* and *So*, but was not repellent to *Cc.* Extracts were highly toxic to *Cc* and *Tca*, but only moderately toxic to *So* (329).

6.3 COMPARISON OF PLANT SPECIES

When different plants are compared, striking differences can be found. *Dodonaea viscosa* was effective, but *Vitex negundo* and *Cocos nucifera* did not produce any effective insecticidal substances against *Cm* (129). *Ricinus communis* and *Solanum nigrum* were more toxic than *Azadirachta indica* and the other plants tested by Tierto Niber *et al.* (331). *Capsicum frutescens* was effective in reducing female fecundity and oviposition of *Cm*, whereas *Capsicum annuum* showed no effect (159). *Piper nigrum* was more effective than *Piper guineense* as a contact toxicant and a grain protective agent against *Cm* (317). *Piper guineense* caused adult mortality of *Cm, Csu* and *Sz* whereas *Napoleona imperialis, Mitracarpus scaber* and *Diodia sarmentosa* did not show any insecticidal effect (176).

Even if different plant parts or different components of one extract are compared, the results can vary greatly. *Azadirachta indica* fruits reduced the damage caused by the F1 generation by more than 7 times (285) and were more effective than *Azadirachta indica* leaves (287). *Citrus limon* peels contained four major compounds that were less toxic to adults of *Cm* and *So* than the mixture of these compounds in the complete extract (322). Three amides from *Piper nigrum* differed in their toxicity to adults of *Cm*. Male beetles were more sensitive than females (321).

6.4 DURATION OF THE EFFECTS

The short-term knockdown effect of plant extracts can be important. LD_{50} for *Cm* was reached after 24 hours with *Ocimum basilicum* and with *Piper guineense*, whereas for *Eucalyptus citriodora*, *Capsicum frutescens*, and *Tetrapleura tetraptera* it took 48 hours (97).

Not much is known about the long-term grain protection. *Carum roxburghianum* and *Psoralea corylifolia* gave almost complete protection up to 135 days, and *Saussurea lappa*, *Withania somnifera* and *Embelia ribes* protected up to 90 days (45). *Allium sativum* protected stored gram against *Cc* for 135 days, but after this period, the damage increased (228). *Dodonaea viscosa* was effective for less than 33 days only (129).

6.5 EFFECTS ON THE STORED PRODUCT

No effects of plant extracts on stored seeds have been noted in the screened literature. Germination of seeds treated with *Azadirachta indica* remained almost equal to control seeds (169; 170). *Monodora myristica* did not reduce germination of treated cowpea seeds (210).

6.6 CONCLUSIONS

Extracts are usually more effective than powders. They are mostly effective against adult beetles, either as repellents or as toxicants. Other developmental stages of the beetle can be susceptible as well. The effect of extracts on the stored product is usually negligible. Large quantities of plants are often needed to obtain sufficient amounts of extracts. Solvent availability can impose a limitation on the use of extracts.

7 GENERAL DISCUSSION

For each plant species, sorted alphabetically in Table 7, the common name, the descriptor and a summary of the information from literature, with regard to the different types of applications for the control of seed beetles are given. In this table, several plants are mentioned for which the use is noted as unknown. In the cited references, these plants have been mentioned, often as traditionally used or effective plants, without enough detail about their application to justify incorporation in the separate tables in earlier chapters. Relevant synonyms from the scientific nomenclature are shown in the table with a reference to the name that has been used in the other tables in this review.

7.1 MODE OF ACTION

The authors of the publications cited in this review tried to assess whether plants are effective in protecting stored seeds from beetle attack. Some focussed on adult beetles, others on larvae or on the insect population as a whole. The effect of the treatment and the most affected developmental stage can be found only if the beetles are examined during their whole developmental cycle, which is rarely done. For users of plant material against insect pests and for many of the cited authors, the eventual effect is usually more important than the mechanism of action against each developmental stage of the beetles. However, knowledge of the mechanism may be essential in the development of effective applications for beetle control.

The articles mostly refer to laboratory tests with a plant product applied to uninfested beans as loose grains to which beetles are added. However, traditionally, beans are often infested at harvest and stored in their pods. Efficacy of powders, ashes, volatile oils and extracts could be different when used under these conditions. The pods around the beans would serve as an extra barrier for the beetle but at the same time, they would act as a barrier between the seeds and the protective plant product.

Application of non-volatile oils is only effective if loose seeds are stored. The pod with its cracks, pubescence and rough surface would not be appropriate to apply a film of oil to.

7.2 COMPARISON OF BEETLE SPECIES

A range of beetle species were subjected to bioassays, although most of the studied species belong to the families of Bruchidae and Curculionidae. Some authors refer to comparative research between two or more of these beetle species or families, but the range of species compared in such publications is rarely the same. None of the tested beetle species has been analysed thoroughly enough to know all its properties. Therefore, none of the beetle species could serve as a control species with known or predictable responses to seed treatments. Plant products can therefore not be ranked for their toxicity according to their effect on such a beetle species.

The reactions of different biotypes or of individual beetles within a species can be variable. Beetles of the same species, but of different geographical origin have been found to show differences in life history and in response to treatments, even after their rearing in the laboratory for several generations (70; 56). Differences between females and males, which often differ in size, have been reported as well.

7.3 COMPARISON OF APPLICATION METHODS

The used plant materials are inherently biologically variable and can show considerable differences in activity. For plants, the composition and contents of secondary metabolites, usually involved in defence of the plant, can differ greatly between ecotypes, and even between individuals. The amount of these components per plant can vary with, among others, the growth and storage conditions, with the time of harvest and with the plant part. For plant extracts, the results can also be dependent on the quality and purity of the solvents.

The applied dosages are often expressed in different units. Units of weight or volume are not uniformly used. Furthermore, in many studies the plant material was applied to filter paper or directly to various developmental stages of the insects, not to the seeds.

In some cases plant materials are as effective as, or even more effective than synthetic insecticides. *Zanthoxylum zanthoxyloides* (212) and *Azadirachta indica* were as effective as pirimiphos-methyl and permethrin against *Cm* (211). *Tamarindus indica* ash was as effective as actellic (pirimiphos-methyl) dust against *Tg* (5). No significant difference in effect against bruchids was found between *Zea mays* oil, pirimiphos-methyl, and permethrin dust (309).

Striking differences exist between approaches of application methods of plant material to stored seeds. For non-volatile oils, there are only few plants tested, but for each oil many references can be found. For powders and extracts, the opposite is true, many plant species have been tested, but per plant only few references are found.

Different applications of the same plant will show different effects. Secondary products such as oils and extracts are usually more effective than powders or whole plant parts from which they were obtained. Seed powder of *Piper guineense* was less effective than its ether extract in enhancing adult mortality in *Cm* (178). Oil of *Azadirachta indica* seeds was much more effective than the seed powder. This was mainly because the oil could penetrate into the egg whereas powders cannot do so (161). Treatment of beans with oil even at less than 1 ml/kg was more effective than treatment with ashes (338).

Depending on the quantity used and the duration of the experiment, the efficacies of volatile and non-volatile oils can vary. Volatile oil of *Piper guineense* was more effective than non-volatile oil of *Azadirachta indica*, against *Cm* (124). Oils of *Jatropha curcas, Azadirachta indica, Calophyllum inophyllum* and *Madhuca longifolia* were all effective against *Cm,* whereas the volatile oil of *Eugenia aromatica* was much less effective (129).

If plant products are mixed, again different activities can be found. Efficacy can be enhanced or decreased. For instance, powder of *Piper nigrum* gave a better protection of stored seeds when used in conjunction with non-volatile mustard oil (149). Very few studies explored the possibility of using mixtures. Potentially the use of two or more plant products could enhance their efficacy, especially when the different components act along different mechanisms.

Care should be taken that the effect measured is really attributable to the plant and that other factors are stable and ineffective. *Azadirachta indica, Lantana camara, Ageratum conyzoides, Thevetia peruviana* and *Ipomoea carnea,* diluted with benzene all repelled adult *Cc* beetles and prevented oviposition. However, pure benzene had the same effect as the extracts (230).

7.4 DURATION OF THE EFFECTS

If the period of action is mentioned in the literature, it is either presumed to be the time needed to kill the adult beetles or the period over which the product provides satisfactory protection against the insects. In some cases, the time is measured in which a population of a certain number of beetles can build up, or in which a certain percentage of damage is inflicted.

Efficacy of plant products is shown by either their postponing effect on the development of individual beetles or of a beetle population, or as a decrease in the damage after a certain amount of time. Long-term (more than a week of incubation) and short-term (a few hours to a week) tests each make up about half of the total number of experiments in the screened articles.

7.5 EFFECT ON THE STORED PRODUCT

Beans are affected by storage even if insect infestation does not occur. Cooking time, seed germination and seedling vigour can be affected. For those reports where the treated samples perform better than the control, it is not always clear whether the control sample has been infested with beetles or not. Seeds, from which adult beetles have emerged, do not germinate readily. If the effect of the treatment with (effective) plant products is to be analysed, this should be done against seeds that are as much infested as the treated seeds, otherwise the effect of bruchid infestation on seed properties would be tested.

Many of the effects, such as changes of colour and effects on taste of the seeds due to decomposition of the applied plant material, are only important if the seeds are to be sold or eaten. For sowing seeds, only germination and seedling vigour need to be preserved or improved by the treatment.

7.6 CONCLUSION

Seed beetles cause an important part of the total insect damage to seed crops. In store, they usually are the main pests. Much research has already been done to develop methods to prevent this damage. Many different plant species have been tested for their effect on the beetles. However, no general ranking of insecticidal or repellent effect can be given. This lack of ranking is on the one hand due to the lack of experimental detail and statistical analyses of the results in many of the cited publications. On the other hand, the potential efficacy of a plant product can depend on the plant species, the individual plant, the plant part, and the time and way of harvesting. In bioassays, the application mode, the quantity, the preparation of the plant material, the state (humidity, intactness of the seed skin and/or pod, rate of infestation) of the product to store and the tested beetle species are important for the outcome of the tests. The mere fact that natural products are used, implies that considerable variation is to be expected in the outcome of the experiments.

Results in literature are often contradictory, but many of the tested plants do show effects against seed beetles. The most effective plants or methods of application are not yet known, but results are promising and plant material can be an effective weapon in the battle against the beetles. Plants can be an effective replacement for chemical insecticides to protect stored seeds.

Table 7: Common names of the plants and the type of application reported.

	Plant species	**Author**	**Common name**	**Plant (sub-) family**	**Application**					
					A	**E**	**O**	**P**	**V**	**Unknown**
1	*Acacia albida*	Del.	Winter thorn	Leguminosae Mimosoideae						34; 35; 113
	Acacia arabica	Willd.	See *Acacia nilotica*	Leguminosae Mimosoideae						
2	*Acacia concinna*	DC.	Soap pod	Leguminosae Mimosoideae				1		109
3	*Acacia laeta*	L.		Leguminosae Mimosoideae						113
4	*Acacia nilotica*	(L.) Willd. ex Delile	Gum Arabic tree/ babul acacia	Leguminosae Mimosoideae	1					109
5	*Acacia senegal*	(L.) Willd.	Gum arabic	Leguminosae Mimosoideae						34; 35; 114
6	*Acacia sinuata*	(Lour.) Merr.	Soapnut	Leguminosae Mimosoideae				2		
7	*Acacia* spp.	Mill.	Acacia	Leguminosae Mimosoideae	1					65
8	*Achyranthes aspera*	L.	Devil's horsewhip	Amaranthaceae				1		
9	*Acorus calamus*	L.	Sweetflag	Araceae				5	8	65; 68; 95; 109; 164; 224; 233; 258; 312; 336; 351
10	*Adhatoda* spp.	Mill.	Water willow	Acanthaceae				1		
11	*Adhatoda vascia*	Nees	Malabar nut	Acanthaceae		1		2		65; 95; 340
12	*Aerva javanica*	(Burm. f.) Juss. ex Schult.	Java aerva	Amaranthaceae						15; 18; 114; 171
13	*Aframomum melegueta*	Schum.	Melegueta pepper	Zingiberaceae		1		1		
14	*Afrormosia laxiflora*	(Benth. ex. Bak.) Harms		Leguminosae-Papilionoideae						103; 109
15	*Afzelia africana*	Sm. ex Pers.	African mahogany	Leguminosae-Caesalpinioideae	3					114
16	*Ageratum conyzoides*	L.	Goat weed/ tropical whiteweed	Asteraceae		1		1	1	95; 198
17	*Ageratum houstonianum*	Mill.	Bluemink	Asteraceae						109
18	*Aglaia elliptica*	Blume		Meliaceae		1				

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
19	*Ajuga remota*	Benth.	Bugle	Lamiaceae						109
20	*Allium cepa*	L.	Garden onion	Liliaceae		3				95; 208; 312; 336; 340
21	*Allium sativum*	L.	Cultivated garlic	Liliaceae		2		2		65; 109; 312; 340
22	*Alnus nepalensis*	D. Don	Nepal alder	Betulaceae						109
23	*Aloe marlothii*	A. Berger	Mountain aloe	Liliaceae				1		
24	*Alpinia galanga*	(L.) Sweet	Greater galangal/ ginger lily	Zingiberaceae				2		62
25	*Alpinia zerumbet*	(Pers.) Burtt & R.M. Sm.	Shell ginger	Zingiberaceae						62
26	*Alysicarpus ovalifolius*	(Schumach.) J. Léonard	Alyce clover	Leguminosae-Papilionoideae						34; 35
27	*Amaranthus graecizans*	L.	Pigweed	Amaranthaceae						15; 18; 114; 171
	Amoora rohituka	Wight & Arn.	See *Aphanamixis polystachya*	Meliaceae						
28	*Anacardium occidentale*	L.	Cashew	Anacardiaceae				2		65; 109
29	*Ancistrocladus barteri*	Scott-Elliot		Ancistroclada-ceae						116
30	*Andrographis paniculata*	(Burm. f.) Wall. ex Nees	False waterwillow	Acanthaceae		1				
	Andropogon citratus	DC. ex Nees	See *Cymbopogon citratus*	Poaceae						
31	*Anethum graveolens*	L.	Dill	Apiaceae		1		1	1	336
	Annona arenaria	Thonn.	See *Annona senegalensis*	Annonaceae						
32	*Annona glabra*	L.	Pond apple	Annonaceae		1				
33	*Annona muricata*	L.	Soursop	Annonaceae		1				312
34	*Annona reticulata*	L. ,	Custard apple	Annonaceae				1		65; 109; 249; 252; 312
35	*Annona senegalensis*	Pers.	Wild custard apple	Annonaceae				2		18; 19; 34; 35; 103; 109; 114; 171; 270
36	*Annona* spp.	L.	Annona	Annonaceae				1		

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
37	*Annona squamosa*	L.	Sweetsop/ sugar apple	Annonaceae		1		3		109; 312; 336
38	*Anogeissus leiocarpus*	(DC.) Guill. & Perr.		Combretaceae						34; 35; 113
39	*Aphanamixis polystachya*	Wall. & Parker	Pithraj	Meliaceae		2		1		184
40	*Apium graveolens*	L.	Wild celery	Apiaceae					1	
41	*Apium* spp.	L.	Celery	Apiaceae						291
42	*Arachis hypogaea*	L.	Groundnut/peanut	Leguminosae-Papilionoideae			48			34; 35; 65; 66; 95; 109; 114; 164; 258; 312; 336; 339
43	*Argemone mexicana*	L.	Mexican prickly poppy	Papaveraceae						109
44	*Artemisia absinthium*	L.	Absinth sagewort	Asteraceae		1				
45	*Artemisia dracunculus*	L.	Green sagewort	Asteraceae		1				120
46	*Artemisia* spp.	L.	Wormwood/ sagewort	Asteraceae						65; 109; 291
47	*Artemisia tridentata*	Nutt.	Big sagebrush	Asteraceae				1		
48	*Aspilia africana*	(Pers.) C. D. Adams		Asteraceae				1		
49	*Atriplex lentiformis*	(Torr.) S. Watson	Quail bush/ salt bush	Chenopodiaceae		1				95
50	*Azadirachta indica*	Juss.	Neem	Meliaceae	2	13	34	35		13; 18; 19; 23; 24; 26; 27; 34; 35; 65; 66; 68; 94; 95; 109; 114; 119; 164; 171; 173; 184; 198; 205; 247; 252; 258; 270; 274; 281; 312; 328; 336

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
51	*Balanites aegyptiaca*	(L.) Delile	Desert date	Zygophyllaceae				1		34; 35; 114; 116
52	*Balsamorhiza sagittata*	(Pursh) Nutt.	Arrowleaf balsamroot	Asteraceae				1		
53	*Barringtonia acutangula*	(L.) Gaertn.	Freshwater mangrove	Lecythidaceae						139
54	*Barringtonia asiatica*	(L.) Kurz		Lecythidaceae						312
	Bassia latifolia	Roxb.	See *Madhuca longifolia*	Sapotaceae						
55	*Blumea balsamifera*	(L.) DC.	Sambong/ nagi camphor	Asteraceae					1	198
56	*Boesenbergia padurata*	Schl.	Fingerroot	Zingiberaceae						62
57	*Borassus aethiopum*	C. Mart.	Fan, palmyra palm	Arecaceae						34; 35; 113; 114
58	*Boscia salicifolia*	Oliv.	Willow shepherds tree	Capparaceae						15; 18; 34; 35; 114
59	*Boscia senegalensis*	(Pers.) Lam. ex Poir.	Senegal boscia	Capparaceae		1		7		18; 19; 24; 34; 35; 66; 109; 114; 171; 270
60	*Bougainvillea* spp.	Comm. ex Juss.	Bougainvillea	Nyctaginaceae						109
61	*Brassica juncea*	(L.) Czern.	Rape/ Indian mustard	Brassicaceae			9			95; 109; 336
62	*Brassica rapa*	L.	Turnip/ rape mustard	Brassicaceae						109
63	*Brassica* spp.	L.	Mustard	Brassicaceae			24			65; 109; 149; 312; 336
64	*Bridelia ferruginea*	Benth.		Euphorbiaceae				1		
	Butyrospermum paradoxum	(Gaertn. f.) Hepper	See *Vitellaria paradoxa*	Sapotaceae						
	Butyrospermum parkii	(G. Don) Kotschy	See *Vitellaria paradoxa*	Sapotaceae						
65	*Cactus* spp.		Cactus	Cactaceae						65; 109
66	*Cadaba farinosa*	Forssk.	Cadaba	Capparaceae						34; 35
67	*Caesalpinia bonduc*	(L.) Roxb.	Yellow nicker/ bonduc nut	Leguminosae-Caesalpinioideae		1				

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
68	*Caesalpinia pulcherrima*	(L.) Sw.	Dwarf poiciana	Leguminosae-Caesalpinioideae						109
69	*Caesalpinia sappan*	L.	Sappan wood	Leguminosae-Caesalpinioideae						139
70	*Callistemon citrinus*	(Curtis) Stapf	Crimson bottlebrush	Myrtaceae					1	186
	Callistemon lanceolatus	(Sw.) DC.	See *Callistemon citrinus*	Myrtaceae						
71	*Callistephus chinensis*	(L.) Nees	China aster	Asteraceae						109
72	*Calophyllum inophyllum*	L.	Alexandrian laurel/ undi	Clusiaceae			3			336
73	*Calotropis gigantea*	(L.) Aiton f	Giant milkweed	Asclepiadaceae						109
74	*Calotropis procera*	(Ait.) W.T. Aiton	Roostertree/ swallowwort	Asclepiadaceae						15; 18; 34; 35; 114; 171
75	*Canna indica*	L.	Indian shot	Cannaceae						109
76	*Cannabis sativa*	L.	Marijuana	Cannabinaceae						109
77	*Capsicum annuum*	L.	Chilli, hot, cayenne pepper	Solanaceae		1		5		34; 35; 95; 151; 208; 252; 336
78	*Capsicum chinense*	Jacq.	Aji	Solanaceae				1		
79	*Capsicum frutescens*	L.	Piment/ red pepper	Solanaceae		2		8		24; 65; 66; 198; 284; 312; 339
80	*Capsicum* spp.	L.	Pepper	Solanaceae				1		15; 18; 19; 35; 86; 109; 114; 171; 312; 336
81	*Carica papaya*	L.	Papaya/ pawpaw	Caricaceae						258; 270; 284
82	*Carthamus tinctorius*	L.	Safflower	Asteraceae			12			65; 109; 111; 312
83	*Carum roxburghianum*	Benth. ex Kurz	Bishops weed	Apiaceae		1				291
	Caryophyllus aromaticus	L.	See *Eugenia aromatica*	Myrtaceae						

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
	Cassia nigricans	Vahl	See *Chamaecrista nigricans*	Leguminosae-Caesalpinioideae						
	Cassia occidentalis	L.	See *Senna occidentalis* Coffee sena	Leguminosae-Caesalpinioideae						
84	*Cassia singueana*	Del.	Cassia tree	Leguminosae-Caesalpinioideae						15; 18; 34; 35; 114; 171; 270
85	*Cassia* spp.	L.	Cassia	Leguminosae-Caesalpinioideae						109
86	*Castanospermum australe*	Cunn.	Black bean/ moreton bay chestnut	Leguminosae-Papilionoideae						328
87	*Casuarina indica*	Pers.		Casuarinaceae	1					
88	*Casuarina* spp.	L.	Casuarina	Casuarinaceae						65; 109
89	*Cedrus deodara*	(Roxb. ex D. Don) G. Don f.	Deodar cedar	Pinaceae					1	
90	*Cedrus* spp.	Trew	Cedar	Pinaceae					1	
91	*Ceiba pentandra*	(L.) Gaertn.	Kapok tree	Bombacaceae	1		2			
92	*Celastrus angulata*	Maxim.	Bittersweet	Celastraceae						109
93	*Centaurea perrottetii*	DC.		Asteraceae						34; 35
94	*Cestrum nocturnum*	L.	Night flowering jasmine	Solanaceae		1				
95	*Chamaecrista nigricans*	(Vahl) Greene		Leguminosae Caesalpinioideae		1		6		23; 65; 114; 153; 312; 336; 339
96	*Chamomilla recutita*	(L.) Rauschert	German chamomile	Asteraceae		1				120; 291
97	*Chenopodium ambrosioides*	L.	Mexican tea	Chenopodiaceae				1		95
98	*Chromolaena odorata*	(L.) R.M. King & H. Rob.	Siam weed/ hagonoy	Asteraceae		1		4	2	
99	*Chrozophora brocchiana*	Vis.	Chrozophora	Euphorbiaceae						34; 35
100	*Chrysanthemum cinerariifolium*	(Trevir.) Vis.	Pyrethrum	Asteraceae						312
101	*Chrysanthemum indicum*	L.	Manzanilla	Asteraceae					1	198
102	*Chrysanthemum* spp.	L.	Daisy	Asteraceae		1				

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
103	*Cinnamomum camphora*	(L.) J. Presl	Camphor tree	Lauraceae				2		
104	*Cinnamomum mercadoi*	Vid.	Cinnamon	Lauraceae					1	
105	*Cinnamomum* spp.	Schaeff.	Cinnamon	Lauraceae						65
106	*Cinnamomum verum*	J. Presl	Cinnamon	Lauraceae					1	109; 333
	Cinnamomum zeylanicum	Blume	See *Cinnamomum verum*	Lauraceae						
107	*Cissampelos owariensis*	P. Beauv. ex DC.	Pareira brava/ velvet leaf	Menispermaceae		1				
108	*Cissus quadrangularis*	L.	Pirandai/ petch-sang-kart	Vitaceae						153
109	*Citrullus colocynthis*	(L.) Schrad.	Water melon/ colocynth	Cucurbitaceae						34; 35
110	*Citrus aurantifolia*	(Christm.) Swingle	Lime	Rutaceae				2	5	65; 109
	Citrus aurantium	L.	See *Citrus sinensis*	Rutaceae						
111	*Citrus crematifolia*	Lush.		Rutaceae				2		
112	*Citrus grandis*	(L.) Osbeck	Pomelo	Rutaceae				1		
113	*Citrus limon*	(L.) Burm. f.	Lemon	Rutaceae		1		3	7	109; 252; 291; 336
114	*Citrus paradisi*	Macfad.	Grapefruit	Rutaceae				3	5	109; 291
115	*Citrus reticulata*	Blanco	Tangerine/ mandarin	Rutaceae				2	4	
116	*Citrus sinensis*	(L.) Osbeck	(sweet) orange	Rutaceae		1		8	5	109; 291
117	*Citrus* spp.	L.	Citrus	Rutaceae		1		1		65; 109; 164; 336
118	*Citrus X tangelo*	J.W. Ingram & H.E. Moore	Tangelo	Rutaceae					2	
119	*Clematis vitalba*	L.	Travellers joy/ evergreen clematis	Ranunculaceae						65; 109
120	*Clerodendrum inerme*	(L.) Gaertn.	Garden quinine/ embrert	Verbenaceae		2				86; 95
121	*Cocculus trilobus*	(Thunb.) DC.	Huehue	Menispermaceae						109
122	*Cocos nucifera*	L.	Coconut palm	Arecaceae		1	33			65; 95; 109; 164; 198; 247; 312; 336
123	*Coffea arabica*	L.	Arabian coffee	Rubiaceae	1	1				

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
124	*Coleus amboinicus*	Lour.	Oregano	Lamiaceae					1	198; 291; 292; 293
125	*Combretum apiculatum*	Sond.	Red bushwillow	Combretaceae				1		
126	*Combretum imberbe*	Wawra	Motswere tree/ leadwood	Combretaceae	3			1		
127	*Conomorpha peruviana*	DC.		Myrsinaceae						109; 116
128	*Coriandrum sativum*	L.	Coriander/ Chinese parsley	Apiaceae		1			2	291
129	*Crinum defixum*	Ker. Gawl.	Swamplily/ kesarachettu	Amaryllidaceae				1		
130	*Crotalaria juncea*	L.	Sun hemp	Leguminosae-Papilionoideae						65; 109
131	*Crotalaria ochroleuca*	G. Don.	Crotalaria/sunhemp/ slender leaf rattlebox	Leguminosae-Papilionoideae						312
132	*Croton bonplandianus*	Baill.	Bonpland's croton	Euphorbiaceae						168
133	*Croton gratissimus*	Burch.	Croton	Euphorbiaceae				1		
134	*Croton tiglium*	L.	Purging croton	Euphorbiaceae						312
135	*Cucurbita foetidissima*	Kunth	Missouri, buffalo gourd	Cucurbitaceae						116
136	*Cucurbita* spp.	L.	Gourd/cucurbit	Cucurbitaceae						109
137	*Cuminum cyminum*	L.	Cumin	Apiaceae					1	
138	*Curcuma aeruginosa*	Roxb.	Black temu	Zingiberaceae						62
139	*Curcuma amada*	Roxb.	Mango ginger	Zingiberaceae				1		62
140	*Curcuma aromatica*	Salisb.	Wild turmeric	Zingiberaceae						62
	Curcuma domestica	Val.	See *Curcuma longa*	Zingiberaceae						
141	*Curcuma heyeana*			Zingiberaceae						62
142	*Curcuma longa*	L.	Common turmeric	Zingiberaceae				3		65; 66; 312; 340
143	*Curcuma zedoaria*	(Christm.) Roscoe	Zedoary	Zingiberaceae				1		62
144	*Cymbopogon citratus*	(DC. ex Nees) Stapf	Lemon grass	Poaceae				5	8	111; 291
145	*Cymbopogon giganteus*	(Hochst.) Chiov.		Poaceae						34; 35; 114
146	*Cymbopogon nardus*	(L.) Rendle	Citronella grass	Poaceae	1	1		1	7	111

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
147	*Cymbopogon schoenanthus*	(L.) Spreng.	Camel grass	Poaceae				2	3	66; 114
148	*Cymbopogon* spp.	Spreng.	Cymbopogon	Poaceae		1				65; 109
149	*Cyperus rotundus*	L.	Nutgrass	Cyperaceae		1				
	Datura fastuosa	L.	See *Datura metel*	Solanaceae						
	Datura innoxia	Mill.	See *Datura metel*	Solanaceae						
150	*Datura metel*	L.	Thornapple/ angel trumpet/ horn of plenty	Solanaceae		1				34; 35
151	*Datura stramonium*	L.	Jimson weed/ thorn apple	Solanaceae		2				65; 103; 109; 167; 284
152	*Delonix regia*	(Bojer ex Hook.) Raf.	Royal poinciana	Leguminosae-Papilionoideae						109
153	*Dennettia tripetala*	Baker f.	Dennettia	Annonaceae				1	1	65; 312
154	*Derris elliptica*	(Wall.) Benth.	Jewelvine/derris	Leguminosae-Papilionoideae						65; 66; 109; 139; 312
155	*Derris inudata*	Lour.	Derris	Leguminosae-Papilionoideae				1		
156	*Derris malaccensis*	Prain/Hend.		Leguminosae-Papilionoideae						312
157	*Derris* spp.	Lour.	Derris	Leguminosae-Papilionoideae				1		
158	*Derris trifoliata*	Lour.	Threeleaf derris	Leguminosae-Papilionoideae						312
	Derris uliginosa	(Willd.) Benth.	See *Derris trifoliata*	Leguminosae-Papilionoideae						
159	*Diheteropogon hagerupii*	Hitchc.		Poaceae						113
160	*Dillenia retusa*	Thunb.		Dilleniaceae				1		249
161	*Diodia sarmentosa*	Sw.	Tropical buttonweed	Rubiaceae		1		1		
162	*Diplolophium africanum*	Turcz.		Apiaceae					3	
163	*Dodonaea viscosa*	(L.) Jacq.	Florida hopbush/ dodonaea	Sapindaceae		1				
164	*Dolichos buchananii*	Harms		Leguminosae-Papilionoideae						116

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
165	*Dolichos kilimandscharicum*	Taub.	Lablab	Leguminosae-Papilionoideae						109
166	*Duranta plumieri*	L.	Duranta	Verbenaceae						86
167	*Dysoxylum cauliflorum*	Hiern		Meliaceae		1				
168	*Echinochloa frumentacea*	Link	Japanese millet	Poaceae						109
169	*Eclipta prostrata*	(L.) L.	False daisy	Asteraceae		1				
170	*Eichhornia crassipes*	(Mart.) Solms	Water hyacinth	Pontederiaceae		2				
171	*Elaeis guineensis*	Jacq.	African oil palm	Arecaceae			23			65; 95; 109; 258; 336; 339
172	*Eleusine coracana*	L. Gaertn.	Finger millet/ragi	Poaceae						65; 109
173	*Embelia ribes*	Brun	Baibarang	Myrsinaceae		2				95
174	*Emilia sonchifolia*	(L.) DC.	Lilac tasselflower	Asteraceae				1		
175	*Entada africana*	Guill. & Perr.		Leguminosae Mimosoideae				1		
176	*Eragrostis tremula*	Hochst. ex Steud.	Lovegrass	Poaceae						15; 18; 114; 171
	Eruca sativa	Mill.	See *Eruca vesicaria*	Brassicaceae						
177	*Eruca vesicaria*	(L.) Cav.	Rocket salad	Brassicaceae			2			
	Erythrophleum guineense	G. Don	See *Erythrophleum suaveolens*	Leguminosae-Caesalpinioideae						
178	*Erythrophleum suaveolens*	(Guill. & Perr.) Brenan	Sasswood	Leguminosae-Caesalpinioideae		2		1		103
179	*Eucalyptus citriodora*	Hook.	Lemon scented eucalyptus	Myrtaceae		1		1	4	164; 223
180	*Eucalyptus globulus*	Labill.	Fever tree/ Tasmanian blue gum	Myrtaceae				1	1	68; 86; 164; 223
181	*Eucalyptus* spp.	L'Hér.	Eucalyptus	Myrtaceae				4	1	65; 91; 109; 312
182	*Eucalyptus tereticornis*	Sm.	Forest red gum	Myrtaceae		1			1	
183	*Eugenia aromatica*	(L.) Baill.	Cloves	Myrtaceae		2		1	3	358
	Eugenia caryophyllata	Thunb.	See *Eugenia aromatica*	Myrtaceae						
184	*Eugenia uniflora*	L.	Surinam cherry	Myrtaceae				1	2	

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
185	*Eupatorium capillifolium*	(Lam.) Small	Dogfennel	Asteraceae					1	186
	Eupatorium odoratum	L.	See *Chromolaena odorata*	Asteraceae						
186	*Eupatorium* spp.	L.	Thoroughwort/ fennel	Asteraceae				1		291
187	*Euphorbia balsamifera*	Aiton	Balsam spurge	Euphorbiaceae						15; 18; 34; 35; 114; 171
188	*Euphorbia poissonii*	Pax	Tinya	Euphorbiaceae						34; 35
189	*Euphorbia tirucalli*	L.	Milk bush/ Indian tree spurge	Euphorbiaceae				1		
190	*Feretia apodanthera*	Del.		Rubiaceae						34; 35
191	*Ficus exasperata*	Vahl		Moraceae				1		
192	*Ficus sycomorus*	L.	Sycamore, common cluster fig	Moraceae						18; 114; 171
193	*Fortunella* spp.	Swingle	Kumquat/fortunella	Rutaceae					2	
194	*Galega* spp.	L.	Galega/rue	Leguminosae-Papilionoideae					1	291
195	*Geranium viscosissimum*	Fisch. & C.A. Mey. ex C.A. Mey.	Sticky geranium	Geraniaceae				1		
196	*Gloriosa superba*	L.	Flame lily	Liliaceae		1				
197	*Glycine max*	(L.) Merr.	Soybean	Leguminosae-Papilionoideae			22			65; 91; 95; 109; 173; 293; 312; 336
198	*Gossypium hirsutum*	L.	Upland cotton	Malvaceae			17			65; 109; 114; 171; 194; 293; 312; 336
199	*Grewia carpinifolia*	Juss.		Tiliaceae		1				
200	*Guiera senegalensis*	J. F. Gmel.		Combretaceae						19; 34; 35
201	*Guizotia abyssinica*	(L. f.) Cass.	Ramtilla/niger	Asteraceae			2			95
202	*Haplophyton cimicidum*	A. DC.	Cockroach plant	Apocynaceae						312
203	*Harpullia arborea*	(Blanco) Radlk.	Uas	Sapindaceae						116
204	*Harrisonia abyssinica*	Oliv.		Simaroubaceae						109

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
205	*Helianthus annuus*	L.	Common sunflower	Asteraceae			16			65; 109; 173; 258; 312
206	*Heliotropium bacciferum*	Forssk.		Boraginaceae		1				
207	*Hibiscus chinensis*	L.		Malvaceae						109
208	*Hibiscus sabdariffa*	L.	Roselle	Malvaceae						15; 18; 34; 35; 114; 171
209	*Hyptis spicigera*	Lam.	Marubio/ black sesame	Lamiaceae		1		5	1	13; 20; 23; 34; 35; 65; 66; 95; 103; 109; 114; 180; 312; 336; 339
210	*Hyptis suaveolens*	(L.) Poit.	English basil/pignut	Lamiaceae		1		2	2	34; 35; 180
211	*Imperata cylindrica*	(L.) Beauv.	Ekon grass/ cogongrass	Poaceae						109
212	*Inula graveolens*	(L.) Desf.	Dill	Asteraceae						65; 109
213	*Ipomoea asarifolia*	(Desr.) Roem. & Schult.		Convolvulaceae						34; 35
214	*Ipomoea carnea*	Jacq.	Gloria de la manana	Convolvulaceae		2		2		95
215	*Ipomoea mauritiana*	Jacq.		Convolvulaceae				1		
216	*Ipomoea palmata*	Forssk.		Convolvulaceae		1				95
217	*Jacquinia barbasco*	Mez	Braceletwood	Theophrastaceae						116
218	*Jasminum* spp.	L.	Jasmine	Oleaceae						109
219	*Jatropha curcas*	L.	Physic, Barbados nut	Euphorbiaceae			1			312; 336
220	*Jatropha indica*		Jatropha	Euphorbiaceae			1	1		
221	*Juglans* spp.	L.	Walnut	Juglandaceae				1		
222	*Justicia adhatoda*	L. ,	Malabar nut tree	Acanthaceae						109
223	*Kaempferia galanga*	L.	Galanga	Zingiberaceae						62; 109
224	*Kaempferia rotunda*	L.	Round rooted galangal	Zingiberaceae						62
225	*Khaya senegalensis*	(Desr.) A. Juss.	African mahogany	Meliaceae		1		2		23; 24; 34; 35; 65; 109
226	*Lannea fruticosa*	Engl.		Anacardiaceae						15; 18; 114; 171

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
227	*Lantana camara*	L.	Aripple/ common lantana	Verbenaceae		4		4	2	95
228	*Lantana rugosa*	Thunb.		Verbenaceae						65; 103; 109
229	*Lantana salviifolia*			Verbenaceae						109
230	*Lantana* spp.	L.	Lantana	Verbenaceae						109
231	*Laurus nobilis*	L.	Sweet laurel, bay leaves	Lauraceae				2	2	291; 292; 293
232	*Lavandula angustifolia*	Mill.	English lavender	Lamiaceae				1	2	292; 293
	Lavandula officinalis	Chaix	See *Lavandula angustifolia*	Lamiaceae						
233	*Lavandula* spp.	L.	Lavender	Lamiaceae					2	291
234	*Ledum palustre*	L.	Marsh Labrador tea	Ericaceae				1		
235	*Lepianthes peltata*	(L.) Raf.	Monkey's hand	Piperaceae		1				
236	*Lepidium aucheri*	Boiss.	Aucher's pepperwort	Brassicaceae		1				
237	*Leptadenia hastata*	(Pers.) Decne.	Spear leaved leptadenia	Asclepiadaceae						19; 34; 35
238	*Linum usitatissimum*	L.	Linseed/ common flax	Linaceae			6			95
239	*Lippia adoensis*	Hochst. ex Walp.		Verbenaceae				1	2	
240	*Lippia chevalieri*	Moldenke		Verbenaceae				1		66
241	*Lippia multiflora*	Moldenke		Verbenaceae				1	4	35
242	*Lobelia columnaris*			Campanulaceae						284
243	*Lobelia nicotianifolia*	Heyne	Wild tobacco	Campanulaceae						109
244	*Lonchocarpus salvadorensis*	Pittier		Leguminosae-Papilionoideae		1				
245	*Lonchocarpus* spp.	Kunth	Lonchocarpus/ lancepod	Leguminosae-Papilionoideae						66
246	*Luffa acutangula*	(L.) Roxb.	Sinkwa towelsponge/ dishcloth gourd	Cucurbitaceae						109; 116
247	*Luffa aegyptiaca*	Mill.	Sponge gourd	Cucurbitaceae						103; 109
	Luffa cylindrica	(L.) M. Roem.	See *Luffa aegyptiaca*	Cucurbitaceae						
248	*Luvunga scandens*	Buch Ham.	Sugandh kokila	Rutaceae						71

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
249	*Lysimachia nummularia*	L.	Moneywort/ creeping jenny	Primulaceae						65; 109
	Madhuca indica	J.F. Gmel.	See *Madhuca longifolia*	Sapotaceae						
	Madhuca latifolia	(Roxb.) J.F. Macbr.	See *Madhuca longifolia*	Sapotaceae						
250	*Madhuca longifolia*	(J. König) J.F. Macbr.	Mahua/ illipe butter tree	Sapotaceae			7			65; 95; 109; 111; 336
251	*Maerua angolensis*	DC.	Bead bean	Capparaceae						153
252	*Maerua crassifolia*	Forssk.	Atil/toothbrush tree	Capparaceae						15; 18; 34; 35
253	*Mammea americana*	L.	Mammee apple	Clusiaceae						312
254	*Mangifera indica*	L.	Mango	Anacardiaceae						65; 109
255	*Maranta arundinacea*	L.	Arrowroot	Marantaceae						109
256	*Marsilea* spp.	L.	Pepperwort	Pteridophyta						65
257	*Melia azedarach*	L.	Chinaberry tree/ Persian lilac	Meliaceae		1	1	3		65; 109; 312; 340
	Melia composita	Willd.	See *Melia azedarach*	Meliaceae						
258	*Melilotus indica*	(L.) All.	Sourclover	Leguminosae-Papilionoideae						65; 109
259	*Melilotus officinalis*	(L.) Lam.	Yellow sweetclover	Leguminosae-Papilionoideae		1				120
260	*Mentha citrata*	Ehrh.	Lemon mint	Lamiaceae					1	
261	*Mentha longifolia*	(L.) Huds.	Horse mint	Lamiaceae						358
262	*Mentha piperita*	L.	Peppermint	Lamiaceae		1		2	2	291; 292; 293
263	*Mentha spicata*	L.	Spear, wild mint	Lamiaceae				1	1	65; 109; 312
264	*Mentha* spp.	L.	Mint	Lamiaceae						336
265	*Mitracarpus scaber*	Zucc.		Rubiaceae		1		2		19; 34; 35
266	*Momordica balsamina*	L.	Balsam apple/ southern balsampear	Cucurbitaceae						34; 35
	Momordica cylindrica	L.	See *Luffa aegyptiaca*	Cucurbitaceae						
267	*Momordica* spp.	L.	Momordica	Cucurbitaceae				1		

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
268	*Monarda fistulosa*	L.	Wild bergamot	Lamiaceae				1		
269	*Monodora myristica*	(Gaertn.) Dunal	Calabash nutmeg	Annonaceae		1		2	1	
270	*Mundulea sericea*	Willd.	Silverbush	Leguminosae-Papilionoideae						65; 109
271	*Murraya koenigii*	(L.) Spreng.	Curryleaf tree/ sweet neem	Rutaceae					1	
272	*Myristica fragrans*	Houtt.	Nutmeg	Myristicaceae					1	
273	*Myroxylon balsamum*	(L.) Harms	Balsam of Tolu	Leguminosae-Papilionoideae				1		
274	*Myrrhis odorata*	(L.) Scop.	Anise	Apiaceae						291; 292; 293
275	*Napoleona imperialis*	P. Beauv.		Lecythidaceae		1		1		
276	*Nardostachys jatamansi*	DC.	Indian spikenard	Valerianaceae						71
277	*Nerium indicum*	Mill.	Scented oleander	Apocynaceae						109
278	*Nerium oleander*	L.	Oleander	Apocynaceae		1		1		95
279	*Nicotiana glutinosa*	L.	Tobacco	Solanaceae						312
280	*Nicotiana rustica*	L.	Rustica, Aztec tobacco	Solanaceae						284; 312
281	*Nicotiana* spp.	L.	Tobacco	Solanaceae						65; 103
282	*Nicotiana tabacum*	L.	Cultivated tobacco	Solanaceae				3		24; 34; 35; 65; 66; 109; 284; 312
283	*Nigella sativa*	L.	Black cumin	Ranunculaceae						109; 291
284	*Ochroma* spp.	Sw.	Ochroma	Bombacaceae						65
	Ocimum americanum	L.	See *Ocimum basilicum*	Lamiaceae						
285	*Ocimum basilicum*	L.	Sweet, forest basil	Lamiaceae		1		6	5	65; 66; 68; 103; 109; 114; 180; 291; 292; 293; 312
	Ocimum canum	Sims	See *Ocimum basilicum*	Lamiaceae						
286	*Ocimum gratissimum*	L.	African, shrubby basil	Lamiaceae				3		66; 114
287	*Ocimum sanctum*	L.	Holy basil	Lamiaceae				1		249
288	*Ocimum* spp.	L.	Basil	Lamiaceae						34; 35

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
289	*Olea europaea*	L.	Olive	Oleaceae			8			
290	*Opuntia burrageana*	Britt. & Rose	Prickly pear	Cactaceae				1		
291	*Origanum majorana*	L.	Sweet marjoram	Lamiaceae					1	
	Origanum serpyllum	Kuntze	See *Thymus serpyllum*	Lamiaceae						
292	*Origanum* spp.	L.	Marjoram	Lamiaceae						65; 291
293	*Origanum vulgare*	L.	Wild marjoram	Lamiaceae				1	2	109
294	*Oryza sativa*	L.	Rice	Poaceae	1		10			65; 109; 336
295	*Pachyrhizus erosus*	(L.) Urb.	Yam bean	Leguminosae-Papilionoideae		1				312
	Parkia africana	R. Br.	See *Parkia biglobosa*	Leguminosae Mimosoideae						
296	*Parkia biglobosa*	(Jacq.) R. Br. ex G. Don f	Nere	Leguminosae Mimosoideae	1			1		34; 35
	Parkia clappertoniana	Keay	See *Parkia biglobosa*	Leguminosae Mimosoideae						
297	*Parkia filicoidea*	Welw. ex Oliv.	African locust bean	Leguminosae Mimosoideae						26
298	*Parthenium hysterophorus*	L.	Santa Maria feverfew/ carrot grass	Asteraceae		1				65; 95; 109
299	*Pelargonium* spp.	L'Hér. ex Ait.	Pelargonium	Geraniaceae					1	
300	*Peltophorum africanum*	Sond.	Weeping, African wattle	Leguminosae-Caesalpinioideae				1		
301	*Peltophorum suringari*	Urb.		Leguminosae-Caesalpinioideae						116
302	*Pennisetum americanum*	(L.) Leeke	Pearl millet/ American fountaingrass	Poaceae						34; 35
303	*Pennisetum* spp.	Rich. ex Pers.	Kikuyugrass/ little millet	Poaceae	2					65; 113; 114
304	*Pergularia tomentosa*	L.		Asclepiadaceae						19; 34; 35; 114
305	*Petroselinum crispum*	(Mill.) Nyman ex A.W. Hill	Parsley	Apiaceae					1	291
306	*Phaseolus* spp.	L.	Bean	Leguminosae-Papilionoideae	1					65

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
307	*Phaseolus vulgaris*	L.	Kidney, French bean	Leguminosae-Papilionoideae		1		1		109
308	*Physalis minima*	L.	Pygmy groundcherry	Solanaceae						109
309	*Phytolacca dodecandra*	L'Hér.	Pokeweed	Phytolaccaceae						167
310	*Picrasma* spp.	Blume	bitterwood	Simaroubaceae						65
311	*Picrolemma sprucei*	Hook. f.		Simaroubaceae						116
312	*Piliostigma reticulatum*	(DC.) Hochst.	Alluba vegetable bush	Leguminosae-Caesalpinioideae						15; 18; 34; 35; 113; 114; 171
313	*Pimenta acris*	(Sw.) Kostel.	Bayrumtree/ wild clove	Myrtaceae						65; 109
314	*Pinus* spp.	L.	Pine	Pinaceae					1	
315	*Piper acutifolium*	Ruiz & Pav.		Piperaceae					1	
316	*Piper guineense*	Schum. & Thonn.	Brown, West African pepper	Piperaceae		4		5	4	164; 336
317	*Piper nigrum*	L.	Black pepper	Piperaceae		7		14	1	65; 91; 109; 164; 198; 249; 252; 336
	Piper umbellatum	L.	See *Lepianthes peltata*	Piperaceae						
318	*Pisum* spp.	L.	Pea	Leguminosae-Papilionideae						65
319	*Podocarpus nakaii*	Hay	Nakai podocarp	Podocarpaceae						109
320	*Pogostemon heyeanus*	Benth.	Patchouli oil	Lamiaceae						109
321	*Poinsettia pulcherrima*	(Willd. ex Klotzsch) Graham	Poinsettia	Euphorbiaceae						109
322	*Polygala butyracea*	Heckel		Polygalaceae				1		
323	*Polygonum hydropiper*	L.	Water pepper/ marshpepper knotweed	Polygonaceae				1		
	Pongamia glabra	Vent.	See *Pongamia pinnata*	Leguminosae-Papilionoideae						
324	*Pongamia pinnata*	(L.) Pierre	Honge/karanjee/ pongam	Leguminosae-Papilionoideae		1	10	2		65; 109; 111; 336; 340

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
325	*Prosopis africana*	(Guill., Perr. & A. Rich.) Taub.	African mesquite	Leguminosae Mimosoideae				1		153
326	*Prosopis juliflora*	(Sw.) DC.	Cuji/mesquite	Leguminosae Mimosoideae						328
327	*Prunus armeniaca*	L.	Apricot	Rosaceae						358
328	*Psoralea corylifolia*	L.	Ku tsu/babchi	Leguminosae-Papilionoideae		1				
329	*Pterocarpus erinaceus*	Poir.	Barwood	Leguminosae-Papilionoideae	2					114
330	*Pterocarpus santalinus*	L. f.	Red sanders, sandalwood	Leguminosae-Papilionoideae						153
331	*Pulicaria crispa*	(Forssk.) Benth. ex Oliv.	False fleabean	Asteraceae						34; 35
332	*Raphanus sativus*	L.	Wild radish	Brassicaceae			1			
333	*Rhazya stricta*	Decne.		Apocynaceae		1				
334	*Ricinus communis*	L.	Castor	Euphorbiaceae		2	17	1		34; 35; 65; 95; 109; 164; 284; 312
335	*Rogeria adenophylla*	J. Gay		Pedaliaceae						34; 35
336	*Rosmarinus officinalis*	L.	Rosemary	Lamiaceae				2	2	291; 292; 293
337	*Rottboellia exaltata*	(L.) L. f.	Itch grass	Poaceae						19; 34
338	*Rumex* spp.	L.	Sorrel/dock	Polygonaceae						113
339	*Ryania speciosa*	Vahl	Ryania	Flacourtiaceae						65; 109; 116; 312
340	*Salvadora persica*	L.	Miswak/pilu	Salvadoraceae						34; 35; 114
341	*Salvia officinalis*	L.	Kitchen sage	Lamiaceae		1			1	291; 292; 293
342	*Salvia* spp.	L.	Sage	Lamiaceae						291
343	*Salvia triloba*	L.	Three lobed sage	Lamiaceae						291; 292; 293
	Sapindus marginatus	Willd.	See *Sapindus saponaria*	Sapindaceae						
344	*Sapindus saponaria*	L.	Wingleaf soap berry	Sapindaceae				1		65; 109; 358
345	*Satureja hortensis*	L.	Summer savory	Lamiaceae				1	1	291
346	*Saussurea lappa*	C.B. Clarke	Costus	Asteraceae		1				65; 109

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
347	*Schoenocaulon officinale*		Sabadilla/ feathershenk	Liliaceae						312
348	*Sclerocarya birrea*	(A. Rich.) Hochst.	Jelly plum/ marula	Anacardiaceae				1		34; 35
349	*Securidaca longepedunculata*	Fres.		Polygalaceae				1		19; 24; 114
350	*Senna occidentalis*	(L.) Link	Septicweed	Leguminosae-Caesalpinioideae		1	2	1		24; 34; 35; 168
351	*Sesamum indicum*	L.	Sesamum/gingelly	Pedaliaceae			23			34; 35; 65; 95; 109; 113; 258; 336
	Sesamum orientale	L.	See *Sesamum indicum*	Pedaliaceae						
352	*Seseli indicum*	Wight & Am.		Araliaceae						71; 187
353	*Shorea robusta*	Gaertn. f.	Sal tree	Dipterocarpaceae			2			336
354	*Sida acuta*	Burm. f.	Spinyhead sida/ broom weed/ common wire-weed	Malvaceae		1		1		
355	*Sida cordifolia*	L.	Country mallow	Malvaceae						34; 35
356	*Skimmia laureola*	(Thurb.) Hook.	Ner	Rutaceae						109
357	*Solanum incanum*	L.	Eggplant/nightshade	Solanaceae				1		
358	*Solanum nigrum*	L.	Black night shade	Solanaceae		1				
359	*Sorghum bicolor*	(L.) Moench	Broomcorn	Poaceae	1					65
360	*Sphaeranthus indicus*	L.	East Indian globe thistle	Asteraceae		1		1		
361	*Sphenoclea zeylanica*	Gaertn.	Sphenoclea	Sphenocleacea				1		
362	*Spigelia marilandica*	(L.) L.	Woodland pink-root	Loganiaceae						109; 116
363	*Spirostachys africana*	Sond.	Tamboti	Euphorbiaceae				1		
364	*Stelechocarpus cauliflorus*	(Scheff.) R.E.Fr.		Annonaceae		1				
365	*Stereospermum kunthianum*	Cham.		Bignoniaceae						15; 18; 34; 35; 114; 171
366	*Strophanthus hispidus*	A. DC.	Arrow poison/ hispid strophanthus	Apocynaceae		1				
367	*Strychnos* spp.	L.	Strychnine tree	Loganiaceae						284

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
368	*Swartzia madagascariensis*	Desv.	Pao ferro	Leguminosae-Papilionoideae						153
	Syzygium aromaticum	(L.) Merr. & Perry	See *Eugenia aromatica*	Myrtaceae						
369	*Syzygium cumini*	(L.) Skeels	Java plum	Myrtaceae						258
370	*Tabebuia rosea*	(Bertol.) DC.	Pink trumpet tree	Bignoniaceae						109
371	*Tacca leontopetaloides*	(L.) Kuntze	Batflower/ Polynesian arowwood	Taccaceae						65; 103; 109
372	*Tagetes minuta*	L.	Stinking roger/ Mexican marigold	Asteraceae		1			1	65; 167
373	*Tamarindus indica*	L.	Tamarind	Leguminosae-Caesalpinioideae	1			1		65; 109
374	*Tecoma indica*	Juss.	Tecoma	Bignoniaceae						109
375	*Tephrosia candida*	DC.	White hoarypea	Leguminosae-Papilionoideae						109
376	*Tephrosia* spp.	Pers.	Hoarypea/tephrosia	Leguminosae-Papilionoideae						65
377	*Tephrosia vogelii*	Hook. f.	Vogel's tephrosia	Leguminosae-Papilionoideae				2		95
378	*Terminalia avicennioides*	Guill. & Perr.	Almond	Combretaceae						34; 35
379	*Terminalia sericea*	Burch. ex DC.	Mangwe/almond	Combretaceae				1		
380	*Tetradenia riparia*	(Hochst.) Codd		Lamiaceae				1		
381	*Tetrapleura tetraptera*	(Schum. & Thonn.) Taub.	Akpa	Leguminosae Mimosoideae		1				
	Thevetia neriifolia	Juss. ex Steud.	See *Thevetia peruviana*	Apocynaceae						
382	*Thevetia peruviana*	(Pers.) K. Schum.	Yellow oleander/ lucky nut	Apocynaceae		1		2		23; 95; 116
383	*Thujopsis dolabrata*	Siebold & Zucc.	Hiba/mock thuja	Cupressaceae		1				
384	*Thymus serpyllum*	L.	Breckland thyme	Lamiaceae		1		1	1	120; 292
385	*Thymus vulgaris*	L.	Garden thyme	Lamiaceae		1		2	2	120; 291; 292
386	*Tilia cordata*	Mill.	Littleleaf linden	Tiliaceae				1		
387	*Tinospora* spp.			Menispermaceae						139
388	*Tragia senegalensis*	Muell. Arg.	Noseburn	Euphorbiaceae						23

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
389	*Tridax procumbens*	L.	Coatbuttons/ Mexican daisy	Asteraceae		1				95; 109; 336
390	*Trigonella foenum-graecum*	L.	Sicklefruit fenugreek	Leguminosae-Papilionoideae		1		1		65; 109
391	*Verbena officinalis*	L.	Herb of the cross	Verbenaceae					1	
392	*Verbesina encelioides*	(Cav.) Benth. & Hook. f. ex Gray	Golden crownbeard	Asteraceae						168
393	*Vigna angularis*	(Willd.) Ohwi & Ohashi	Adzuki bean	Leguminosae-Papilionoideae		1				
394	*Vigna unguiculata*	(L.) Walp.	Cowpea/ blackeyed pea	Leguminosae-Papilionoideae		1				34; 35
395	*Vitellaria paradoxa*	Gaertn. f.	Shea butter tree/ karite	Sapotaceae	3		3			65; 66; 103; 109; 114; 164; 171; 336
396	*Vitex altissima*	L. f.	Chaste tree	Verbenaceae				1		
397	*Vitex doniana*	Sweet	Black plum	Verbenaceae						19; 34; 35
398	*Vitex negundo*	L.	Begunia/ negundo chastetree	Verbenaceae		1		2	1	65; 95; 109; 182; 183; 184; 198; 247; 340
399	*Vitex* spp.	L.	Chastetree	Verbenaceae				1		
400	*Warburgia ugandensis*	Sprague	Pepper-bark	Canellaceae						109
401	*Weinmannia longiflora*			Cuniniaceae						167
402	*Withania somnifera*	(L.) Dunal	Winter cherry/ withania	Solanaceae		1				
403	*Xanthosoma sagittifolium*	(L.) Schott	Cocoyam/arrowleaf elephant's ear	Araceae						65; 109
404	*Xeromphis spinosa*	Thumb. Keay	Kucuruman	Rubiaceae						109
405	*Ximenia americana*	L.	Tallow wood	Olacaceae						15; 18; 114; 171
406	*Xylocarpus moluccensis*	(Imkhan.) Roem.	Cannonball tree	Meliaceae						109
407	*Xylopia aethiopica*	(Dunal) A. Rich.	West African pepper tree/ Ethiopian pepper	Annonaceae				2	1	

	Plant species	Author	Common name	Plant family	A	E	O	P	V	Unknown
408	*Zanthoxylum alatum*	Roxb.	Wingleaf prickly ash	Rutaceae		1				109
409	*Zanthoxylum zanthoxyloides*	(Lam.) Zepern. & Timler		Rutaceae		1		3		
410	*Zea mays*	L.	Maize/corn	Poaceae			12			34; 35; 65; 109; 312; 336
411	*Zingiber cassumunar*	Roxb.	Cassumunar ginger/ plai	Zingiberaceae						62
412	*Zingiber officinale*	Roscoe	Garden ginger	Zingiberaceae				4		164; 258; 340
413	*Zingiber spectabile*	Griff.	Black gingerwort	Zingiberaceae				1		
414	*Zingiber zerumbet*	(L.) Sm.	Bitter ginger	Zingiberaceae				1		
415			Cattle dung		2					26; 65; 109; 194
416			Daddoya	Acanthaceae						270
417			Dalda				1			
418			Goga masu							270
419			Wood		11					15; 16; 18; 19; 23; 26; 34; 65; 91; 109; 113; 114; 119; 151; 153; 208; 258; 270; 312; 339; 354

*: A = ashes, E = extracts, O = oils (non-volatile), P = powder or fresh, U = unknown #, V = volatile oil, numbers indicate the number of references mentioned in the separate tables.
#: Application, quantity, beetle species and/or effect are not noted in the references.

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