**RESEARCH REVIEW No. 42**

# ALTERNATIVES TO ORGANOPHOSPHORUS COMPOUNDS FOR THE CONTROL OF STORAGE MITES

FEBRUARY 2000

Price £6.50

# RESEARCH REVIEW No. 42

## ALTERNATIVES TO ORGANOPHOSPHORUS COMPOUNDS FOR THE CONTROL OF STORAGE MITES

by

D A COLLINS

Central Science Laboratory, Sand Hutton, York YO4 1LZ

This review was funded by HGCA as part of a research project on the alternatives to organo-phosphorus compounds for the control of storage mites. The work started in October 1998 and lasts in total for 42 months. The total grant (£174,534) covers ongoing research as well as this review (Project no. 2084).

**CONTENTS**

| | | | Page |
|---|---|---|---|
| 1. | Introduction | | 1 |
| 2. | Insect Growth Regulators (IGRs) | | 3 |
| | 2.1 | Juvenile Hormone Analogues (JHAs) | 4 |
| | 2.2 | Moulting hormone (ecdysone) analogues | 6 |
| | 2.3 | Chitin synthesis inhibitors | 6 |
| 3. | Inert Dusts | | 8 |
| 4. | Botanicals | | 11 |
| | 4.1 | Azadirachtin (Neem) | 11 |
| | 4.2 | Other plant derived products | 13 |
| 5. | Pyrethroids | | 16 |
| 6. | Novel Compounds | | 18 |
| | 6.1 | Chemosterilants | 18 |
| | 6.2 | Fatty Acids | 21 |
| | 6.3 | Inorganic Salts | 21 |
| | 6.4 | Antibiotics | 22 |
| 7. | Biological Control | | 25 |
| | 7.1 | Parasites, Parasitoids and Predators | 26 |
| | | 7.1.1 Parasitoids | 26 |
| | | 7.1.2 Nematodes | 27 |
| | | 7.1.3 Predators | 28 |
| | 7.2 | Pathogens | 29 |
| | | 7.2.1 Bacteria | 31 |
| | | 7.2.2 Viruses | 32 |
| | | 7.2.3 Protozoa | 33 |
| | | 7.2.4 Fungi | 34 |
| 8. | Alternatives to Admixture Treatment | | 37 |
| | 8.1 | Hygiene | 37 |
| | 8.2 | Cooling | 37 |
| | 8.3 | Heating | 37 |
| | 8.4 | Drying | 37 |
| | 8.5 | Cleaning and conveying | 38 |
| | 8.6 | Fumigation | 38 |
| | 8.7 | Modified Atmospheres | 38 |
| 9. | Conclusions | | 38 |
| 10. | Future Work | | 40 |
| 11. | Acknowledgements | | 40 |
| 12. | References | | 40 |
| | Table 1 | | 69 |
| | Table 2 | | 74 |

## 1. Introduction

Mites are very common pests of stored grain and oilseeds in the U.K. A survey of commercial grain stores during 1988/89 and oilseed stores in 1995, detected the presence of mites in 81.3 % and 89 % of the stores respectively (Lynch et al., 1991; Prickett, 1997). The most common species in the grain stores were *Acarus siro, Lepidoglyphus destructor, Tyrophagus longior* and *Tyrophagus putrescentiae*, identified in 59%, 51.2%, 15.9% and 12% of stores respectively (Lynch et al., 1991). In the oilseed stores the predominant species were *Acarus siro* (67%), *Lepidoglyphus destructor* (37%), *Tyrophagus putrescentiae* (31%) and *Tyrophagus longior* (19%) (Prickett, 1997).

Some mites feed on the germ of cereals (Solomon, 1946a) and hollow out rapeseed leaving only the seed coat (Anon, 1982), thus reducing germination and decreasing the value for seed and malting. Heavy infestations can have a strong smell which taints the grain, and makes it unpalatable to livestock and unsuitable for milling (Wilkin and Stables, 1985). Research has found reduced growth rates in pigs fed a diet heavily infested with mites (Wilkin and Thind, 1984). Mites in finished cereal products are also a cause of concern. A recent investigation found 22% of cereal based products contained at least one mite (Anon, 1996). Infestations may arise as a result of mites entering the product during any stage in its manufacture, transport and storage (Anon, 1996). There is also the potential risk to the health of workers involved in grain and flour handling by development of serious allergies following exposure to stored product pests (Stengard Hansen et al., 1996). Mites have also been implicated in the transmission of micro-organisms, especially fungi, with recent suggestions of a role as vectors of prions (Sigrianskii, 1940; Griffiths et al, 1959; Wisniewski et al., 1996).

There is a requirement for traded grain to be pest-free; EC regulation 689/92 states in Article 2, that to be accepted for intervention, 'cereals must be free from live pests (including mites) at every stage of their development' (Intervention Board, 1996). In the U.K. stored grain protection has relied heavily on bulk admixture with insecticides. A survey of commercial grain stores in 1988/89 found that 67.5% of the sites had used contact pesticides on all or part of the grain, with two thirds treating for prophylactic reasons (Prickett, 1991). The only contact pesticides approved by the Pesticides and Safety Directorate for the treatment of stored grain and oilseed are the organophosphorus (OP) compounds pirimiphos-methyl (Actellic), etrimfos (Satisfar) and chlorpyrifos-methyl (Reldan) (Whitehead, 1997). The survey of commercial stores found that pirimiphos-methyl, chlorpyrifos-methyl and etrimfos were used in 73%, 21% and 12% of sites that treated grain, respectively (Prickett, 1991).

However, none of the pesticides are now particularly effective against field strains of mites. Results from recent surveys have found widespread resistance in populations of *Acarus siro* to one or more of these compounds. Resistance to twice the recommended rate of pirimiphos-methyl was detected in 15% of *Acarus siro* strains from farm stores (1987), 71% of strains from commercial stores (1988/89), 91% from animal feed mills (1992) and 93% from oilseed stores (1995) (Starzewski, 1991; Prickett, 1994; Prickett, 1997). In the latter survey resistance to chlorpyrifos-methyl was also detected in 63% of stores but only in mites from stores where pirimiphos-methyl resistance was found (Prickett and Buckland, 1997). Resistance to etrimfos was also detected in two pirimiphos-methyl resistant strains (Prickett and Buckland, 1997). Unpublished data from the Central Science Laboratory by Binns and Buckland, found one *Acarus siro* population from a commercial store to be resistant to pirimiphos-methyl, etrimfos and chlorpyrifos-methyl. This indicates the presence of mites resistant to all available compounds used for treating stored grain. Collins and Binns (1996) also found that 8 mg kg $^{-1}$ of pirimiphos-methyl and etrimfos failed to provide complete mortality of a susceptible strain of *Acarus siro*, when exposed to treated oilseed rape for 14 days.

Thind et al. (1996) also detected cross-resistance to chlorpyrifos-methyl and etrimfos in a pirimiphos-methyl resistant field strain of *Lepidoglyphus destructor*. This suggests that resistance to OPs in this case, has conferred cross-resistance to all three compounds, and it is possible that a single mechanism is responsible (Thind et al., 1996). Therefore, the use of any one compound may lead to selection for resistance to the others.

The ability of some mites to survive treatments with OPs, is due to the development of resistance mechanisms. OPs have been found to inhibit acetylcholinesterase (AChE) in mites and ticks (Errampalli and Knowles, 1990; Roulston et al., 1966). When AChE is inactivated, degradation of the neurotransmitter, acetylcholine, is prevented and hyperexcitation of nerve tissues results in eventual exhaustion and tetany (Dekeyser and Downer, 1994). The first resistance mechanism to OPs developed by the acarina was based on a deviant AChE enzyme (Nolan and Roulston, 1979). In tetranychids, alterations in AChE cause a considerable decrease in the sensitivity to certain OPs (Helle, 1984). AChE insensitivity is the most common type of OP-resistance in the spider mite *Tetranychus urticae* (Helle, 1984). Roulston et al. (1966) also found that death in ticks treated with OPs was highly correlated with the inhibition of AChE. Another type of OP-resistance is based on a detoxication mechanism (Nolan and Roulston, 1979). In phytoseiid mites the most common OP resistance mechanism is based on detoxication by increased activity of glutathion-S-transferases (Helle, 1984).

As well as concerns regarding the development of resistant pests, the costs and consumer resistance to toxic chemicals in food, have led to increasing pressures for a reduction in pesticide use. The Maximum Residue Limits (MRLs) for OPs on stored grain have been reduced in the EU to 5 mg kg $^{-1}$ (S.I., 1994), which is close to the recommended application rates and there are pressures for further reductions.

Cooling and drying is also used to protect grain from pest infestation. By reducing the temperature of grain to below 5$^{o}$C mite breeding is prevented; and by drying grain to below 60% rh development can be inhibited (Cunnington, 1976). However, many sale contracts stipulate that the maximum moisture content of grain to be purchased is 15% (McLean, 1989). At 25$^{o}$C, a moisture content of 15%, depending on variety, is at equilibrium with about 70% rh (Henderson, 1987), which is within the range of conditions required by *Acarus siro, Lepidoglyphus destructor* and *Tyrophagus putrescentiae* to complete their development in the laboratory (Cunnington, 1976). Furthermore, during the winter, surface layers may reabsorb moisture from the atmosphere (Burrell and Havers, 1976) locally increasing product moisture content and enhancing the development of surface mite infestations (Armitage, 1984).

Surface grain cannot be kept cool or dry enough to limit mite numbers, so a surface pesticide treatment may be required.

The future of OPs looks bleak. There are strong pressures for their replacement, linked to their reputed involvement in Chronic Fatigue Syndrome (CFS) following use as sheep dips, the possible involvement in Gulf War Syndrome, a suggested link to spongiform encephalopathies by causing prion mutation, claims that they cause autoimmune diseases and continuing concerns over residues in foodstuffs (Vial et al., 1996; Wester et al., 1996; Stephens et al. 1996; Fairhall, 1996; Davies, 1997; Warden, 1996). However, there is also the need for high quality pest-free grain and together with suggestions that mites are implicated in the development of allergies and the spread of prions (Wisniewski et al, 1996), it is obvious that alternatives need to be sought.

There are a number of alternative compounds used effectively against acarine pests in field agriculture, veterinary and public health control programs, which may also prove effective against storage mites. These include insect growth regulators, inert dusts, botanicals, novel compounds and biological control agents. Each of these groups will be discussed including the advantages and disadvantages of their use in a storage environment, together with modes of action; with the aim of identifying potential alternatives that may warrant further investigation.

This review covers results of efficacy testing of a wide range of mite species, so it is probably in order to explain their relationship to the commonly-occurring grain storage species, as it is not unreasonable to expect that different orders or families of mites will have varying susceptibilities to toxicants. The main mite pests of stored products in the UK are all members of the order Astigmata, which rely solely on cutaneous respiration and are thus weakly sclerotised and vulnerable to desiccation. Other Astigmatid mites which are important in other contexts include the house dust mite, *Dermataphagoides* spp. and *Psoroptes* spp., the scab or mange mites. Another commonly occurring UK grain species is *Cheyletus eruditus*, a predatory mite of the order Prostigmata, which are a well-sclerotised group with tracheate systems which open via a pair of stigmata just beneath the mouthparts. Other well-studied Prostigmatid mites include *Tetranychus*, spider mite pests of plants, and *Varroa*, the bee parasite. The Mesostigmata are equally well-sclerotised mites with the stigmata opening mid-way along the body. There are several species of the genera *Haemogamasus*, *Blattisocius* and *Androlaelaps* which occur in association with stored products, in particular with processed cereals. *Amblyseius* sp., a predator of spider mites and *Dermanyssus* sp., the chicken or poultry red mite, are well-studied pests in other contexts. The ticks are external sucking parasites and form the order Metastigmata. They are also well-studied agricultural pests but there are no grain storage representatives. The Mesostigmata and the Metastigmata form the superorder Parasitiformes with the poorly-known unigeneric Tetrastigmata. The Astigmata and the Prostigmata form the superorder Acariformes with the Cryptostigmata, which are heavily-armoured soil dwellers, sometimes known as ‘beetle mites’.

## 2. Insect Growth Regulators (IGRs)

IGRs are compounds that disrupt the normal development of insects by mimicking the action of insect hormones and/or by interfering with hormone regulated processes.

They have been used in a variety of practical applications, such as for mosquito and cockroach control, and have shown to be effective against stored product insects (Loschiavo, 1976; Kramer et al., 1985 and Bengston, 1987).

The role of hormones in the regulation of development and reproduction in insects has been extensively studied. However, in acarines this regulation is less well understood, although it is believed that hormone-like substances are responsible (Soneshine, 1991). In ticks it has been suggested that the lateral segmental organs and the retrocerebral organ complex are possible endocrine glands (Binnington, 1986), however the nature of their secretions is unknown.

There are three main types of IGRs used in pest control : juvenile hormone analogues, moulting hormone analogues and chitin synthesis inhibitors.

**2.1 Juvenile Hormone Analogues (JHAs)**

In immature insects, JH affects development by suppressing the formation of adult characteristics. During diapause, development is inhibited by high levels of JH which are thought to inhibit the brain-prothoraic gland system (Eaton, 1985). In adults, JH stimulates ovarian development and yolk production by the fat body. Although no JH or JH-like substance has been identified in the Acari, many investigators support their existence and physiological role (Soneshine, 1991). Several JHAs appear to affect mite development by disrupting normal morphogenesis to the adult, resulting in abnormal mites, with combined juvenile and adult characteristics, that cannot feed or reproduce and eventually die; these JHAs also appear to affect embryonic development resulting in failure of egg hatch (Dekeyser and Downer, 1994). A wide range of JHAs have been tested for their toxic effects on a variety of acarine species, however, information on the effects on stored product mites is limited.

Czaja-Topinska et al. (1979) listed the effects of 56 JHAs on *Tyrophagus putrescentiae* (Astigmata) and reported a range of morphogenetic, ovicidal and sterilising effects. Although not all had significant action on the mites, effects ranged from reduced fecundity in treated females, to a significant increase in the number of larvae unable to complete development to the adult stage. The most sensitive stage to the JHAs was the egg stage from which larvae emerged but did not feed and soon died.

Thind and Edwards (1990) found that fenoxycarb, a carbamate insecticide with JH-like properties, stimulated egg production in *Acarus siro* (Astigmata). Incorporation into food at 10 mg kg $^{-1}$ and 100 mg kg $^{-1}$ increased egg production by 43% and 99% respectively; and total mite populations were significantly higher in the treated media than in controls. It was suggested the effects of fenoxycarb indicated that JH-like compounds may act as gonadotrophins. This gonodotropic effect has also been observed in *Tetranychus urticae* (Prostigmata) when treated with the JH mimic farnesol (Regev and Cone, 1976). Females treated topically with 200 ppm farnesol in 40% ethanol laid more eggs than females treated with only ethanol.

However, Buchi (1990) found that fenoxycarb reduced the number of adult *Acarus siro* (Astigmata) produced by between 37.1% and 94.9%, when added to food media at doses ranging from 0.5 ppm to 8 ppm. The numbers of larvae were also reduced by between 34.6% and 95.3%. Methoprene, another JHA, also reduced the numbers of adults by 53.4% to 88.1% and larvae by 53.6% to 83.6%, when added to food at doses of between 47.5 ppm and 190 ppm (Buchi, 1990).

Downing et al. (1990) evaluated the effects of fenoxycarb, methoprene and hydroprene, on adult and immature mites of *Dermatophagoides farinae* (Astigmata), when exposed to treated filter papers. Methoprene was most effective at suppressing population growth especially at concentrations of 1% (10 000 ppm) and 5% (50 000 ppm). Hydroprene also suppressed mite populations but not as consistently as methoprene. The numbers of mites exposed to fenoxycarb were only significantly different to the controls at a concentration of 5% after 30 days exposure, however, there was no difference after 90 days.

Downing et al. (1993) also assessed methoprene and hydroprene against adults and immature mites of *Dermatophagoides farinae* (Astigmata) by contact and diet incorporation assays. Both compounds significantly suppressed population growth, with methoprene more effective than hydroprene. When applied at 7.5%, the number of mites over a 13-week period, did not increase significantly compared to the controls, however, the average numbers of mites were significantly higher in the diet incorporated assays compared to the contact assays.

Saleh et al. (1976) found that altosid and altozar (methoprene) affected and retarded the development of tritonymphs of *Dermatophagoides farinae* (Astigmata) to adulthood, when exposed to treated food. There was a reduction of 26.7% to 75.5% with altosid and 28.3% to 91.7% with altozar when exposed to doses between 0.00016 ppm and 0.032 ppm.

El-Banhawy (1979) found that the eggs of the predatory mite *Amblyseius brazilli* (Mesostigmata) were more sensitive to methoprene than females, whereas females of its prey, *Tetranychus desertorum* (Prostigmata), were more sensitive than its eggs. Spraying eggs with methoprene resulted in dead larvae or larvae that died just after emergence. Feeding female *Amblyseius brazilli* on a diet incorporating methoprene caused a depression in reproduction and sterility.

Nelson and Show (1975) showed that compounds containing a cyclopropane moiety provide control of *Tetranychus urticae* (Prostigmata) in the field, having direct ovicidal effects and causing temporary sterilisation of adult females. Several chlorinated JHAs, including 3,3 dichloroallyloxy-alkyl 4-ethyl phenyl ethers, have also showed high ovicidal activity against *Tetranychus urticae* by preventing hatching of eggs (Piccardi et al., 1980). As well as ovicidal activity a moderate toxicity ($LD_{90}$ ~ 1 g $l^{-1}$) was observed. Some of the compounds also exhibited good ovicidal effectiveness against *Panonychus ulmi* (Prostigmata) (Piccardi et al., 1980). Also in ticks the effects of various JHAs included a reduction in hatchability, which was shown to be due to desiccation of treated eggs (Soloman and Evans, 1977).

Anti-juvenile hormones also have potential for mite control. They interfere with the synthesis or action of JH and result in precocious metamorphosis (Dekeyser and Downer, 1994). Chicken mites, *Dermanyssus gallinae* (Mesostigmata), produce fewer progeny when treated with the anti-juvenile hormone precocene II, and then recover following treatment with JH III (Oliver et al., 1985). Precocenes have been proposed as a means to control the bee mite, *Varroa jacobsoni* (Prostigmata) (Nemec et al., 1990). In the tick *Ornithodorus parkeri* (Metastigmata), precocene II blocked yolk production and subsequent embryogensis (Oliver et al., 1985). Leahy and Booth (1980) also found that precocene II induced sterility and inhibited ecdysis in argasid and ixodid ticks, although precocious metamorphosis was not observed.

### 2.2 Moulting hormone (ecdysone) analogues

Ecdysone is a steroidal hormone secreted by the prothoracic gland in insects, which after release is converted to 20-hydroxyecdysone, which induces moulting (ecdysis) and metamorphosis (Dekeyser and Downer, 1994). Ecdysone analogues may therefore be expected to promote a premature moult (Dekeyser and Downer, 1994). The hormone may also regulate yolk production (Hagdorn, 1983), diapause termination Wright, 1969), and sex pheromone production (Blomquist et al., 1984).

Although the moulting process in acarines has not been extensively studied, experimental work has indicated that ecdysteroid hormones are involved in the initiation and control of the moulting process in ticks (Soloman et al., 1982), with the moulting cycle appearing to resemble that in insects (Evans, 1992, Mango and Moreka, 1979). Dees et al. (1984) also confirmed the existence of ecdysteroid material in the ticks *Dermancentor variablis* (Metastigmata) and *Hyalomma dromedarii* (Metastigmata). Chambers et al (1996) found the highest titres of ecdysteroids in *Dermanyssus gallinae* (Mesostigmata) were present 24 hours after feeding. Sakagami et al. (1992) identified 2-deoxyecdysone (a precursor of ecdysone and 20-hydroxyecdysone in insects) from *Tyrophagus putrescentiae* (Astigamata) and suggested that the two ecdysteriods may exist in small amounts in the mite, although no biological activity was observed. Ellis and Obenchain (1984) suggest that cells associated with the fat body are the source of ecdysteroids in ticks. Whereas Oliver and Dotson (1993) suggest that the epidermis is the site of ecdysone production, and the fat body the site of 20-hydroxylation in the tick *Ornithodorus parkeri* (Metastigmata). As well as their role in ecdysis, ecdysteroids in ticks have also shown effects on salivary glands (Kaufman, 1991), sex pheromone production (Dees et al., 1984), oogenesis and oviposition (Diehl et al., 1986) and in termination of diapause (Wright, 1969).

Ecdysone analogues have not received as much attention from industry as have JHAs due to their complex structure and difficulty in penetrating the insect cuticle (Piccardi et al., 1980). Also the field use of compounds resembling steroid hormones, which have roles in man and higher animals, need extensive testing for possible side effects (Piccardi et al., 1980).

### 2.3 Chitin synthesis inhibitors

Chitin synthesis inhibitors are another class of IGR which although do not mimic insect hormones, prevent normal moulting of larvae. Although these compounds work by inhibiting chitin synthesis, the precise mechanism of this inhibition remains unclear (Oberlander et al., 1997).

The cuticle in mites serves as an anchorage for skeletal muscles, protects against physical damage, penetration of pathogens and desiccation (Dekeyser and Downer, 1994). The procuticle comprises mainly of chitin and protein (Dekeyser and Downer, 1994), with cuticular synthesis controlled by 20-hydroxyecdysone (Mothes-Wagner, 1986).

Benzoylphenylureas affect the immature stages of mites and also prevent hatching of eggs; they are also relatively non-toxic to mammals (Dekeyser and Downer, 1994). They interfere with the moulting process by inhibiting chitin incorporation into the mite cuticle, but their precise mode of action is unknown, although they do not appear to inhibit the chitin-synthesising enzyme, chitin synthetase (Dekeyser and Downer, 1994).

Lipa and Chmielewski (1976) mixed 'Dimilin' (diflubenzuron) with wheat germs at doses of 0.00001 to 100000 ppm and added known numbers of different developmental stages of *Tyrophagus putrescentiae* (Astigmata). The development time from egg to adult and the percentage of adult mites obtained were used as the criteria of effectiveness. No difference in the development time of mites was observed between those on food treated with low doses of Dimilin, and those on untreated food; there was also no difference in the percentage of adult mites obtained. It was suggested that the inactivity may be due to the lack of chitinous hypostracum in the cuticle of mites belonging to the family Acaridae. The hypostracum is analogous to the endocuticle of insects but since it is lacking in some acarina it may not be as important a structure in mites as in insects. Although there was a lack of effect on moulting of *Tyrophagus putrescentiae*, only 60-70% of larvae reached adulthood on food treated with 1000 ppm or more. It was suggested that mortality was caused by the mechanical effect of the Dimilin dust which covered the bodies.

Downing et al. (1990) found that diflubenzuron and triflumuron failed to suppress adults and immature mites of *Dermatophagoides farinae* (Astigmata) when exposed to treated filter papers. It was also suggested that the compounds may, in fact, stimulate reproduction in some cases.

Diflubenzuron has also been shown to be effective for the control of citrus rust mites (Phyllocoptruta oleivora) (Prostigmata) in citrus crops (Grosscurt, 1978); and other benzoylphenylureas e.g. flufenoxuron and flucloxuron are highly effective against a range of spider mites (Anderson et al., 1986; Grosscurt et al., 1988). Flufenoxuron is principally effective against immature stages of mites that are undergoing moults between instars, however, Anderson et al. (1986) demonstrated that adults of *Tetranychus urticae* (Prostigmata) treated with flufenoxuron laid sterile eggs. Perugia et al. (1986) and El-Atrouzy et al. (1989) found the flufenoxuron containing product 'Cascade', to be effective against *Panonychus ulmi*, *Panonychus citri* and *Tetranychus arabicus* (Prostigmata). El-Kady et al. (1986) found one-day old eggs of *Tetranychus urticae* to be more susceptible to 'Andalin' than 2 and 3-day old eggs. The larval stage also exhibited high sensitivity to the compound compared to the protonymphal stage.

El-Banhawy (1979) found Dimilin to have activity against eggs and females of *Amblyseius brazilli* (Mesostigmata) and *Tetranychus desertorum* (Prostigmata). The eggs of both species were more tolerant than the females, with the females of *Amblyseius brazilli* the most sensitive. Eggs treated with Dimilin failed to hatch and when incorporated into the diet of *Amblyseius brazilli* females, Dimilin caused a depression in reproduction and sterility.

Zaki et al. (1990) assessed 4 chitin synthesis inhibitors on mites inhabiting animal dung. In buffalo dung Dimilin was the most toxic compound to mites of the suborders Acaridida and Oribatida while XRD was most toxic to Gamasida and Actinedida. Dimilin was found to have low toxicity to the predacious mites of the Gamasida. In sheep dung, Dimilin appeared the most toxic to Gamasida and Oribatida, while IKI was the most toxic to Acaridida.

Mothes-Wagner (1984) demonstrated the effects of the chitin synthesis inhibitor complex nikkomycin on oogensis in *Tetranychus urticae* (Prostigmata). In addition to the primary action on chitin synthesis, there were secondary effects on reproduction. The effect on yolk synthesis in oocytes and egg shell synthesis, resulted in inhibition of egg deposition.

The advantages in using IGRs for pest control were originally thought to be their selectivity for insects and consequently low mammalian toxicity, as well as less likelihood for the development of resistance (Oberlander et al., 1997). However, insects have developed resistance to IGRs (Staal, 1975) with cross-resistance shown in OP-resistant strains of stored product insects (Bengston, 1987). Although there is the potential for the development of resistant strains, Bengston (1987) reports no incidences of field failures. IGRs also need to maintain their persistence in the field. To be effective the compounds must persist in the active form for as long as it takes most of the target population to pass through the critical sensitive stage. The effectiveness of IGRs in the field against stored product insects over prolonged periods (Bengston et al., 1990), suggests that biological activity can be maintained within the storage environment and may therefore be effective against mites. The specificity of IGRs against target pests also indicates that they could be used where biological control with parasites or predators are employed, as part of an integrated pest management program.

### 3. Inert Dusts

Inert dusts have been used traditionally as stored grain protectants (Golob and Webley, 1980), and there is increasing interest in their use as alternatives to chemical control measures. A number of studies on the efficacy of inert dusts against stored product insects have been reported (White et al., 1966; La Hue, 1970; Le Patourel, 1986; Desmarchelier and Dines, 1987; Aldryhim, 1990, 1993 and Subramanyam et al., 1994). They have proved effective as grain protectants (Desmarchelier and Dines, 1987), as structural treatments in empty stores (Bridgeman, 1994) and as surface treatments in conjunction with aeration (Nickson et al., 1994). Diatomaceous earths have been registered for storage use in USA, Canada, Australia, Japan, Indonesia and Saudi Arabia.

The products are based on inert materials such as silica gel or diatomaceous earth, and contain no insecticide or knock down agents. They are residue-free, effective against chemically resistant species, and are stable at high and low temperatures (McLaughlin, 1994). In contrast to chemical insecticides which induce rapid immobilisation and kill, the action of inert dusts is progressive, and extended exposure to treated grain for 20 days or longer, may reduce the doses of dusts required to kill an insect population (McLaughlin, 1994). Most products, at the appropriate concentration, provide protection for at least 12 months (McLaughlin, 1994).

Inert dusts act by physical means, with insect mortality thought to occur by desiccation as a result of the dust adsorbing lipids from the cuticle (Ebeling, 1971). By their sorptive ability the dusts damage the protective lipid layer and, depending on the relative humidity of the air, the insects lose body moisture through the damaged areas and eventually die (Ebeling, 1971). Insects may die from dehydration due to wicking of hydrocarbons from pores that help slow down water loss (Anon, 1997). In addition to the sorptive ability, some dusts also have abrasive properties (Korunic, 1997). They act through the digestive tract or may cause suffocation, these two effects often work in combination (Korunic, 1997). There are probably other unknown mechanisms (Quarles, 1992b).

Although inert dusts do not affect metabolic pathways by chemical action, they may be chemically active under some circumstances (Golob, 1997). It is also postulated that because the action of the dusts is not dependent on metabolic pathways, insects will not be selected genetically by the action of the dusts, so that physiological resistance is unlikely occur (Golob, 1997). However, it is still conceivable that a mutation conferring enhanced or altered lipid content could confer resistance. It may also be possible for pests to develop a behavioural response to the dust and avoid contact (Ebeling, 1971).

In ticks, lipids on the outer layer of the cuticle (epicuticle) result from secretions of the dermal gland, and are of primary importance in restricting water loss (Soneshine, 1991). Damage to the lipid layer by abrasion, adsorption or dissolution results in desiccation and eventual death. The lipid layer in ticks is very different from that found in insects (Soneshine, 1991). In *Dermacentor variabilis* (Metastigmata) neutral lipids and glycolipids comprise most of the lipid material, phospholipids and unknowns the remainder (Soneshine, 1991). The neutral lipid fraction was found to be a mixture of sterols, triacylglycerols, fatty acids, methyl esters and sterol esters; with triacylglycerols constituting the largest component of the fraction (Soneshine, 1991). Cholesterol and cholesteryl esters were most abundant as sterol/sterol esters. Cherry (1969) also identified cholesterol among the lipids of female *Boophilus microplus* (Metastigmata). Other important components are believed to be saturated long chain acids and alcohols, largely in the form of esters. Leal and Kuwahara (1991) classified astigmatid mites according to their cuticle wax components and identified 4 groups : 1) ester type, 2 ) insect hydrocarbon type, 3) medium sized hydrocarbon type and 4) all-compounds-from-food type. Three of the groups (1, 3 and 4) were completely different from those of insects.

Several studies have investigated the efficacy of inert dusts against parasitic mites. Tarshis (1964) found that the inert dust Dri-die eliminated the northern fowl mite (*Ornithonyssus sylvarium*) (Mesostigmata) from infested dwellings within 48 hours of application. Residual treatments of Dri-die have been shown to be effective against the snake mite (*Ophionyssus natricus*) (Mesostigmata) (Tarshis, 1960), the tropical rat mite (*Ornithonyssus bacoti*) (Mesostigmata) (Ebeling, 1960), the house mouse mite (*Allodermanyssus sanguineus*) (Mesostigmata) (Ebeling, 1960) and the chicken mite (*Dermanyssus gallinae*) (Mesostigmata) (Melicher and Willomitzer, 1967). Protect-

It, a new Canadian formulation of inert dust, is also recommended for use in the home and garden for mite and tick control (Korunic, 1996).

Knowledge of the effects of inert dusts against stored product mites is very limited. Cook and Armitage (1996) investigated the efficacy of 'Dryacide', applied at 1g/kg and 3 g/kg, against *Acarus siro* (Astigmata) and *Lepidoglyphus destructor* (Astigmata) at temperatures of 10, 17.5 and 25$^{o}$C; and moisture contents (mc) of 10, 12, 14 and 16%. No mites survived in treated or untreated grain at 10% mc and 12% mc due to the low relative humidity below their survival threshold. At 14% mc and 17.5$^{o}$C, both doses were completely effective at controlling both species. At 16% mc and 17.5$^{o}$C, 3g/kg was fully effective against *Acarus siro* but not against *Lepidoglyphus destructor*. At 16% mc, there was some effect against *Lepidoglyphus destructor* at 10$^{o}$C and 25$^{o}$C. However, at 25$^{o}$C a new generation of mites was observed indicating that the mites were able to reproduce with a lack of efficacy against different mite stages.

Further work by Cook and Armitage (1999) assessed the efficacy of 'Dryacide' on wheat against *Acarus siro* (Astigmata) and *Lepidoglyphus destructor* (Astigmata) at doses of 1, 3 and 5 g/kg, moisture contents (mc) of 14.5, 15.5 and 16.5% and temperatures of 10, 17.5 and 25$^{o}$C. After 28 days exposure at 10$^{o}$C, all doses were effective against *Acarus siro* (Astigmata) with the exception of 1 g/kg at 16.5% mc. Against *Lepidoglyphus destructor* (Astigmata) complete control only occurred at 3 g/kg and 14.5% mc and at 5 g/kg at 14.5% and 15.5% mc. At 17.5$^{o}$C the dust was fully effective against *Acarus siro* (Astigmata) at 3 and 5 g/kg but only at 14.5% mc, and fully effective against *Lepidoglyphus destructor* (Astigmata) at 5g/kg and 14.5% mc after 28 days. At 25$^{o}$C after 14 days exposure, *Acarus siro* (Astigmata) was completely controlled at 3 and 5 g/kg at 14.5% mc as was *Lepidoglyphus destructor* (Astigmata) after 28 days exposure. It was suggested that a dose of 3 g/kg may be an effective replacement for organophosphorus pesticide surface treatments in an integrated storage strategy based on grain cooling.

Fields and Timlick (1995) found that the product 'Super Insecolo' reduced predaceous and grain feeding mite species by over 98% when applied to wheat at 50 ppm. Tarshis (1960) found that 'SG67' (Dri-die 67) had no effect on the eggs of *Tyrophagus* sp. (Astigmata) when placed in dishes containing 20 mg of the dust. However, the larvae that emerged from the eggs were seen to be completely desiccated. Mixed stages were also seen to die within 3 hours when exposed to 50 mg of the dust with or without culture media. The dead dust-treated mites also appeared shrivelled and well desiccated.

The use of inert dusts as grain protectants may become increasingly more significant as alternatives to conventional chemicals are sought. Their advantages include low mammalian toxicity (e.g. for Insecto the acute oral rat LD50 > 5000 mg/kg; Subramanyam et al., 1994), cost effectiveness, persistence and lack of toxic residues on grain. Disadvantages have included the very high treatment rates required, which affect the physical properties of the grain, particularly bulk density, angle of repose and flow rate (Jackson and Webley, 1994). However, with some of the newer improved formulations, application rates have been reduced, e.g. 'Insecto' is effective (under certain temperatures and mc) against several stored-product beetles when applied at 0.5-1.0 g/kg grain (Subramanyam et al., 1994). Also due to the particle size of some dusts they are considered to be respirable and therefore represent a potential hazard to users (Golob, 1997). However, dusts of larger particle sizes e.g. 'Dryacide' and 'Insecto', are relatively safe to use with minimum protective equipment (dust mask). Inert dusts are also less effective at high relative humidities and moisture contents (Desmarchelier and Dines, 1987; Ebeling, 1971; Le Patourel, 1986), which is a major consideration for their use as grain protectants in UK. The higher doses that may be required for control may have an adverse effect on the physical properties of the grain. However, these disadvantages would be minimised if used as a surface treatment, in conjunction with cooling as part of an integrated storage strategy.

## 4. Botanicals

Plant parts and plant extracts have been, and still are used in many parts of the world to kill or repel insects (Secoy and Smith, 1983); with a resurgence of interest during recent years into the use of plant derived pesticides. Some 2400 plant species have been reported to have some pest control properties (Grainge and Ahmed, 1988). The most promising botanical pesticides for use at present and in the future, are derived from species of the families Meliaceae, Rutaceae, Asteraceae, Annonaceae, Labiatae and Canellaceae (Jacobson, 1989). Only 20 plant materials are authorised as plant protection products by the EC, and of these only three botanical insecticide materials, Nicotine, Pyrethrins and Rotenone, are approved by MAFF for use on farms in U.K. (Pinniger et al., 1996; Whitehead, 1997). A commercial product of neem, 'Margosan-O' is currently used on certain non-food crops and in nurseries in USA and Europe.

Plants are known to produce a range of secondary metabolites such as terpenoids, alkaloids, polyacetylenes, flavanoids and unusual amino acids and sugars (Benner, 1996), for defence from attack by pests. Plant extracts can possess multiple modes of action, making possible a wide spectrum of use, while retaining selective action within each pest class (Quarles, 1992a). Some may exhibit acute toxicity, while others have repellent, antifeedant or antioviposition effects, or inhibition of growth, development or reproduction (Coats et al., 1991).

The use of plant derived compounds against stored product insects has been reviewed by Jacobson (1984), Nawrot and Harmatha (1994), Golob and Webley (1980) and Saxena et al., (1989). However, information against stored product mites is again limited.

### 4.1 Azadirachtin (Neem)

One of the most extensively studied botanical sources of pesticidal compounds is *Azadirachta indica* A. Juss, the neem tree, which is native to arid areas of Asia and Africa. Extracts of various parts of the tree, but especially of the seeds, have been shown to possess pesticidal properties (Jacobson, 1989). Several tetranortriterpenoids have been isolated and identified, but the major entomologically active component is azadirachtin (Jacobson, 1989).

Azadirachtin is effective as a feeding deterrent, repellent, toxicant, sterilant and growth disruptant in insects at dosages as low as 0.1 ppm (Jacobson, 1989). Azadirachtin-containing insecticides act primarily as oral poisons, however, the mechanism of action is unclear. Some authors report a reduction in the ecdysone titre and/or the delay of ecdysone production (Schmutterer, 1988). An interference with the neuroendocrine system controlling ecdysone and juvenile hormone synthesis is suggested, but also inhibition of ecdysone release (Schmutterer, 1988).

Neem derivatives have been found effective against 123 species of insect pest, including those infesting stored products (Jacobson, 1986; Saxena et al., 1989; Golob and Webley, 1980). However, the efficacy against mite species appears to be concentrated on phytophagous pests. Dimetry et al. (1993), Sundaram and Sloane (1995) and Sanguanpong and Schmutterer (1992), showed that different formulations of azadirachtin, including 'Margosan-O' and 'Neem Azal-S', affected repellency, feeding rate, oviposition, reproduction and mortality of *Tetranychus urticae* (Prostigmata) females. A significant reduction in the number of eggs laid and hatching was also observed (Dimetry et al., 1993) as well as a reduction in the survival of nymphs hatching from treated eggs (Sanguanpong and Schmutterer, 1992). Mansour et al. (1993), found that 'Margosan-O' and 'Azatin' were not toxic to *Tetranychus cinnabarinus* (Prostigmata) although they were repellent. However, 'RD9-Repelin', which has a lower azadirachtin content, was highly toxic. It was suggested that formulations with higher oil contents were more acaricidally active than formulations with high azadirachtin contents (Mansour et al. 1993; Sanguanpong and Schmutterer, 1992).

Gulati (1998), however, assessed neem products for their effect on fecundity and development of *Tyrophagus putrescentiae* (Astigmata). The number of eggs laid was reduced from 147.6 in untreated wheat to 10.2, 21.4 and 27.6 on treatment with 0.4 % neem oil, neemark and neem cake respectively. Other stages showed a similar trend but the neem products were more deleterious to eggs and larvae than mature stages.

'Margosan-O' has also been shown to be effective at controlling tracheal mites in colonies of honey bees (Liu, 1995), with azadirachtin found to delay the onset of oviposition in ixodid ticks (Kaufman, 1988).

An important consideration in the use of neem extracts is the lack of adverse effects on predators. Dimetry et al. (1994) tested the effect of 'Neem Azal-S' and 'Margosan-O' on the predatory mites *Amblyseius barkeri* (Mesostigmata) and *Typhlodromus richteri* (Mesostigmata). Both formulations decreased egg laying and food consumption rate, however were considered safe against *Amblyseius barkeri*, with 'Margosan-O' harmless to *Typhlodromus richteri*. Mansour et al. (1993), also found 'Margosan-O', and 'Azatin' to be harmless to *Typhlodromus athiasae* (Mesostigmata).

Neem derivatives are considered safe to man and warm-blooded animals (Saxena et al., 1989). In sub-acute dermal toxicity tests no overt signs of toxicity or abnormal behaviour were observed in albino rats administered with a daily dose of 'Neemrich-100' (technical grade neem oil) at 200, 400 or 600 mg/kg (Qadri et al., 1984).

The residual effect on neem based products is restricted to a few days under field conditions, with temperature, ultraviolet light, pH, rainfall and other environmental factors having negative effects (Schmutterer, 1990). However, persistence may be extended in storage environments to provide adequate protection without the need for repeated applications (Saxena et al., 1989). There is also a delayed effect on insects, and although feeding continues, the amount of food is considerably reduced owing to secondary anitfeedant effects (Schmutterer, 1990). Because of a relatively weak contact effect in insects and the unique mode action on the hormonal system, neem products are quite selective. Attempts to select for resistance in the laboratory with the diamond back moth (*Plutella xylostella*) have been unsuccessful (Vollinger, 1987).

### 4.2 Other plant derived products

An array of plant derived products have been evaluated against storage and domestic mites, with varying degrees of efficacy.

The resin of the Peruvian tree *Myroxylon balsarum* var. *pereirae*, has been used in European medicine since 1853 (Kneist and Bischoff, 1995) against the itch mite, *Sarcoptes scabiei* (Astigmata), the cause scabies in man and mange in domestic and wild mammals (Kettle, 1990). Benzyl benzoate was discovered as the active principle and has been used in pure form since 1912 (Kneist and Bischoff, 1995); and was used during World War II against scabies. In literature from eastern Europe *Sarcoptes scabiei* is sometimes referred to as *Acarus siro* (Kettle, 1990). The reason for the confusion is that Linnaeus thought that the itch mite and the grain mite were identical, and in 1758 he described them as subspecies *scabiei* and *farinae* of *Acarus siro* (Kettle, 1990). Western workers retain *Acarus siro* for the free-living mite associated with grain, and transfer *scabiei* to *Sarcoptes*, while some eastern European workers retain *Acarus siro* for the mange mite (Kettle, 1990).

Benzyl benzoate has also been used as a spasmolytic, antiseptic, vasodilator, emetic, cathartic and amoebicide (Kneist and Bischoff, 1995). As well as its medical uses it has a broad application in the perfume, cosmetic and food industries (Kneist and Bischoff, 1995). Benzyl benzoate and benzyl benzoate containing products are considered relatively safe with no adverse effects when investigated for acute (estimated $LD_{50}$ > 2000 mg/kg in oral and dermal acute toxicity tests) and chronic toxicity, sensitivity and irritation as well as mutagenicity and teratogenicity (Kniest and Bischoff, 1995). Benzyl benzoate has FDA approval for food use, and the Council of Europe listed it with an ADI of 5 mg/kg (Kneist and Bischoff, 1995).

Benzyl benzoate also has acaricidal properties and has been proved effective against house dust mites when used to treat carpets, furnishings and upholstery in the houses of allergic patients (Bischoff et al., 1989; Schober et al., 1987). Kneist et al. (1992) found that ‘Acarosan’, an acaricide based on solidified benzyl benzoate, was 88% more effective than intensive cleaning, at killing house dust mites and removing allergens. Kneist et al. (1996) detailed the use of benzyl benzoate formulated as foam, dust, spray and cold wash treatments. The treatments were found to be effective on fibres, and retreatments were only recommended if allergens were detected.

Elixmann et al. (1991) treated carpets, stuffed furniture and mattresses with a single treatment of ‘Acarosan’. Only after 12 months was a slow recovery of *Dermatophagoides* sp. (Astigmata) observed. Even after 2 years the population only reached 10% of the original density. A slow recolonisation of the mattresses and upholstery by *Cheyletu*s sp. (Prostigmata) was observed, however, *Acarus* sp.

(Astigmata), *Lepidoglyphus* sp. (Astigmata), *Tyrophagus* sp. (Astigmata) or *Tarsonemus* sp. (Prostigmata) did not reappear after the treatment.

Koren (1995) found a reduction of 99% of *Dermatophagoides pteronyssinus* (Astigmata) in 8 weeks on mattresses treated with 'Acarosan', whereas 'Allersearch BT' (containing a benzyltannate complex and alcohol) reduced mite populations by 85%. After 24 weeks reductions of 24% and 78% were recorded for 'Allersearch BT' and 'Acarosan' respectively.

Kalpaklioglu et al. (1996) assessed the contact, short term persistence and residual effects of various concentrations (3.2, 0.8, 0.4, 0.2, 0.1 and 0.5%) of benzyl benzoate against *Dermatophagoides farinae* (Astigmata) when applied to the surface of wells. The wells consisted of approximately 1cm$^3$ space covered on one side with black filter paper and on the other side with a glass slide. All mites were killed within 15 minutes with 0.8% solution, 1 hour with 0.4% solution and 3 hours with 0.1%. Phenyl salicylate, which has a similar structure to benzyl benzoate, killed most of the mites within 1 hour, with 100% mortality after 3 hours at 0.4%.

Benzyl benzoate has also been shown to be highly toxic to the chigger mite, *Eutrombicula hirsti* (Prostigmata) when impregnated on cloth. When applied to filter papers $ED_{50}$ values of 1.42 mg/cm$^2$ were recorded, compared to 0.26 mg/cm$^2$ with DEET (Frances, 1988).

Although no resistance to benzyl benzoate has been reported in pyroglyphid mites (Astigmata) (Kalpaklioglu et al., 1996) or detected with 'Acarosan' after 10 years of use (Kneist - personal communication), in agricultural use, mites have developed resistance to this compound (Kalpaklioglu et al., 1996).

Perrucci (1995) found that the essential oils of 2 lavender species and of peppermint killed 100 % of *Tyrophagus longior* (Astigmata) by contact and inhalation action, when applied to petri dishes at 1.0 µl. Eucalyptus oil was the least active. Among the essential oil constituents, menthol killed all the mites at 0.25 µl by direct contact and at 6µl by inhalation. Linalool, fenchone and menthone also showed good acaricidal activity, with eucalyptol having the lowest activity.

Li et al. (1994) assessed the influence of temperature and modified atmosphere on the effectiveness of *Lavandula angustifolia* Mill. oil for controlling *Tyrophagus putrescentiae* (Astigmata). The major factors affecting mite mortality were : plant oil concentration > $CO_2$ concentration > $O_2$ concentration. Increasing the $CO_2$ level or lengthening fumigation time were found to enhance the effects of the plant fumigant against the mite.

Watanabe et al. (1989) found that 52 essential oils had acaricidal properties against *Dermatophagoides pteronyssinus* (Astigmata), *Dermatophagoides farinae* (Astigmata) and *Tyrophagus putrescentiae* (Astigmata). Of these almond bitter oil, caraway oil, dill oil, spearmint oil, ho oil and wintergreen oil were very effective, with $LD_{100}$ values ranging from 1µl to 5µl. Of the essential oil components, benzaldehyde, d-carvone, l-carvone, linalool and methyl salicylate showed very high activities. No correlation was observed between mite killing effect and inhibition of cholinesterase.

Kalpaklioglu et al. (1996) assessed the effectiveness of tea (*Thea sinensis*) leaf extract and the essential oils of eucalyptus and laurel against *Dermatophagoides farinae* (Astigmata). Laurel oil at 3.2% killed 77.5% of mites after 24 hours, however the eucalyptus oil was ineffective. The tea extract at 9.5% tannin killed 18.03% mites after 24 hours and 62.3% after 1 week.

Lozzia et al. (1994) evaluated 16 essential oils, at 1% in acetone, against *Dermatophagoides pteronyssinus* (Astigmata) and *Glycyphagus domesticus* (Astigmata). All the oils were ineffective against *Dermatophagoides pteronyssinus* and partially ineffective against *Glycyphagus domesticus*. With the latter species, eugenia and garlic produced mortalities of 41% and 36% respectively, after 24 hours. The remainder produced mortalities of < 29.5%.

Ottoboni et al. (1992) evaluated the efficacy of 10 essential oils on the mortality of *Dermatophagoides pteronyssinus* (Astigmata). The most effective were caraway, garlic, black pepper and Peru balsam. The main components of caraway oil, carvone and carvacrol, were also assessed. Carvone had similar effects as caraway oil while carvacrol was particularly effective after 30 minutes.

Czajkowska (1971) assessed the effect of 29 oils, 18 alkaloids and 11 glycosides on the length of development and mortality of *Acarus siro* (Astigmata), *Acarus farris* (Astigmata), *Tyrophagus putrescentiae* (Astigmata), *Rhizoglyphus echniopus* (Astigmata) and *Carpoglyphus lactis* (Astigmata). With *Acarus siro*, 100% mortality was achieved with 16.8 % parsley oil, 2% caffeine and ergotamine, 10% quininine and 40% arbutine. With *Tyrophagus putrescentiae*, 100% mortality was observed with 8.4% parsley oil, 0.6% colchicine, 8% caffeine, 40 % quinine and 0.4% digitoxine. Several oils were shown to have a stimulating effect on *Tyrophagus putrescentiae*. The alkaloids showed the strongest inhibitory effects on *Carpoglyphus lactis, Acarus siro* and *Tyrophagus putrescentiae*. Higher doses of some glycosides also inhibited the reproduction of *Acarus siro* and *Tyrophagus putrescentiae*.

Potts and Rodriguez (1978) incorporated spice oils into the diet of *Tyrophagus putrescentiae* (Astigmata) and assessed the effects on inhibition of growth and development. Sassafras and vaniprox were moderately inhibitory at a concentration of 0.001 %. The remainder of the oils influenced moderate to high inhibition at concentrations of 0.01% and 0.1 %. The order of inhibition from high to low, was oils of bitter almond < sage < onion < clove < oleoresin black pepper < mace < black pepper.

Rodriguez et al. (1979) investigated the possible effects of dried spices and flavouring oils on *Tyrophagus putrescentiae* (Astigmata). Whole and ground spices incorporated into pet foods at 2% produced kairomone (phagostimulatory) and allomone (deterrent) effects, when presented to mites in free-choice feeding tests. Curry powder, lemon/pepper seasoning, mace and sage showed particular allomone effects. All the flavouring oils mixed into a standard laboratory casein-wheat germ-agar diet or pet food produced some inhibition of mite growth at levels of 0.1% to 0.00001%. In the laboratory diet at 0.1%, total mite inhibition was produced by all oils except the citrus oils, whereas at 0.01%, the inhibition was less than 50% in most cases, with the exceptions of sage, sassafras, vaniprox and orange. In the pet food at 0.1%, inhibition ranged from 76% for oleoresin black pepper to 92% for clove; at 0.01% from 82.4%

for almond to 96% for sassafras; at 0.001% from 74.2% for oil of black pepper to 94.2% for sassafras.

Afifi and Hafez (1988) assessed the toxicity of different plant extracts against *Tyrophagus putrescentiae* (Astigmata) when mixed with flour. Caraway fruit extracts were more effective than fenugreek and lupin extracts. At 12 ppm, complete mortality was achieved after 48 and 72 hours with the caraway and fenugreek extracts respectively, with more than 72 hours required with the lupin extracts. At 100 ppm, complete mortality was achieved after 24 hours exposure to the fenugreek and caraway extracts, and after 48 hours with the lupin. The mites could also differentiate between treated and untreated flour, being attracted to the untreated.

Gulati and Mathur (1995) showed that different concentrations of powdered leaves of *Eucalyptus* and *Mentha* and rhizomes of *Curcuma* (tumeric) had pronounced effects on the fecundity and development of *Tyrophagus putrescentiae* (Astigmata) when applied to wheat flour. The *Eucalyptus* and *Mentha* powders were effective at concentrations from 100% to 5%, in decreasing mite fecundity and reducing the number of eggs to approximately 52 and 25 per female, for the respective materials (at 5%), compared to approximately 98 eggs in the controls. Rhizomes of *Curcuma* reduced egg laying to approximately 8 eggs per female even at 0.1%, and inhibited adult development at all concentrations. The materials were found to affect the eggs and larval stages more than the nymphs and adults. They were also more effective when mixed with whole grains compared to flour. No antifeedant effects were observed.

There is great potential in the use of botanical pesticides for stored product protection. Natural plant extracts are used in many developing countries to control insect pests in small-farm storages because economic conditions do not justify the use of conventional chemical protectants (Niber, 1994). However, before such products can be used commercially they must meet the following criteria : 1. safe for plant and animal life, 2. biodegradable (environmentally safe), 3. ready availability of the plant or capability for cultivation, 4. determination of isolation procedures of the active component or components from the plant (or of formulation of extracts prepared from plant parts) or 5. establishment of synthetic procedures for the active components (Jacobson, 1989). With the vast array of chemical compounds derived from plants and the many diverse behavioural and physiological effects induced, the possibility of pests developing resistance may be less likely. However, as with other pesticides, over or misuse may increase the possibility. The multiple modes of action possessed by some plant extracts, makes possible a wide spectrum of use, however the effects on beneficial organisms have to be considered. Unfortunately the use of some plant extracts that have proved effective against mites may be limited, due to tainting of grain and cereal products.

## 5. Pyrethroids

One of the best known plant-derived pesticides is pyrethrum, obtained from the flower petals of *Chrysanthemum* sp. such as *Chrysanthemum cinerariaefolium* (Grossman, 1993). However, although natural pyrethrum, which consists of six closely related compounds, is still used commercially, it has been largely superseded by the synthetic pyrethroids, which have greatly improved insecticidal properties and photostability.

Pyrethroids degrade slowly on wheat under normal conditions of storage with increased rate of loss at higher temperatures and moisture levels (Noble et al., 1982). Pyrethroids have shown to be effective against storage insects, and also demonstrate a negative temperature coefficient, i.e toxicity is greater at lower temperatures (Subramanyam and Cutkomp, 1987; Thaung and Collins, 1986; Longstaff and Desmarchelier, 1983; Watters et al., 1983). Pyrethroids act on the nerve membrane with synapses the initial target site (Narahashi, 1976). They act on the ion channels by keeping sodium channels open, resulting in a continuous slow depolarisation which eventually blocks nerve conduction and causes paralysis (Narahashi, 1976).

Several pyrethroids are effective against stored product mites. Cypermethrin applied to wheat at 2, 4 and 8 ppm, gave 5%, 45% and 66% mortality of *Acarus siro* (Astigmata), at the respective doses, after 4 weeks storage; compared to permethrin where 0%, 20% and 54% mortality was recorded (White, 1984). However, Wilkin et al. (1988) found cypermethrin to be ineffective against *Acarus siro* at doses ranging from 0.125 mg/kg to 2.0 mg/kg, 1 day, 2, 4 and 6 months after treatment. Against *Lepidoglyphus destructor* (Astigmata) all doses, except the lowest, produced ~ 75% mortality after 1 day and 2 months storage, 100% after 4 months and 75% after 6 months storage.

Wilkin and Hope (1973a) found that bioresmethrin applied to wheat at 2 ppm produced complete mortality of *Acarus siro* and *Lepidoglyphus destructor* (Astigmata) after 14-days exposure, with > 75 % mortality of *Tyrophagus putrescentiae* (Astigmata). However, when 20 ppm piperonyl butoxide was added to 2 ppm bioresmethrin, the mortality of *Lepidoglyphus destructor* decreased to > 75%. Both bioallethrin and pyrethrins, applied to wheat at 2 ppm, were ineffective against all three species. However, pyrethrins plus piperonyl butoxide (20 ppm) produced complete mortality of *Acarus siro* and >75% mortality of *Lepidoglyphus destructor.*

Stables (1984) found that bioresmethrin and piperonyl butoxide applied to wheat at 10 ppm + 10 ppm produced approximately 50% mortality of strains of *Tyrophagus longior, Tyrophagus palmarus* and *Tyrophagus putrescentiae* (Astigmata) after 7 days exposure, with mortality increasing to approximately 75% after 14 days exposure. Practical trials showed that bioresmethrin and piperonyl butoxide applied at 4 ppm + 20 ppm, 2 ppm + 20 ppm and 2 ppm + 2 ppm, controlled mites in the fabric of buildings and in stored grain, and also controlled lindane resistant strains (Wilkin, 1975a). Anderson and Wilkin (1984) found that although bioresmethrin and piperonyl butoxide applied at 0.5 %, killed large numbers of mites infesting cheeses, considerable survival was observed 3 weeks after treatment.

Chisaka et al. (1984) found phenothrin, fenopropathrin and permethrin to be the most effective pyrethroids against *Tyrophagus putrescentiae* (Astigmata) at 500 ppm. Mortalities of 99.7 %, 99.5% and 98% were recorded for the respective compounds 3 weeks after treatment. They also found that the pyrethroids were more effective against *Dermatophagoides farinae* (Mesostigmata) than *Tyrophagus putrescentiae.*

Lozzia et al. (1994) evaluated 'Pertrin E' (pure permethrin 5%), 'Pertrin S' (permethrin 5% with pyrethrum extract 3%) and 'Cipertrin T' (cypermethrin 2.5% with tetramethrin 1%) applied in an aqueous solution of 2%, against various mite species. All the pyrethroids showed fairly good acaricidal activity against the house and storage mites. 'Cipertrin' was significantly more efficacious and had a greater speed of action on all the species. Twenty four hours after treatment, mortalities of 22.3%, 44%, 83%, 64.1%, 97.6% and 96.2% were recorded respectively for *Dermatophagoides farinae, Dermatophagoides pteronyssinus, Acarus siro, Tyrophagus putrescentiae, Glycyphagus domesticus* and *Lepidoglyphus destructor* (Astigmata). The sensitivity to the 3 pyrethroids varied considerably from family to family increasing from Pyroglyphidae to Acaridae, Chortoglyphidae, Labidophoridae and Glycyphagidae.

Dekeyser and Downer (1994) suggest that bifenthrin is probably the most effective pyrethroid against mites. Binns (1989) found that emulsifiable concentrate and flowable concentrate formulations of bifenthrin, and a flowable concentrate of deltamethrin were more effective than pirimiphos-methyl against *Acarus siro* (Astigmata) at 17.5$^{o}$C and 75% rh. Both bifenthrin formulations produced 100 % and 75 % mortality with 1.0 and 0.5 mg/kg respectively after 1 day. At 4 weeks, 1.0 mg/kg of both formulations produced 50% mortality, however after 12 weeks neither were effective. Deltamethrin was least effective after 1 day, producing 25% and 75% mortality with 0.5 mg/kg and 1 mg/kg respectively. After 4 weeks deltamethrin was as effective as bifenthrin, however, after 12 weeks no mortality was recorded.

One disadvantage of using pyrethroids against some mite species is that at doses which fail to produce complete mortality, there is an increase in egg production, resulting in a sudden increase in mite numbers (B. Thind - personal communication).

## 6. Novel Compounds

A range of other novel compounds have been evaluated for use against stored product and domestic mite pests. These include compounds that act as chemosterilants, fatty acids, inorganic salts, avermectins and other medicinal products.

### 6.1 Chemosterilants

Chemosterilants are chemicals that arrest or adversely affect reproductive capacity and are therefore obvious candidates for use in pest control programs. Since 1960 interest in the potential of chemosterilants as a practical means of insect control has increased rapidly, being stimulated by the practical applications of gamma radiation for male sterilisation programmes, and the demonstration that insects could be sterilised chemically (Smith et al., 1964).

Chemosterilants may act in one of three principal ways. They may lead to failure to produce ova or sperm, death of the sperm and ova after they have already been produced, or they may produce multiple dominant lethal mutations or severely injure the genetic material in the sperm and ova (Smith et al., 1964). In the last case, although the sperm and ova remain alive, the zygotes, if formed, do not complete development into mature progeny (Smith et al., 1964). This type of action is desired because males so sterilised compete readily with normal males for females thereby satisfying the mating requirements of the females (Smith et al., 1964). If sterile and normal adults compete for mates, the result is a reduction in the number of progeny in the following $F_1$ generation (Hodges, 1984b). If further sterile adults are available to compete with the $F_1$ and subsequent generations, the pest population may be reduced still further to a negligible level (Hodges, 1984b). The speed at which this is achieved is dependent upon the ratio of sterile to normal adults (Hodges, 1984b).

Information on the effect of chemosterilants against stored product insects is limited (Brower and Jurd, 1980; Gangrade and Pant, 1970 a & b; Rizvi et al., 1980). However, against mites, Ignatowicz and co-workers have reported the effects of several potential chemosterilants against *Acarus siro* (Astigmata) and *Tyrophagus putrescentiae* (Astigmata). Under optimum conditions (15$^{o}$C and 90% rh) in the laboratory, *Acarus siro* can average an output of 435 eggs per female, with a maximum of 858 (Cunnington, 1985). However, in order to achieve maximum egg production repeated matings were required (Cunnington, 1985). Chemosterilants therefore offer an alternative approach for mite control, by preventing or reducing egg laying.

Ignatowicz (1982a) found that potassium iodide (KI) applied to wheat germ at concentrations higher than 0.25% prevented egg laying by *Acarus siro* (Astigmata). Egg production was also suppressed in females which were already laying eggs. Sterility was found to be permanent with females more susceptible than males. Exposure time of the mites to KI was more important than its concentration. It was thought that KI probably concentrates in the ovary of females and prevents formation of the eggs. The activity may be the result of a specific reaction with one or more essential components of cells of the tissue responsible for forming the ova.

Potassium iodate and tin iodide added to wheat germ at concentrations higher than 0.25% prevented most females of *Tyrophagus putrescentiae* (Astigmata) from laying eggs permanently (Ignatowicz, 1986). The compounds also suppressed production of eggs in females which were already laying eggs. However, the concentration of the iodine salts required to produce significant sterility were thought to be too high for direct economic use (Ignatowicz, 1986).

Ignatowicz and Boczek (1979) found that females of *Tyrophagus putrescentiae* (Astigmata) were more susceptible than the males to iodine salts (potassium iodide and iodate). They concluded that this may be due to the effect upon egg formation. Some females laid incompletely formed eggs, though, the viability of normal formed eggs exceeded 90%. Iodine salts induce sterility in *Tyrophagus putrescentiae* by reduction in egg production rather than by reduction in hatchability. The salts also inhibit egg yolk production during oogenesis causing incompletely developed eggs to form. It is suggested that this is caused when the iodine compounds bind proteins during egg formation and inhibit their activities.

Ignatowicz (1982b) found that boric acid applied to food at concentrations higher than 0.5%, was lethal to *Tyrophagus putrescentiae* (Astigmata), sodium borate, however, was less toxic. The concentrations of boric acid and sodium borate required for complete infecundity, and those that resulted in rapid death, were close. The lowered fecundity produced by sub-lethal concentrations of boric acid and sodium borate was temporary. Mites exposed to treated diets partially recovered their reproductive abilities after a return to an untreated food, therefore boric acid and sodium borate appeared to exhibit weak chemosterilant activity against *Tyrophagus putrescentiae*.

Ignatowicz (1983a) observed that sodium fluoride (NaF) was toxic to *Tyrophagus putrescentiae* (Astigmata) when added to food at doses higher than 1%. At a dose of 2%, 58% of females failed to produce eggs, however, at doses of 0.25% or 0.5% only 6-8% of females did not produce eggs. Exposure to NaF resulted in suppression of fecundity rather than acting as a chemosterilant. Egg laying was recovered to some extent after a return of the females to untreated food. The doses required to give complete sterilisation and high mortalities were very close.

Ignatowicz, (1987a) found that the fecundity and viability of eggs of *Tyrophagus putrescentiae* (Astigmata) and *Acarus siro* (Astigmata) decreased with increasing concentration of thiourea in food. However, mites recovered their reproductive potential to some extent when returned to untreated foods. Females treated with high concentrations of thiourea produced eggs only during the early period of oviposition after which they were infecund. At 1-2% thiourea caused both high mortality and sterility, and also suppressed postembryonic development. At 2%, longevity of mites was significantly affected. Females were more affected than males, with *Acarus siro* more susceptible than *Tyrophagus putrescentiae*.

5-fluorouracil (FU) causes sterility only in the females of *Tyrophagus putrescentiae* (Astigmata) and *Acarus siro* (Astigmata) (Ignatowicz, 1987b). At low concentrations in the diet (0.25%-0.5%), FU fed for one week caused partial sterility, with permanent sterility caused at high concentrations (2%). FU when ingested considerably reduced egg production and viability and suppressed egg production in mites already laying eggs. At concentrations higher than 0.5%, longevity was reduced in males and females. FU is an analogue of uracil and thymine and can be incorporated into RNA as an abnormal nucleotide. The main action is reported to be interference with the thymidylate synthetase system, causing a marked inhibition of DNA synthesis (Heidelberger et al., 1957).

Colchicine, when ingested, reduced fecundity and fertility and produced high mortalities of *Tyrophagus putrescentiae* (Astigmata) and *Acarus siro* (Astigmata) (Ignatowicz, 1987c). When fed at 0.01%, fecundity and fertility of *Acarus siro* were reduced by 24.4% and 63% respectively. Whereas the productivity of *Tyrophagus putrescentiae* was lowered by 89.2%. At 0.1%, colchicine was very toxic to the mites. Rapid death of males and females occurred after the 2nd or 3rd week of treatment. The concentrations required to effect complete sterility and rapid death were close.

Szlendak (1998) assessed the influence of folic acid, methionine and riboflavin on the fecundity and mortality of *Tyrophagus putrescentiae* (Astigmata). Low doses of riboflavin (0.5-2%) and folic acid (1%) applied to the diet were insufficient to cause mite sterility and even had a stimulating effect on fecundity. Only methionine at doses equal to or higher than 5% had a negative influence of fecundity and the population parameters.

The disadvantages of using chemosterilants are that their activity may not be restricted to the target pest and may therefore have adverse effects on non-target organisms. However, they could be used in combination with baits and attractants to ensure only the target pest is affected (Smith et al., 1964). Also chemosterilants are usually highly toxic and therefore should not come into contact with food (Hodges, 1984b). It is therefore unlikely that such compounds would ever be approved for use on stored grain or even for use as fabric treatments.

## 6.2 Fatty Acids

The use of fatty acids against stored product insects has been reported by House and Graham (1967), Williams and Hurlock (1969) and Simpson (1973).

The short chain fatty acids, propionic, butyric, caproic, caprylic and capric acids have been found to be effective in inhibiting growth and development of *Tyrophagus putrescentiae* (Astigmata) when incorporated into commercial dog food (Rodriguez, 1972). No eggs were oviposited in foods containing a 1% concentration of capric acid and 2% concentration of the other fatty acids. Propionic, caproic and capric acids retarded growth to the extent of a significant loss in weight when incorporated into an agar based diet at 0.05%. It was suggested that the routes of entry of fatty acids are by ingestion, adsorption through the integument and in some cases by vapour action (Rodriguez, 1972).

Simpson (1973) found that *Acarus siro* (Astigmata) did not survive in grain treated with 0.5-0.8% of propionic acid. Williams and Hurlock (1969) also found propionic acid to be an effective acaricide against *Acarus siro* and *Thyreophagus* sp. (Astigmata) when applied to barley. It was suggested that its effects on the mites may have been due to the lethal effect on the moulds on which the mites feed (Williams and Hurlock, 1969). However, it has also been found that the effect of propionic acid wears off with time (D M Armitage - personal communication).

Propionic acid also inhibits growth of mould, bacteria and yeasts and has been used to protect grain stored at high moisture contents (Simpson 1973). The quantity of acid used depends on the moisture content of the grain, but should not exceed 1.5% by weight if grain is for animal feed, or 0.3% if for human consumption (Simpson 1973). Grain so treated loses its germinative capacity and is unsuitable for seed or malting (Simpson 1973).

## 6.3 Inorganic Salts

Tricalcium phosphate is used as a supplemental mineral additive to processed foods and flour (Baker et al., 1976), however, several studies have shown toxic effects against stored product insects (Majumder and Bano, 1964; Highland, 1975; Baker et al., 1976 and Press et al., 1972). This food additive is unique in that it possesses both nutritional properties for vertebrates and toxicological properties towards insects (Baker et al., 1976). Baker et al. (1976) suggested that tricalcium phosphate acted in a similar way to that of inert dusts and that insect death was probably as a result of water loss. However the exact mechanisms of action are not fully understood (Boczek et al., 1984).

Boczek and Ignatowicz (1979) and Ignatowicz (1980) evaluated the effects of tricalcium phosphate, when mixed with food, on *Tyrophagus putrescentiae* (Astigmata). The fecundity, longevity and mortality of mites was only slightly affected when the salt was added at concentrations of 1-6%. A 50% reduction in fecundity was achieved at 18% in the diet, with an 84% reduction at 31.5%. Egg viability was only reduced at concentrations of 30 and 31.5%. Mortality during development and egg viability were practically unaffected until a concentration of 31.5%.

Boczek and Ignatowicz (1979) and Ignatowicz (1981) also showed that tricalcium phosphate had a very strong contact action causing 100% mortality of mites after 3-5 hours when in contact with 0.5-1 mm of the salt on wheat germ. During exposure the mites did not feed at all. The finely powdered salts were seen to attach to the mite body forming a thin layer, with dead mites seen to have stretched bodies and legs. It was suggested that the action of tricalcium phosphate was of a physical nature, similar to that of inert dusts, causing scratching and wax adsorption of the cuticle. Resistance of mites to tricalcium phosphate may also be less likely, because, as with inert dusts, the action is physical rather than chemical, and is therefore not dependent on metabolic pathways. Related species, *Tyrophagus casei, Tyrophagus similis, Tyrophagus palmarum, Tyrophagus longior, Tyrophagus neiswanderi, Acarus siro* and *Tyreophagus entomophagus* (Astigmata) were more sensitive to the contact action than *Tyrophagus putrescentiae* (Boczek and Ignatowicz, 1979; Ignatowicz, 1981).

Eggs, immobile larvae and nymphs were, however, tolerant to the salt and 100% emergence to next developmental stage was observed. It was suggested that the resistance of the inert stages may be due to the fact that the new cuticle originates under the old one and therefore moulting mites have two cuticular layers which may protect more from water loss (Ignatowicz, 1981). In addition, the immobile stages do not move and therefore may not pick up as many particles (Ignatowicz, 1981).

Caustic soda (NaOH) is also added to grain to improve nutritional qualities and is thought to provide a method of preserving damp grain (Thind, 1991). Thind (1991) found that caustic soda added to grain at 3%, 2% and 1% did not suppress populations of the wet grain mite *Caloglyphus berlesei* (Astigmata), with the exception of grain treated with 3% soda and incubated at 24% rh.

Ignatowicz (1981) also found that ferric phosphate rapidly killed various acarid mites when placed in contact with a 1mm layer of the salt. However, ferric phosphate can be harmful to man and domestic livestock.

Ignatowicz (1983b) and Boczek et al. (1984) evaluated the effects of different mineral salts as food additives, on the fecundity and egg viability of *Tyrophagus putrescentiae* (Astigmata). Different concentrations of the salts had varying effects on fecundity and egg viability, ranging from stimulation to total suppression. Boczek et al (1984) found the most suppressive salts were those containing the elements Ag, Ba, Cd, Co, Cu, F, I, Li, Mn, Mo and Zn. $Ag_2SO_4$ and $AgNO_3$ prevented egg laying at concentrations above 1% and reduced adult longevity above 3%. Some of the salts commonly used as food additives, including tricalcium phosphate, produced only slight to little effect on fecundity and egg viability.

## 6.4 Antibiotics

Avermectins are macrocyclic (large ring compounds usually containing repeating units) lactones isolated from the soil bacterium *Streptomyces avermitilis* (Lasota and Dybas, 1991). Avermectins are a family of broad-spectrum, antiparasitic agents.

Originally identified in screens of natural products with antihelmintic activity, these compounds have also demonstrated nematicidal, insecticidal and acaricidal activity (Lasota and Dybas, 1991).

There are 8 components ($A_{1a}$, $A_{1b}$, $B_{1a}$, $B_{1b}$, $A_{2a}$, $A_{2b}$, $B_{2a}$ and $B_{2b}$) of the avermectin complex, and of these avermectins $B_{1a}$ and $B_{2a}$ are the most promising candidates as agricultural pesticides (Putter et al., 1981). Avermectins are thought to act on the neurotransmitter GABA (4-aminobutyric acid). GABA is a major inhibitory neurotransmitter which activates a chloride ion channel in insect nervous systems, leading to rapid hyperpolarisation (Pitman, 1971). Avermectins are thought to act as agonists or stimulate GABA release or binding of GABA to its receptor, thereby increasing chloride-ion channel conductance and causing paralysis (Wright, 1986). GABA has been found in ticks and it is thought that it may play a similar role as in other arthropods (Binnington and Obenchain, 1982). Avermectins can also inhibit chitin synthesis (Calcott and Fatig III, 1984) and causes histopathological changes in the ovaries of fire ant queens (Glancy et al., 1982).

In ticks the mode of action of avermectins is unknown, however, it has been suggested that they may interfere with hormonal systems (Lundke and Kaufman, 1992). Abamectin is the common name assigned to avermectin $B_1$ and which has been used commercially as an acaricide. Ivermectin (synthetic abamectin) has been shown to suppress engorgement, moulting and reproduction (Campbell et al., 1983). In the ixodid tick *Amblyomma hebraeum* (Metastigmata), an avermectin analogue inhibited ovary maturation and yolk production and also lowered the haemolymph ecdysteroid concentration in engorged females (Lundke and Kaufman, 1992).

Abamectin has shown excellent initial and residual control of immature and adult motile mites, with a broad spectrum of activity against mites in the families Tetranychidae (Prostigmata), Eriophyidae (Prostigmata) and Tarsonemidae (Prostigmata), with $LC_{90}$ values in the range of 0.02-0.24 ppm (Lasota and Dybas, 1991). Also no cross resistance has been identified in resistant populations (Lasota and Dybas, 1991). It has also shown to be effective against ticks (Drummond and Miller, 1984) and cause mortality and reduce fecundity in *Psoroptes ovis* (Astigmata), the common scab mite (Guillot and Wright, 1984).

Against tetranychid spider mites, abamectin has shown a high contact activity against all motile stages, although no true ovicidal activity has been observed (Lasota and Dybas, 1991). Although avermectin has been found to be significantly more toxic to *Tetranychus urticae* (Prostigmata) than to the predacious mite *Metaseilus occidentalis* (Mesostigmata) (Hoy and Cave, 1985), its value as a selective acaricide is dependent on the rates applied. In the laboratory, avermectin $B_{1a}$ has demonstrated high toxicity to *Tetranychus urticae* and also against other tetranychids and eriophyids including the citrus rust mite (*Phyllocoptruta oleivora*) (Prostigmata), citrus red mite (*Panonychus citri*) (Prostigmata) and the strawberry spider mite (*Tetranychus turkestani*) (Prostigmata) (Putter et al., 1981). Laboratory evaluations suggest that avermectin kills *Tetranychus urticae* both by contact and oral action although it has a slow-acting effect (Putter et al., 1981).

Hoy and Conley (1987) reported no resistance to abamectin in field populations of *Tetranychus urticae* (Prostigmata) and *Tetranychus pacificus* (Prostigmata) selected up to 15 times. Also, no cross-resistance to the sulfite acaricide, propargite, and the organotins, cyhexatin and fenbutatin oxide, was detected (Hoy and Conley, 1987). However, Campos et al. (1995, 1996) detected resistance to abamectin in the laboratory, with field populations of *Tetranychus urticae*, although no field failures had been reported. Roush and Wright (1986) reported a lack of abamectin cross-resistance in houseflies to various insecticides (diazinon, dieldrin, DDT, permethrin); Scott (1989) reported conflicting results of polygenic cross-resistance to abamectin in two pyrethroid resistant strains of houseflies.

Milbemycins belong to the same class of 16-membered macrolides as avermectins and were isolated from *Streptomyces hygroscopicus* f. sp. *aureolacriosus* (Takiguchi et al., 1980). A mixture of mibemycin $A_3$ and $A_4$ (milbemectin) has been practically used for the control of *Tetranychidae* on tea trees and egg plants since 1990 (Yamaguchi, 1996). Toxicity to mammals is low, but to fish is high (Yamaguchi, 1996)

Polynactins are macrotetrolide antibiotics produced by *Streptomyces aureus* strain S-3466 (Ando et al., 1971). They have been found effective against the carmine spider mite (*Tetranychus cinnabarinus*) (Prostigmata), two spotted spider mite (*Tetranychus urticae*) (Prostigmata) and European red mite (*Panonychus ulmi*) (Prostigmata) (Yamaguchi, 1996). Polynactins show least activity by direct contact with mites in a dry state, however, they exert marked miticidal activity under wet conditions, therefore, water is an essential factor for their activity (Yamaguchi, 1996). It is suggested that polynactins cause leakage of a basic cation, such as $K^+$, through the lipid layer of the membrane in mitochondria (Ando et al., 1974). Acute toxicity to mice and rats is very low, though, toxicity to fish is high (Yamaguchi, 1996).

Natamycin is used in drugs and alimentary products as a broad spectrum fungicide. In addition to fungicidal activity, natamycin also has acaricidal properties. Saint Georges-Gridelet (1987) found that natamycin prevented larval hatching, but not embryonic development, in the house dust mite *Dermatophagoides pteronyssinus* (Astigmata). Schober et al. (1987) found that a 3% natamycin solution induced no significant acaricidal effects on 10 house dust mites (*Dermatophagoides farinae*) (Astigmata) soaked in the solution. However, a 10% solution added to food, significantly reduced the numbers of mites after 5 weeks. Koren (1995) found a 40% reduction in *Dermatophagoides pteronyssinus* (Astigmata) when 'Tymasil' (3.33% w/v natamycin and 0.02% w/v benzalkonium chloride) was applied to mattresses. Bronswijk et al. (1987) also detected some effect on mite population growth after treatment with 'Tymasil'. It is suggested that the acaricidal mechanism of natamycin is a nutrient effect, caused by suppressing the fungi that predigest essential lipid components for the mites (Koren, 1995). Although storage mites can survive on fungal diets when a grain store is empty of commodities, it is not their ideal diet. However, it is suggested that the fungi may act as substrate enhancers for the mites (Parkinson et al., 1991a and b).

Boczek and Czajkowska (1968) assessed 22 antimicrobial agents and 13 antibiotics mixed with diet against *Carpoglyphus lactis* (Astigmata), *Acarus siro* (Astigmata) and *Tyrophagus putrescentiae* (Astigmata). *Acarus siro* was more sensitive to the antimicrobials and less sensitive to the antibiotics than *Carpoglyphus lactis*. *Tyrophagus putrescentiae* was the most tolerant to the additives studied. Some antimicrobials not recommended as additives to food products (borax, boric acid, hexamethylen, tetramine and salicylic acid), inhibited the development of the mites. Compounds like potassium sorbate, benzoic acid and calcium propionate, which were considered as suitable food additives, also had a distinct inhibitory effect. As no symbiotic organisms were found in the mite bodies, it was suggested that the compounds had a direct effect on the mites, through their metabolic processes.

Fusariotoxin, isolated from the microfungus *Fusarium sporotrichilla*, showed toxicity to *Tetranychus telarius* (Prostigmata), at concentrations of 0.01, 0.02 and 0.03% (Chhabra, 1971). Sterility was also induced in treated females (Chhabra, 1971). After 10 days the populations of mites on treated plants remained at 28.8, 19.2 and 15.9 % of the control levels for the respective concentrations, whereas after 15 days the populations were 59.6, 18 and 9.1% respectively (Chhabra, 1971).

Benzyl alcohol is a pharmaceutic aid with bacteriostatic properties and is also considered non-toxic to man at low concentrations (oral $LD_{50}$ : 500 mg/kg) (Castagnoli et al, 1996). Its acaricidal effects were evaluated against *Dermatophagoides pteronyssinus* (Astigmata), *Dermatophagoides farinae* (Astigmata), *Euroglyphus maynei* (Astigmata) and *Tyrophagus putrescentiae* (Astigmata) (Castagnoli et al., 1996). Eggs and motile stages were sprayed with 3.25% water solution of benzyl alcohol. Immediately after spraying all mites appeared immobilised. The highest mortalities of the motile stages were recorded after 24 hours : 83% for *Euroglyphus maynei* and *Dermatophagoides farinae*, 84% for *Dermatophagoides pteronyssinus* and 87% for *Tyrophagus putrescentiae*. The effectiveness of benzyl alcohol was lower against eggs with 56% hatchability of *Tyrophagus putrescentiae* and 25-30% of the other species. Benzyl alcohol also appeared to have a repellent effect.

## 7. Biological Control

The term 'biological control' is used here in referring to the use of biological agents, i.e. predators, parasites and pathogens, as a method of reducing pest damage. In a broader sense 'biological control' is sometimes used to include the manipulation of other biotic factors of the pest's life system, such as its reproductive processes, its behaviour, the quality of its food etc. (Evans, 1984).

In the past there have been several constraints placed on the potential use and success of biological control in the stored grain ecosystem. 1) The low level of pest infestation tolerable to grain exporters and consumers makes it very difficult for pest populations to be sufficiently abundant and persistent for biological agents to establish themselves and become effective (Snelson, 1987). 2) Natural enemies are slow to overtake and suppress pest populations and only appear in significant numbers after a product has become heavily infested and severe damage has already occurred (Arbogast, 1984). However, deliberate releases of natural enemies during the early stages of infestation may overcome this problem (Arbogast, 1984). 3) The introduction of predators and parasites would increase contamination of the product as they themselves would be regarded as contaminants (Snelson, 1987). However, the presence of contaminants is of little concern in some products, such as seed grain, animal feed and raw commodities that will be cleaned during processing (Arbogast, 1984). 4) The physical conditions, especially low moisture, of well-stored grain are not those which favour the spread of pathogens (Snelson, 1987).

The use of biological agents for the control of stored product pests has been reviewed by Evans (1984), Arbogast (1984) and Wilkin and Cox (1996).

### 7.1 Parasites, Parasitoids and Predators

A parasite is an organism that benefits by feeding upon, and securing shelter or transportation from one or more organisms, its hosts, which although adversely affected, may not necessarily be killed (Evans, 1984). In contrast, a parasitoid invariably kills its host and requires only one host for development (Evans, 1984). A predator is an organism that feeds on one or more host but seldom obtains shelter or transport from them. They also always kill their hosts (Evans, 1984).

The abundance or density of a parasite or predator generally depends on the abundance of the host, that is, it is density-dependent. Characteristically, the relative numbers of the host and parasite oscillate somewhat out of phase, an increase in the host population is followed by a corresponding, but delayed, increase in the parasite or predator population (Evans, 1984). The reduced host population cannot support the increased parasite population which gradually wanes and allows the pest population to recover and another oscillation to start (Evans, 1984).

#### 7.1.1 Parasitoids

Although predators are the regulating agents of some pest insects, the majority of success in biocontrol of insects have involved parasitoids especially parasitic Hymenoptera (McMurty, 1984). Many species of parasitic Hymenoptera are known to attack stored grain insects. Examples include *Anisopteromalus calandrae*, *Choetospila elegans*, *Bracon hebetor* and *Venturia canescens* and *Trichogramma* sp. The two former species attack a range of hosts, including species of *Sitophilus*, whereas the latter are parasitoids of phycitid moths (Arbogast, 1984). The ability of parasitoids to suppress pest populations has been investigated by Cline et al. (1986), Flinn et al., (1996) and Brower and Press (1990).

However, against pest acarines, predators rather than parasitoids are the most prevalent natural enemies (McMurty, 1984). Several parasitic wasps have evolved to be predators rather than parasitoids in that they make use of more than one host to complete their development (Quicke, 1997). *Aprostocetus eriophyes*, a member of the Eulophidae family (subfamily Tetrastichinae), is known to be predaceous on gall-mites having has as its hosts the eriophyid mites *Acaria rudis*, *Ceciodophyopsis ribis*, *Phytoptus avellanae* and *Pytoptus tiliae* (Goulet and Huber, 1993; Graham, 1987).

Parasitic Hymenoptera are only known to act as parasitoids on one group of acarines, namely the ticks (McMurty, 1984). The two major parasitoids of ticks that have been widely studied are *Ixodiphagus texanus* and *Ixodiphagus hookeri*, which have been reported to infect various species of ticks in different parts of the World (Kaaya, 1992). Mwangi et al. (1994 and 1997) and Kaaya (1992) describe the use of *Ixodiphagus hookeri* against *Amblyomma variegatum* (Metastigmata). Over a period of 1 year, 150,000 parasitoids were released and the numbers of ticks decreased from

44 to 2 ticks per animal, with numbers remaining low up to 1 year after parasitoid release, although the numbers of the brown ear tick, *Rhiciephalus appendiculatus* (Metastigmata), increased (Mwangi et al., 1997).

### 7.1.2 Nematodes

Nematode parasitism of insects can result in sterility, reduced fecundity, delayed development, aberrant behaviour and very often rapid host mortality (Kaya, 1985). Nematodes from the families Steinernematidae and Heterorhabditidae are used commercially against insect pests in agriculture and in households. The infective nematodes (third stage juveniles) are attracted to the their host by a chemotactic response (Gaugler et al., 1980) and after penetrating, release symbiotic bacteria into the haemolymph, which proliferate and kill the host by septicemia, mostly within 24-48 hours (Gaugler, 1987). The nematodes feed on the bacteria, produce two to three generations within the host, then as the host's resources are depleted, a new generation of infective juveniles is formed, which emerge in search of new hosts (Gaugler, 1987). As the bacterium kills the host very quickly, its nematode partner need not adapt to any specific host life cycle (Gaugler, 1987). Consequently various insect species including many of economic importance are susceptible to these nematodes. However, so far, their effect on most beneficial insects has been found to be negligible (Kaya, 1985). Despite the large insect host range, the nematode-bacterium complex represents no hazard to mammals (Gaugler and Boush, 1979).

Entomophageous nematodes have been evaluated for their ability to parasitize ticks (Mwangi et al., 1991). Mauleon et al. (1993) found the ticks *Boophilus microplus* (Metastigmata) and *Amblyomma variegatum* (Metastigmata) to be tolerant to 17 isolates of nematodes whereas *Boophilus annulatus* (Metastigmata) was susceptible to all of them. Samish and Glazer (1991) found that strains of *Steinerma carpocapsae* and *Heterorhabditis bacteriphora* killed *Boophilus annulatus* very efficiently. All fully engorged ticks were killed, under laboratory conditions, within 4 days post infestation. However, although the ticks were highly susceptible to nematode infection, they did not appear to be suitable hosts for the development and reproduction of the steinernematid nematodes (Glazer and Samish, 1993). Samish et al. (1996) found that different tick stages varied considerably in their susceptibility to a strain of *Steinerma carpocapsae*, with fed adults being the most susceptible. Haq (1991) found parasitic nematodes belonging to the genus *Rhabditis* had potential in controlling the oribatid mite *Galumna triquetra* (Cryptostigmata), a known intermediary host of cestode parasites of cattle and sheep.

The only known parasitic nematodes for which mites are the definitive host, belong to the family Allantonematidae in the order Tylenchida (Poinar and Poinar, 1998). However, cases of this association are extremely rare, with hosts including gamasid mites (Poinar and Poinar, 1998). The infective free-living stage of these mite nematodes is a fertilised female which penetrates the host cuticle and enters the body cavity (Poinar and Poinar, 1998). This stage matures into a parasitic female that produces eggs and juveniles in her body (Poinar and Poinar, 1998). After the first or second moult the juveniles leave the female through the vulva and enter the host's body cavity (Poinar and Poinar, 1998). After another moult the juveniles exit from the mite and develop to maturity in the environment (Poinar and Poinar, 1998).

Typically allantonematid nematodes do not kill their host outright but slowly debilitate it by partially or completely sterilising it or shortening its life cycle (Poinar and Poinar, 1998). It is thought that in nature, these nematodes may play an important role in the regulation of gamasid mites (Poinar and Poinar, 1998). However, because these obligate parasites have not been cultured on artificial media, their usefulness as biological control agents is limited (Poinar and Poinar, 1998).

There is no information on the ability of nematodes to parasitize storage mites, though, several species of storage insect have shown to be susceptible (Morris, 1985, Pezowicz and Sandner, 1983). However, the use of nematodes in stored grain protection is thought to be extremely unlikely as nematodes usually require a wet environment to infect their hosts (Cox and Wilkin, 1996). The provision of adequate conditions for free living and infective phases in relatively dry stored grains would therefore be difficult (Evans, 1984).

### 7.1.3 Predators

The predatory mite, *Cheyletus eruditus* (Prostigmata), is commonly found in temperate grain stores where it feeds on larvae of moths and beetles, pscocids as well as mites of the families Acaridae and Glycyphagidae (Astigmata) (mainly *Acarus siro, Tyrophagus putrescentiae* and *Lepidoglyphus destructor*) (Coombs and Woodroffe, 1968 and Zdarkova, 1986). The characteristics possessed by *Cheyletus eruditus* that make it an efficient mite predator include not having a rapid rate of development or a high capacity for prey consumption (Beer and Dailey, 1956; Solomon, 1969). Fecundity is fairly high - up to 129 eggs per female (Summers and Witt, 1972), it reproduces parthogenetically with almost all progeny being female (Solomon, 1961; Hughes, 1976). It has a high ability to survive and find prey at low densities and cannibalism is a major factor enabling it to survive if there are no prey (McMurty, 1984). As the predator becomes more numerous and the prey scarcer, it spends more time reacting to its own species (Solomon, 1969; Burnett, 1977).

*Cheyletus eruditus* (Prostigmata) is commonly used for biological control of stored food mites in the Czech Republic (Zdarkova, 1994). The predators are supplied in bags containing 2000-3000 specimens and are applied at a rate of one pack per 100 $m^2$ of floor area in an empty store (Zdarkova and Horak, 1990).

Pulpan and Verner (1965) reported successful results on the introduction of the predacious mites to grain. They recommended that the predators be introduced in ratios of between 1 : 100 and 1 : 1000 (predator : prey) by sprinkling over the grain surface between April and June before pest mites become too abundant (i.e. over 1000 mites/kg of grain). The predators can also be added to non infested grain as a preventative measure in the ratio of 1 predator/100kg grain.

Solomon (1946b) and Norris (1958) reported the efficacy of *Cheyletus eruditus* (Prostigmata) at controlling *Acarus siro* (Astigmata) and *Lepidoglyphus destructor* (Astigmata) in bulk grain; and Coombs and Woodroffe (1968) achieved similar results with *Acarus farris* (Astigmata). Zdarkova and Horak (1990) markedly reduced the numbers of acarid mites in empty stores by releasing 2000-3000 predators per 100$m^2$. Application of the biopreparation ‘Cheyletin’ reduced the population density of Astigmatid mites by 8.4 times (Zdarkova, 1991).

However, *Cheyletus eruditus* (Prostigmata) is seldom effective enough to be a reliable controlling agent, due in part, to its inability to breed at relatively low temperatures that still permit its host to multiply (Evans, 1984). Solomon (1969) found the predator to be much less effective at low temperatures and found at 10$^{o}$C the longest survival of *Cheyletus* (young adults and large nymphs) was 20 days. However, Zdarkova and Pulpan (1973) describe the successful storage of mites at 0 ± 1$^{o}$C for up to 3 months.

*Blattisocius dentriticus* (Mesostigmata) is another mite predator and attacks both *Acarus siro* (Astigmata) and *Tyrophagus putrescentiae* (Astigmata) (Burnett, 1977). It feeds primarily on larvae and protonymphs, although it attempts to attack all stages of the prey (Burnett, 1964). Eggs 2-4 days old and larger stages of prey were largely immune to attack by the predator (Burnett, 1964). Burnett (1977) found that *Blattisocius dentriticus* could not coexist in the system with *Cheyletus eruditus* and *Acarus siro*. *Cheyletus eruditus* (Prostigmata) apparently outcompetes other species (McMurty, 1984). *Androlaelaps casalis* (Mesostigmata) also predates on acarid mites in stored cereals, and has also been found to feed on the predator *Blattisocius keegani* (Mesostigmata) and the young larvae of the confused flour beetle, *Tribolium confusum* (Barker, 1968).

A major limitation to the use of predatory mites in stored grain in the U.K. is that they themselves are considered as a contaminant and therefore require controlling as much as the pest species. Zdarkova (1994) showed that *Cheyletus eruditus* (Prostigmata) was less susceptible to organophosphorus pesticides than its mite prey and that different field strains had different tolerances to the pesticides (Zdarkova, 1997). However, they may have some practical use in the disinfestation of empty stores.

### 7.2 Pathogens

The successful use of diseases for biological control depends on the biology and characteristics of both host and microorganism (Maddox, 1975). The host must occupy habitats suitable for the introduction of the pathogen and have habits that facilitate its transmission and spread (Evans, 1984). As diseases act in a density dependent manner, pests that aggregate or are abundant are more likely to be suitable for biocontrol with pathogens than those that are well dispersed and seldom attain high density (Evans, 1984).

The success of any pathogen infection is dependent on the ability to overcome the host's immune system. As in insects, the immune response to pathogens and foreign bodies, is mediated in ticks by the haemocytes, which constitute up to 50-60% of the haemolymph (Soneshine, 1991). In insects, the mechanisms of immune response for which haemocytes are responsible include phagocytosis, nodule formation, encapsulation and haemocytic killing mechanisms (Salt, 1970). Ticks have at least 5 classes of haemocytes : 1. prohemocytes, 2. plasmatocytes, 3. granulocytes, 4. sphenulocytes and 5. oenocytoids, although the knowledge of the function of the cells is incomplete (Binnington and Obenchain, 1982). Prohemocytes are believed to be the essential stem cell from which the other types of haemocyte are formed (Soneshine, 1991). Plasmatocytes are believed to serve as phagocytes perhaps as the major phagocytic cell type in ticks (Soneshine, 1991). It is suggested that plasmatocytes exhibit non-specific responses to corpuscular antigens and inert particles as well as to foreign cells (Soneshine, 1991). In insects, plasmatocytes are usually the most numerous haemocyte type (Lackie, 1988). Granulocytes also have a role in phagocytosis as well as serving to encapsulate foreign material (Soneshine, 1991).

In ticks, as in many other arthropods, a well developed capability for phagocytising microbes and other foreign organisms appears to exist (Soneshine, 1991). Particles too large to be phagocytised may be encapsulated with layers of haemocytes removing them from contact with the tissues and rendering them harmless (Soneshine, 1991). Encapsulation in the tick *Dermacentor variabilis* (Metastigmata) was shown to be similar to that in insects having two phases, a recognition phase and a capsule-forming phase (Eggenberger et al. 1990). In insects, the first phase of recognition is mediated by granulocytes which lyse within minutes of implantation of the foreign body, producing a modified clot and probably releasing some chemotactic factor which initiates the second phase (Schmit and Ratcliffe, 1977). During the capsule-forming phase, plasmatocytes are specifically attracted to the implant forming the capsule. Necrotic haemocytes and coagulated haemolymph form a layer at the surface of the implants thus forming the capsule and removing the foreign body from contact with the host's tissues (Schmit and Ratcliffe, 1977).

Ticks also produce the protein, lysozyme, which acts as an antibacterial and antirickettsial agent in tick-microbe interactions (Podboronov, 1991). Lectins are sugar-binding proteins or glycoproteins (Schooneveld and Veenstra, 1988). It is not known whether serum lectins of arthropods are present in the plasma as well as being released from haemocytes, and there is no clear understanding of their role (Lackie, 1988). However, it seems that lectins are important molecules in reactions of recognition and defence of invertebrates (Renwrantz, 1983). It is thought that they play a role in the destruction non-self objects as well as in transmission of pathogens by invertebrate vectors (Grubhoffer et al., 1991). They can react either with self glyconjugates or with glycosylated components of viral, bacterial or protozoan pathogens (Grubhoffer et al., 1991). Grubhoffer et al. (1991) found that lectins in the haemolymph of four tick species, *Ixodes ricinus* (Metastigmata), *Ornithodorus tartakovskyi* (Metastigmata), *Ornithodorus papillipes* (Metastigmata) and *Argas polonicus* (Metastigmata), had agglutination activities, and supposed that the lectins played an important role in the processes of self-non-self recognition and defence reaction.

Stored product insects are subject to infections by numerous pathogenic organisms including protozoa, bacteria, fungi and viruses (Arbogast, 1984). Transmission of pathogens may occur in several ways : by larvae feeding on cadavers of infected larvae or adults, by the consumption of infected stored food, during mating or from the female to its progeny during oviposition (Kellen and Lindgren, 1971; Schwalbe et al. 1974; Shapas et al., 1977). Pathogens may be more suitable for use in stores than in open fields where they run the risk of being inactivated by high temperatures and excessive exposure to ultra violet light (Hodges, 1984a). However, the only diseases likely to be effective in the management of stored product pests are those that have hardy, long lived dormant stages capable of infecting in dry conditions (Hodges, 1984a).

Insect pathogens may be admixed with bulk grain or disseminated by insects lured to a source of pathogens by an attractant; however, due to their specific nature they may have to be integrated with other control procedures for the protection against a wide range of pests (Hodges, 1984a). Control of stored product mites by pathogens appears to have received very little attention compared to stored product insects. The number of micro-organisms that are known to be pathogenic to mites, may not exceed 30 species.

### 7.2.1 Bacteria

One of the most extensively studied insect-pathogenic bacteria is *Bacillus thuringiensis* (Berliner), a gram positive rod-shaped bacterium that forms toxic protein crystals during sporulation, which when ingested are transformed to an active diamond shaped toxin (Arbogast, 1984). The toxins generate pores in the midgut epithelial cell membrane leading to osmotic imbalance, causing the cells to swell and lyse (Mummigatti et al., 1994). Damage to the cells of the insect midgut cause inhibition of feeding which leads to eventual death (Evans, 1984).

*Bacillus thuringiensis* is a complex species existing in numerous different varieties which are pathogenic to different types of insects (Drummond and Pinnock, 1994). These varieties produce different amounts of several types of toxins, the two most commonly used as pesticides are the crystal (δ-endotoxin) proteins and the thuringiensin (β-exotoxin) nucleotide (Drummond and Pinnock, 1994). Most varieties of *Bacillus thuringiensis* are toxic to larvae of certain members of the Lepidoptera (Pathotype-A), some are toxic to Diptera (Pathotype-B) or Coleoptera (Pathotype-C) (Mummigatti et al. 1994). The use of *Bacillus thuringiensis* against stored product beetles and moths has been discussed by McGaughey, 1980; McGaughey and Dicke, 1980; Subramanyam and Cutkomp, 1985 and Mummigatti et al. 1996. However, there are no references on the use of *Bacillus thuringiensis* against stored product mites.

To date, no mite-specific bacteria have been isolated (Poinar and Poinar, 1998). However, Hoy and Ouyang, (1987) found that the β-exotoxin of *Bacillus thuringiensis* (thuringiensin) was toxic to adult female *Tetranychus pacificus* (Prostigmata) and the predatory mite, *Metaseiulus occidentalis* (Mesostigmata), within 48-96 hours of treatment at 0.125-fold to 4-fold the proposed field rate. Egg production by treated females declined, treated larvae were unable to develop to adults and treated eggs hatched but larvae failed to develop. Thuringiensin was found to be effective but unselective at the rates used. Royalty et al. (1990) found immature instars of *Tetranychus urticae* (Prostigmata) were more susceptible to thuringiensin than the adults, although activity was shown to be slow acting initially. However, it was suggested that the high activity against immature stages and sublethal effects, such as reduction in fecundity and feeding inhibition, may offset the initial low mortality observed.

Neal et al. (1987) also found the β-exotoxin of *Bacillus thuringiensis* to be highly effective against *Tetranychus urticae* (Prostigmata) and *Tetranychus cinnabarinus* (Prostigmata) at 0.18% a.i. Autoclaved *Bacillus thuringiensis* var. *thuringiensis* supernatent killed all spider mites (*Tetranychus urticae*) (Prostigmata) within 35 days when sprayed on bean leaves (Kreig, 1968) and application of β-exotoxin at 1.0 %

dilution to orange tree leaves killed citrus red mites (*Panonychus citri*) (Prostigmata) including eggs and immature stages (Hall et al., 1971).

Chapman and Hoy (1991) tested *Bacillus thuringiensis* var. *tenebrionis* wettable powders in the laboratory, to determine the relative toxicity against *Tetranychus urticae* (Prostigmata) and its predator *Metaseiulus occidentalis* (Mesostigmata). At 0.1 x, 0.5 x and 1.0 x the recommended field rate (0.9 kg ai /75.7 l / acre), little mortality of female *Tetranychus urticae* was achieved (90.0 ± 14.2 % survival at field rate), however, mortality was greater with *Metaseiulus occidentalis* (26.0 ± 23.4 % survival at field rate). Neither predator nor spider mite eggs treated at the field rate suffered depression in hatch rate. However, only 65% of the resulting immature predators reached adulthood compared to 88.8% of immature spider mites.

Hassanain et al. (1997) evaluated 3 varieties of *Bacillus thuringiensis* (*kurstaki, israeliensis* and *thuringiensis*) against the soft tick *Argas persicus* (Metastigmata) and the hard tick *Hyalomma dromedarii* (Metastigmata). *Argas persicus* died within 36 hours to 5 days post treatment, with *Hyalomma dromedarii* dying between 48 hours and 10 days, depending on dose. $LC_{50}$ values indicated that 'Dipel 2x' (var. *kurstaki*) was the most potent, followed by 'Vectobac' (var. *israeliensis*) and 'HD703' (var. *thuringiensis*). The soft tick was more affected than the hard tick. Eggs were mostly affected at 16 and 25 days after deposition for the soft and hard ticks respectively.

Advantages in the use of *Bacillus thuringiensis* in stored product environments is that the bacteria are invisible, they can be cultured in artificial media, the toxin protein crystals rapidly halt feeding, they are easy to use in the dry conditions of stores and the crystals are not toxic to humans (Cox and Wilkin, 1996). However, use of the β-exotoxin may be limited due to its unselectivity and concerns about toxicity to bees, poultry and mammals (Keller and Langenbruch, 1993). Another major limitation in the use of *Bacillus thuringiensis* is the development of resistance to the toxins. High levels of resistance to *Bacillus thuringiensis* δ-endotoxins have been demonstrated in at least 6 insect species (McGaughey, 1994a), including field populations of the diamond back moth (*Plutella xylostella*) (Iqbal et al., 1996), and laboratory populations of the Indian meal moth (*Plodia interpunctella*) and almond moth (*Ephestia cautella*) (McGaughey and Beeman, 1988), with high levels of resistance after only a few generations (McGaughey, 1985). The mechanism of resistance involves a change in the binding affinity of the insect's gut membrane that is specific for the particular toxin type (McGaughey, 1994b). Changes in fitness have also been observed in resistant pests (Jonhson and McGaughey, 1996).

### 7.2.2 Viruses

Viral infections have been identified in almost 200 insect species, mostly Lepidoptera and also in arachnids, with the main types of virus being polyhedroses and granuloses (Evans, 1984). Important viruses of stored product insects include granuloses of *Plodia interpunctella* (PGV) and *Ephestia cautella* (CGV) and a nuclear-polyhedrosis of *Ephestia cautella* (Arbogast, 1984). McGaughey (1975a) used surface applications of a granulosis virus to control *Ephestia cautella* in bins of stored maize and wheat; and Vail et al. (1991) demonstrated high levels of control of *Plodia interpunctella* with a granulosis virus in the laboratory.

Few viral diseases of mites are known, with no records of viral infections in stored product mites. All mite viruses belong to the non-inclusion group (Lipa, 1971). The earliest record of a viral infection of a mite was made by Muma (1955) who observed specimens showing low activity and diarrhoea in a population of red citrus mites (*Panonychus citri*) (Prostigmata). The symptoms and signs of disease in *Panonychus citri* are complex and characteristic (Lipa, 1971). The most striking symptoms are complete immobilisation with stiffened legs (Lipa, 1971). Diarrhoea frequently occurs and dead mites are often fixed to the feeding surface by faeces (Lipa, 1971). A characteristic feature are numerous birefringent crystals which accumulate in the haemocoel of infected mites (Smith and Cressman, 1962). The presence of crystals is a sign of infection, and is apparently a result of metabolic disturbances (Lipa, 1971). The virus is not transmitted transovarially (Lipa, 1971), but by contact with the virus in faeces and debris on the plant surface (Reed et al., 1975). Smith et al. (1959) showed that the infection could be easily transmitted to healthy populations. Shaw et al. (1967) found no differences in the consumption of diseased or healthy mites by predators and no apparent reduction in longevity or activity of the predator. Reed (1981) discusses the practical considerations for the use of the virus.

Another viral disease of mites was identified in the European red mite (*Panonychus ulmi*) (Prostigmata) by Steinhaus (1959). Diseased mites are seen to be dark red with black spots (Lipa, 1971). They gradually become immobile and cannot return to a normal position when put on their backs (Lipa, 1971). Mites in the last stage of the disease exhibit diarrhoea and become fixed to the surface by faecal material (Lipa, 1971).

Boudreaux (1959) described virus-like substances transmitted to the offspring of *Tetranychus cinnabarinus* (Prostigmata) and *Tetranychus urticae* (Prostigmata). These substances were responsible for the absence of certain chemosensory setae on the foreleg of females, but otherwise seemed to have no detectable effect on the host organism.

Resistance to viral infections may also occur, for example, resistance to a granulosis virus in *Plodia interpunctella* resulted in reduced egg viability, larvae that took longer to develop and increased pupal weight (Boots and Begon, 1993).

### 7.2.3 Protozoa

Protozoa are single-celled microscopic organisms. Those that are insect pathogens belong to the Class Sporozoa (Orders Gregarinida, Coccidia and Microsporidia) and are common and widespread among natural populations of stored product insects (Arbogast, 1984). The pathogens usually enter the host insect by ingestion of spores (Cox and Wilkin, 1996). The Gregarinida and Coccidia are parasites of the fat body, malpighian tubules or gut of the insect and are characterised by a resistant spore-like or encysted stage (Cox and Wilkin, 1996). The microsporidia *Nosema* spp. are found in the fat body and can be spread by ingestion of spores, during mating or through the ovaries (Khan and Selman, 1989).

The important sporozoans infecting stored product beetles are *Adelina tribolii*, *Farinocystis tribolii*, *Lymphotropha tribolii*, *Nosema whitei*, *Nosema oryzaephili*, *Nosema weiseri*, *Nosema ptinidorium* and *Nosema transitellae* (Khan and Selman, 1989). Khan and Selman (1989) review the potential of *Nosema* spp. as control agents for stored product beetles. Amongst the most promising would seem to be *Nosema whitei* for *Tribolium castaneum* and *Tribolium confusum*, *Nosema whitei* and *Nosema oryzaephili* for *Oryzaephilus surinamensis* (Burges et al., 1971) and *Mattesia trogodermae* for *Trogoderma* spp (Schwalbe et al. 1974; Shapas et al., 1977). *Nosema plodei* has also been isolated for *Plodia interpunctella* (Kellen and Lindgren, 1971), but its use as a control agent has not been studied.

Lipa (1971) reviews the little information that is known regarding protozoan diseases of mites. Weiser (1956) reported the first case of microsporidosis in mites and described *Nosema steinhausi* from *Tyrophagus putrescentiae* (Astigmata). Three microsporidian species have been found in mass rearings of the predatory mites *Amblyseius cucumeris* (Mesostigmata) and *Amblyseius barkeri* (Mesostigmata) (Beerling et al., 1993). One species was detected in predatory mites as well as in the stored product mites *Acarus siro* (Astigmata) and *Tyrophagus putrescentiae* (Astigmata), which are the prey in mass rearings of *Amblyseius cucumeris* (Mesostigmata) and *Amblyseius barkeri* (Mesostigmata) (Beerling and van der Geest, 1991). This microsporidium has small oblong spores (1.8µm x 0.9µm) and belongs to the Pleistophoridae family (Beerling et al., 1993). A second species which occurs regularly in mass rearings has small oval spores (1.4µm x 0.8µm) and has been found exclusively in prey mites (Beerling et al, 1993). A third species occurs occasionally in mass rearings and has large spores (2.6µm x 1.3µm), and is only found in prey mites and is thought to be *Nosema steinhausi* (Beerling et al., 1993). Bjørnson et al. (1996) described the pathology of *Microsporidium phytoseiuli* infecting the predatory mite *Phytoseiulus persimilis* (Mesostigmata).

Rehacek et al. (1996) isolated *Nosema slovaca* from a male *Dermacentor reticulatus* (Metastigmata) tick, which was seen to cause acute infection in partly engorged females, with death occurring within 5-15 days post-infection. *Nosema parkeri* has also been detected in a laboratory colony of the tick *Ornithodorus parkeri* (Metastigmata) (Krinsky, 1977).

Protozoa have received relatively little attention as biocontrol agents mainly because they cause chronic rather than acute infections (Evans, 1984). Protozoa are not as fast acting as some bacteria, viruses or chemical pesticides. However, the reproduction of the host is often curtailed with resultant long-term reduction of the host population rather than a high initial mortality (Evans, 1984). Another disadvantage is the difficulty in production (Khan and Selman, 1989). However, their debilitating sub-lethal effects on the host, the large numbers of species found, their frequently high prevalence and array of transmission routes are advantageous for use in inoculative augmentation (Khan and Selman, 1989). The use of protozoa in controlling storage pests may therefore be most beneficial in long-term storage since they produce slow-acting chronic infections and also show promise when integrated into existing control systems (Khan and Selman, 1989).

### 7.2.4 Fungi

The performance of entomaphagous fungi is often erratic due to the necessity for suitable temperature and humidity conditions to prevail before the spores can germinate and infect their hosts (Evans, 1984). In addition, because of the densitydependence of the pathogens, adequate levels of control are only achieved when the pest has done considerable damage (Evans, 1984).

Two species of entomopathogenic fungi, *Beauveria bassiana* and *Metarrhizium anisopliae*, have been evaluated against stored product insects (Ferron and Robert, 1975; Searle and Doberski, 1984; Hluchy and Saminakov, 1989; Thuy et al., 1994). Infection is initiated by germination of a microscopic spore which penetrates the insect cuticle and spreads through the haemocoel and fills the insect's body with fungal mycelia (Cox and Wilkin, 1996). Hyphae then grow out of the insect and produce spores which disperse to infect other insects (Cox and Wilkin, 1996).

Fungi of the Order Entomophthorales appear to be important pathogens of mites, with species recorded on mites belonging to the genus *Neozygites* (*Entomophthora*) (Lipa, 1971). It is suggested that *Neozygites* spp. play a major role in the regulation of natural spider mite populations (Carner and Canerday, 1968). *Neozygites floridana* and *Neozygites fresenii* have been found to significantly reduce field populations of *Tetranychus urticae* and *Tetranychus cinnabarinus* (Prostigmata) (Carner and Canerday, 1968; Smitley et al., 1986; Mietkiewski et al., 1993); and Fisher (1951) and Muma (1955) reported *Neozygites* sp. on *Panonychus citri* (Prostigmata) . A number of species of *Triplosporium* are also known to parasitise mites, mainly tetranychids (Prostigmata) and their relatives (O'Connor, 1984).

*Hirsutella thompsonii*, a Basidiomycete, is a specific fungal pathogen of Acarina, particularly eriophyids and tetranychid mites (McCoy, 1981). Fisher (1950) found a significant reduction in the citrus rust mite (*Phyllocoptruta oleivora*) (Prostigmata) by *Hirsutella thompsonii* in a grapefruit grove. Gerson et al. (1979) found *Hirsutella thompsonii* to be highly pathogenic to the carmine spider mite (*Tetranychus cinnabarinus*) (Prostigmata) and the oriental spider mite (*Eutetranychus orientalis*) (Prostigmata). The fungus penetrated the mites' integument mainly through the legs and formed hyphal bodies in chains in the haemolymph. Hyphae on which the spores were produced began to emerge through the genital and anal apertures and then all over the body. Representatives of other mite Orders namely the Astigmata (*Rhizoglyphus robini, Tyrophagus palmarium*), Cryptostigmata (*Nothrus biciliatus*), Mesostigmata (*Parasitus timetonum*) and Metastigmata (*Argas persicus*) were not infected by *Hirsutella thompsonii*, suggesting a specificity for the Prostigmata. Although another Prostigmatid mite, the mycophagous *Tarsoneumus* sp., was not affected by the fungus.

The effects of *Hirsutella thompsonii* and *Verticillium lecanii* have been evaluated against storage mites (Anon, 1983). Doses of 1 x $10^7$ spores/ml of *Hirsutella thompsonii* and 1.4 x $10^7$ spores/ml of *Verticillium lecanii* on a mixed culture of Astigmatid mites : *Acarus siro, Acarus chaetoxysilos, Acarus farris, Lepidoglyphus destructor* and *Tyrophagus putrescentiae*, had no detectable effect on any of the mite species (Anon, 1983).

In the U.S. *Hirsutella thompsonii* was registered for control of eriophyid mites on citrus and turf, however, production was terminated in 1985 due to many factors including the sensitivity of the infective unit to available water, fungal survival in the field which influenced its reliability and limitations in storage and transportation to maintain fungal stability (McCoy et al., 1988). The use of the fungus is limited as it is most effective during hot and humid periods when mite populations peak and is best suited to tropical and subtropical regions and in glasshouses with special humidity regimes (McCoy et al., 1988).

Of the infections caused by the Fungi Imperfecti, the most important species are those belonging to the genera *Penicillium*, *Aspergillus* and *Beauveria*, which have been found infecting mites and ticks (Lipa, 1971; Cerepanova, 1964). Leatherdale (1965) also found that *Paecilomyces eriophytis* was infective to *Panonychus ulmi* (Prostigmata).

Mycotoxins are the natural but highly toxic by-products of growth and development of several species of fungi, and some of these, produced by species of *Penicillium* and *Fusarium*, are toxic to storage pests (Cox and Wilkin, 1996). However, they can also be acutely toxic or carcinogenic to higher animals (Rodriguez et al., 1984). Rodriguez et al (1984) challenged *Tyrophagus putrescentiae* (Astigmata) and *Caloglyphus rodriguezi* (Astigmata) with species of *Pencillium, Aspergillus, Fusarium* and *Calviceps purpurea*. *Tyrophagus putrescentiae* egg hatch was generally not adversely affected by contact with the fungi, however, larvae were sensitive to the toxic effect of some fungi. *Tyrophagus putrescentiae* females did not develop or lay eggs when cultured with *Aspergillus versicolor, Aspergillus flavus, Aspergillus nidulans* and *Pencillium islandicum*; and their longevity was significantly shortened. *Aspergillus ochraceus, Aspergillus versicolor, Aspergillus nidulans, Fusarium poae* and *Pencillium rubrum* were most toxic to *Tyrophagus putrescentiae*. Rodriguez et al. (1980) found that certain mycotoxins (aflatoxin, citrinin, ochratoxin and penicillic acid) exhibited mild acute toxicity in the developing generation of *Tyrophagus putrescentiae* that were lethal to the $F_1$ progeny.

Solomon et al. (1964) found that the xerophilic fungi *Sporendonema* (*Wallemia*) *sebi* and *Aspergillus restrictus* caused premature failure of *Acarus siro* (Astigmata) populations when incorporated into the food supply. Reduced reproduction, high mortality and retarded development were observed. Parkinson et al. (1991a and b) found that *Acarus siro*, *Lepidoglyphus destructor* (Astigmata) and *Tyrophagus longior* (Astigmata) always produced fewer eggs on fungal diets of *Cladosporium cladosporiodes, Aspergillus repens, Aspergillus ruber* and *Pencillium cyclopium*. The fungal diets usually shortened male lives. No mycotoxin activity was detected in the experiment, although, the fungal species used have been found to produce mycotoxins (Parkinson, 1991a).

The main advantages in the use of pathogens are that they are fairly host specific and therefore harmless to non-target organisms, they are compatible with, and even at times, synergistic with pesticides, they are relatively easy and cheap to culture and are not associated with rapidly developing mechanisms for host resistance (Evans, 1984). The main disadvantages are their requirement for careful timing of applications relative to incubation periods, their specificity, which may limit their effectiveness where a complex of pest species are involved, and the maintenance of virulence and infectivity with may depend greatly on favourable climatic conditions (Evans, 1984). Due to the rather specific nature of pathogens, the future for biocontrol agents may therefore lie in an integrated approach by combining with other control measures, to achieve protection to a wide range of pests. The effect of fumigation on *Bacillus thuringiensis* and granulosis virus have been investigated (Hodges, 1984a). *Bacillus* *thuringiensis* is compatible with several grain fumigants (McGaughey, 1975b). Methyl bromide inactivated granulosis virus and affected *Bacillus thuringiensis* so that when cultured it failed to produce colonies, however, the bacteria was still potent against *Plodia interpunctella* (Hodges, 1984a).

## 8. Alternatives to admixture treatments

Although this review has concentrated on alternatives to OPs for admixture treatments, it is important to mention other alternative methods that have been assessed for the protection of stored commodities from mite infestation.

### 8.1 Hygiene

Cleaning bin surfaces by steam treatments or vacuuming and removing residues from harbourages will reduce the initial mite inoculum and it is undoubtedly good practise from the point of view of insect control. However, no quantitative studies on the benefits of this approach have been carried out and it is likely only to delay the onset of mite infestation, since these animals are carried by air currents throughout the environment.

### 8.2 Cooling

Most Astigmatid storage mites cannot breed below 5°C (Cunnington, 1984) but can survive lengthy periods of sub-zero exposure (Sinha, 1964). Nevertheless, Armitage (1980, 1984) showed that mite populations in cooled rapeseed were many times less numerous than in uncooled seed, and Hurlock et al. (1980 ) achieved a delay in mite increase in cooled bins of wheat. However, temperatures are not well-controlled at the grain surface which is where mites increase in the winter when atmospheric moisture is absorbed by surface grain (Burrell and Havers, 1976). Therefore a surface pesticide treatment is required (Armitage et al., 1994).

### 8.3 Heating

Although no practical attempt has apparently been made to use heat as a disinfestation measure against mites, most die rapidly above 30°C. *Acarus siro* will only survive 1-4 days at 30°C, 10 hours at 35°C and 35 minutes at 40°C (Cunnington, 1984).

### 8.4 Drying

Mites cannot complete their development below 65-70% r.h., depending on the temperature, which is in equilibrium with a wheat moisture content of about 15% (Henderson, 1987). This can be achieved by 'continuous driers' when the grain is dried at high temperature in a short time, which allows no increase of mites during the process. However, approximately half of the grain is dried 'on-floor' using ambient air or air heated by a few degrees Celsius, which may take several weeks. This allows mites to increase in undried, surface layers of grain as the 'drying front' passes slowly through the bulk. Armitage et al. (1982, 1984 ) and Armitage (1986) showed that mites increase rapidly during drying and that numbers then decline more gently, at a rate that depends on the final moisture content achieved.

## 8.5 Cleaning and Conveying

Burrell and Havers (1973, 1975) showed mite numbers in cleaned barley were 46 times lower than in uncleaned grain, while Armitage (1994) showed that mite populations in cleaned grain were halved and that mite numbers increased with the increasing proportion of dust. Armitage et al. (1996) showed cleaning achieved a 90% mite reduction and that populations in cleaned grain only achieved 20% of those in uncleaned. Mite populations can be reduced by 69-98% by conveying (Megalov, 1934, Wilkin 1975b, Wilkin and Hope, 1973b, Armitage, 1994), however, populations normally build up quickly afterwards so the solution is purely short-term.

## 8.6 Fumigation

Eggs of the commonest Astigmatid storage mites are tolerant of most fumigants (Bowley and Bell, 1981), especially at low temperatures, although the mobile stages are susceptible. Complete control can most easily be achieved by two fumigations at moderate to low doses, separated by between 2 weeks at 20°C and 7 weeks at 10°C, during which time the eggs hatch but do not reach adult stage.

## 8.7 Modified Atmospheres

The use of modified atmospheres (MA) involves a change in the proportions of the atmospheric gases, nitrogen ($N_2$), oxygen ($O_2$) and carbon dioxide ($CO_2$), to produce conditions lethal for pests (Banks and Fields, 1995). $CO_2$ is more toxic than $N_2$ (Navarro and Donahaye, 1990) and does not rely solely on anoxia to be lethal as it causes acidification of the body fluids and subsequent inhibition of glycolysis (Adler, 1994).

Greatest tolerance of low $O_2$ is found in mite eggs as it is related to low $O_2$ consumption. In 99.5% $CO_2$ at 85% r.h., eggs and mobile stages died in 6 days and 1 day respectively (Stepien, 1974). At 15$^{o}$C and 70% r.h., *Tyrophagus longior* was the most tolerant species, surviving for 22 days in 99.5% $N_2$ (Conyers et al. 1996). Burner gas was most effective with 0.5% $O_2$ but with an increase to 2% $O_2$, $CO_2$ became the more effective. At 15$^{o}$C and 75% r.h, Navarro et al (1985) killed *Acarus siro* adults in 4 days using 30% $CO_2$ while 2% $O_2$ in $N_2$, killed all *Acarus siro* in 6 days at 15°C and in 2 days at 26°C. White and Jayas (1991) controlled all mites after 42 days with $CO_2$ at 40% and between 12 and 15$^{o}$C.

## 9. Conclusions

This review has demonstrated the wide range of compounds available for use as acaricides. However, the relatively limited information on the efficacy against storage mites emphasises the need for further research. Table 1 summarises the results of previous research on the use of alternative compounds against storage mites, giving details on the test species, doses, test conditions and methods of application. As seen from the table, it is difficult to directly compare results, as different researchers have used different methods of evaluation.

For compounds to be considered as potential alternatives to OPs, as well as being effective against storage mites, they must also meet the following criteria :

1. effective against storage insects
2. available as commercial products, preferably already cleared for use on grain
3. easy to apply
4. have low mammalian toxicity
5. provide prolonged protection over extended storage periods
6. effective under typical U.K. storage conditions, i.e. low temperatures, high r.h.
7. can be incorporated into an integrated pest management programme e.g. as a surface treatment

Table 2 provides a summary of the advantages and disadvantages in the use of alternative compounds against storage mites.

The aim of this review was to identify compounds which would seem to warrant further investigation as potential alternatives to OPs for the control of storage mites. Of the IGRs, methoprene, appears the most promising, as previous research with fenoxycarb has produced contradictory results, and dimilin is not particularly effective against some storage mites. Inert dusts, such as 'Dryacide', are already used as grain protectants in some countries, however their efficacy under typical U.K. storage conditions may limit their use; although some of the newer products, e.g. 'Protect-It', may prove more efficacious. Pyrethroids have shown varying degrees of efficacy against storage mites, with bifenthrin, bioresmethrin and deltamethrin seeming to warrant further investigation. Azadirachtin containing products have proved effective against storage insects, although efficacy against mites appears to be concentrated on phytophagous pests. Benzyl benzoate has FDA approval for food use and although effective against Astigmatid mites in a domestic environment, has not been assessed for storage use. Although other plant derived products have proved effective, their main limitation may lie in the tainting of grain.

Of the novel compounds, chemosterilants have proved effective against storage mites, however, they are also usually highly toxic. Propionic acid has also proved effective, although treated grain loses its germinative capacity. Tricalcium phosphate is commonly used as a food additive, but high doses are required to be effective against storage mites. Abamectin has been used commercially as an acaricide and has a wide spectrum of activity against Prostigmatid mites, although it has not been assessed against storage mites.

Of the biological control agents, the predator *Cheyletus eruditus*, appears the most promising and is already used in storage facilities overseas. However, the predators themselves would be considered as grain contaminants and therefore need controlling. *Bacillus thuringiensis* may also be promising, as commercial products have been shown to be effective against phytophagous mites and storage insects. Nematodes are unsuitable for use in a dry storage environment, viruses and protozoa are not easily available and fungi produce mycotoxins that may be toxic to mammals.

More than 20 million tonnes of grain is stored annually in the U.K., valued in excess of £2 billion/year. During storage, grain is at risk of spoilage from infestation which is estimated to cost £50 million annually. With increasing concerns over the use of OPs, it is vitally important to investigate the efficacy of alternative compounds as grain protectants.

## 10. Future Work

The aim of initial experiments will be to evaluate approximately a dozen compounds that appear to be promising alternatives to OPs for the treatment of stored grain against mite infestation. Commercially available formulations will be used, where possible, and applied to grain at a wide range of doses, as determined from the literature. Mixed stages of OP-susceptible strains of *Acarus siro*, *Tyrophagus putrescentiae* and *Lepidoglyphus destructor* will be exposed to treated grain for periods long enough to encompasss at least two generations. The numbers of live mites will be assessed using the technique of Solomon (1962), which counts actual mite numbers.

Compounds to be evaluated may include the IGRs : methoprene, fenoxycarb and diflubenzuron; the inert dusts : 'Dryacide', 'Protect-It' and 'Insecto'; the pyrethroids : bifenthrin, bioresmethrin and deltamethrin; the botanicals : azadirachtin and benzyl benzoate; as well as abamectin and *Bacillus thuringiensis*.

These experiments will provide information as to which of the compounds show promise as acaricides for stored grain protection and therefore warrant further investigation.

## 11. Acknowledgements

The author would like to thank David Armitage, Bhushy Thind, Nick Renn, Gay Marris and Simon Conyers for their advice and contributions to the writing of this review; and also the staff in the Information Centre at CSL, York for their help in providing copies of the literature. This review was funded by the Home Grown Cereals Authority.

## 12. References

Adler, C. S. (1994). Carbon dioxide - more rapidly impairing the glycolytic energy production than nitrogen ? In : Highley, E., Wright, E. J., Banks, H. J. and Champ, B. R. (1994). Proc. 6th Int. Working Conf. Stored-Prod. Prot., Canberra, Australia, 17-23 April 1994. CAB International, Wallingford, U.K. pp. 2-6.

Afifi F. A. and Hafez, S. M. (1988). Effect of different plant extracts on the toxicity and behaviour *of Tyrophagus putrescentiae* Shrank (Acari : Acaridae). Annals of Agricultural Science, - Cairo, 33 (2) : 1375-1385.

Aldryhim, Y. N. (1990). Efficacy of the amorphous silica dust, Dryacide, against *Tribolium confusum* Duv. and *Sitophilus granarius* (L.) (Coleoptera: Tenebrionidae and Curculionidae). J. Stored Prod. Res., 26 (4) : 207-210.

Aldryhim, Y. N. (1993). Combination of classes of wheat and environmental factors affecting the efficacy of amorphous silica dust, Dryacide, against *Rhyzopertha dominica* (F.). J. Stored Prod. Res., 29 (3) : 271-275.

Anderson, I. and Wilkin, D. R. (1984). Effect of bioresmethrin on mites infesting cheeses. In : Griffiths, D. A. and Bowman, C. E. (Eds). Acarology VI volume 2. Ellis Horwood, Chichester, p.1034-1039.

Anderson, M., Fisher, J. P. and Robinson, J. (1986). Flufenoxuron - an acylurea acaricide/insecticide with novel properties. Proc. 1986 Brit. Crop Prot. Conf. - Pests and Diseases, 2 : 89-96.

Ando, K., Oishi, H., Hirano, S., Okutomi, T., Suzuki, K., Okazaki, H., Sawada, M. and Sagawa, T. (1971). Tetranactin, a new miticidal antibiotic I. Isolation, characterisation and properties of tetranactin. J. Antibiotics, 33 : 347-352.

Ando, K., Sagawa, T., Oishi, H., Suzuki, K. and Nawara, Y. (1974). Tetranactin, a pesticidal antibiotic. Proc. Ist Intersect. Congr. IAMS (Sci. Council Jpn), 3 : 630-640.

Anon, (1982). Mites in stored grain and oilseeds. ADAS Leaflet IC 1982/7.

Anon, (1983). Testing pathogenic fungi. Storage Pests 1981, HMSO, p. 41-42.

Anon, (1996). Storage mites in foodstuffs. Food Surveillance Information Sheet No. 96. October 1996. Food Safety Directorate, MAFF.

Anon, (1997). How diatomaceous earth works. Fumigants and Pheromones, 44 : 7-8.

Arbogast, R. T. (1984). Biological control of stored-product insects : status and prospects. In : Baur F. J. (Ed.) Insect pest management for food storage and processing. American Association of Cereal Chemists, St Paul, Minnesota. pp. 226-238.

Armitage, D. M. (1980). The effect of aeration on the development of mite populations in rapeseed. J. Stored Prod. Res., 16 : 93-102.

Armitage, D. M. (1984). The vertical distribution of mites in bulks of stored produce. In : Griffiths, D. A. and Bowman, C. E. (Eds). Acarology VI volume 2. Ellis Horwood, Chichester, pp. 1006-1013.

Armitage, D. M. (1986). Pest control by cooling and ambient air drying. Int. Biodet. Suppl., 22 : 13-20.

Armitage, D. M. (1994). Some effects of grain cleaning on mites, insects and fungi. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, 2 : 896-901.

Armitage, D. M., Burrell, N. J. and Llewellin, B. E. (1982). Changes in fungal and mite populations in grain during prolonged drying and subsequent storage. In : Ashworth, J. C. (Ed.). Proc. 3rd Drying Symposium, volume 2. Drying Research Ltd., Wolverhampton, pp. 193-201.

Armitage, D. M., Burrell, N. J. and Llewellin, B. E. (1984). The effect of cooling and drying on mites in stored produce. In : Griffiths, D. A. and Bowman, C. E. (Eds). Acarology VI volume 2. Ellis Horwood, Chichester, pp. 1014-1016.

Armitage, D. M., Cogan, P. M. and Wilkin, D. R. (1994). Integrated pest management in stored grain : combining surface insecticide treatments with aeration. J. Stored Prod. Res., 30 : 303-319.

Armitage, D. M., Cook, D. A. and Duckett, C. (1996). The use of an aspirated sieve to remove insects, mites and pesticides from grain. Crop Prot., 15 : 675-680.

Banks, H. J. and Fields, P. (1995). Physical methods for insect control in stored ecosystems. In : Jayas, D. S., White, N. D. G. and Muir, W. E. (Eds). Stored-grain ecosystems. Marcel Dekker Inc. New York. pp. 353-409.

Baker, J. E., Highland, H. A. and Engle, G. C. (1976). Bulk density of tricalcium phosphate as a significant variable in the suppression of insect populations in flour and wheat soy blend. Environ. Entomol., 5 (5) : 909-919.

Barker, P. S. (1968). Bionomics of *Androlaelaps casalis* (Berlese) (Acarina : Laelapidae) a predator of mite pests in stored cereals. Can. J. Zool., 46 : 1099-1102.

Beer, R. E. and Dailey, D. T. (1956). Biological and systematic studies of two species of Cheyletid mites with a description of a new species (Acarina, Cheyletidae). Kansas Univ. Sci. Bull., 38 : 393-425.

Beerling, E. A. M. and van der Geest, L. P. S. (1991). Microsporidiosis in mass-rearings of the predatory mites *Amblyseius cucumeris* and *A. barkeri* (Acarina : Phytoseiidae). Proc. Exper. & Appl. Entomol. N.E.V. Amsterdam, 2 : 157-162.

Beerling, E. A. M., Rouppe van der Voort, J. N. A. M., Kwakman, P. (1993). Microsporidiosis in mass rearings of predatory mites : development of a detection method. Proc. Exper. & Appl. Entomol. N.E.V. Amsterdam, 4 : 199-204.

Bengston, M. (1987). Insect growth regulators. In : Donahaye, E. and Navarro, S. (Eds). Proc. 4th Work. Conf. Stored-Prod. Prot., Tel Aviv, Israel, Sept. 1986. pp. 35-46.

Bengston, M., Koch, K. and Strange, A. C. (1990). Development of insect growth regulators as grain protectants in Australia and South-East Asia. In : Fleurat-Lessard, F. and Ducom, P. (Eds). Proc. 5th Int. Work. Conf. Stored Prod. Prot., Bordeaux, France. 1990. pp. 485-490.

Benner, J. P. (1996). Pesticides from nature. Part I : Crop protection agents from higher plants - An overview. In : Copping L. G. (Ed.). Crop protection agents from nature. Natural products and analogues. The Royal Society of Chemistry , Cambridge UK. pp 217-229.

Binnington, K. C. (1986). Ultrastructure of the tick neuroendrocrine system. In : Sauer, J. R. and Hair, J. A. (Eds) Morphology, Physiology and Behavioural Biology of ticks., Ellis Horwood, Chichester. pp 152-164.

Binnington, K. C. and Obenchain, F. D. (1982). Structure and function of the circulatory, nervous and neuroendocrine systems of ticks. In : Obenchain, F. D. and Galun, R. (Eds) Physiology of Ticks. Pergamon Press, Oxford UK. pp. 351-398.

Binns, T. J. (1989). The laboratory assessment of 3 pyrethroid formulations and a formulation of pirmiphos-methyl, admixed with grain, on laboratory susceptible strains of 5 major storage pests. MAFF, CSL report No. C/89/0467. 29 pp..

Bischoff, E., Fischer, A. and Liebenberg, B. (1989). Elimination of house dust mite excreta, the carriers of allergens in the indoor air. In : Bieva, C. J. , Courtois, Y. and Govaerts, M. (Eds) Present and Future of indoor air quality. Elsevier Science. pp. 363-370.

Bjørnson, S., Steiner, M. Y. and Keddie, B. A. (1996). Ultrastructure and pathology of *Microsporidium phytoseiuli* n. sp. infecting the predatory mite, *Phytoseiulus persimilis* Athias-Henriot (Acari : Phytoseiidae). J. Invert. Pathol., 68 : 223-230.

Blomquist, G. J., Adams, T. S. and Dillwith, J. W. (1984). Induction of female sex pheromone production in male houseflies by ovary implants or 20-hydroxyecdysone. J. Insect Physiol., 30 : (4) : 295-302.

Boczek, J. and Czajkowska, B. (1968). The effect of antimicrobial agents and antibiotics on some stored products mites (Acaroidea). Roczniki nauk Rolniczych, 93 : 597-612.

Boczek, J. and Ignatowicz, S. (1979). Effect of tricalcium phosphate on *Tyrophagus putrescentiae* (Schr.) (Acari : Acaridae). Proc. 2nd Int. Working Conf. on Stored Prod. Entomol. 1978, pp. 320-327.

Boczek, J., Ignatowicz, S. and Davis, R. (1984). Some effects of mineral salts in the diet of the mold mite, *Tyrophagus putrescentiae* (Schrank). J. Georgia Entomol. Soc., 19 (2) :235-248.

Boots, M. and Begon, M. (1993). Trade-offs with resistance to a granulosis virus in the Indian meal moth, examined by a laboratory evolution experiment. Functional Ecology, 7 : 528-534.

Boudreaux, H. B. (1959). A viruslike transovarian factor affecting morphology in spider mites. J. Insect Pathol., 1 : 270-280.

Bowley, C. R. and Bell, C. H. (1981). The toxicity of twelve fumigants to three species of mites infesting grain. J. Stored Prod. Res., 17 : 83-87.

Bridgeman, B. W. (1994). Structural treatment with amorphous silica slurry : an integral component of GRAINCO's IPM strategy. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, 2 : 628-630.

Bronswijk, J. E. M. H., Reumer, J. W. F. and Pickard, R. (1987). Effects of fungicide treatment and vacuuming on Pyroglyphid mites and their allergens in mattress dust. Exp. Appl. Acarol., 3 : 271-278.

Brower, J. H. and Jurd, L. (1980). Mortality and sterility of the Indian meal moth and the red flour beetle treated with eight candidate chemosterilants. J. Georgia Entomol. Soc., 15 (4) : 390-398.

Brower, J. H. and Press, J. W. Interaction of *Bracon hebetor* and *Trichogramma pretiosum* in suppressing stored-product moth populations in small inshell peanut storages. J. Econ. Entomol., 83 : 1096-1101.

Buchi, R. (1990). Effects of the two IGRs Methoprene and Fenoxycarb on *Liposcelis bostrychophilus* and *Acarus siro*. In : Fleurat-Lessard, F. and Ducom, P. (Eds). Proc. 5th Int. Working Conf. on Stored Products. pp. 495- 495.

Burges, H. D., Canning, E. U. and Hurst, J. A. (1971). Morphology, development and pathogenicity of *Nosema oryzaephili* n. sp. in *Oryzaephilus surinamensis* and its host range among granivorous insects. J. Invert. Pathol., 17 : 419-432.

Burnett, T. (1964). An acarine predator-prey population infesting stored products. Can. J. Zool., 42 : 655-673.

Burnett, T. (1977). Biological models of two acarine predators of the grain mite, *Acarus siro* L. Can. J. Zool., 55 : 1312-1323.

Burrell, N. J. and Havers, S. J. (1973). Effect of grain cleaning on mite infestations. Pest Infestation Control Report. HMSO, London p. 98.

Burrell, N. J. and Havers, S. J. (1975). Effect of grain cleaning on mite infestations. Pest Infestation Control Report 1971-73 HMSO, London p. 106.

Burrell N. J. and Havers, S. J. (1976). The effects of cooling on mite infestations in bulk grain. Ann. Appl. Biol., 82 : 192-197.

Calcott, P. H. and Fatig, R. O. (1984). Inhibition of chitin metabolism by avermectin in susceptible organisms. J. Antibiot., 37 : 253-259.

Campbell, W. C., Fisher, M. H., Stapley, E. O., Albers-Schonberg, G. and Jacob, T. A. (1983). Ivermectin : A potent new antiparasitic agent. Science, 221 : 823-828.

Campos, F., Dybas, R. A. and Krupa, D. A. (1996). Susceptibility of twospotted spider mite (Acari : Tetranchyidae) populations in California to abamectin. J. Econ. Entomol., 88 (2) : 225-231.

Campos, F., Krupa, D. A. and Dybas, R. A. (1996). Susceptibility of populations of twospotted spider mites (Acari : Tetranychidae) from Florida, Holland and the Canary Islands to abamectin and characterization of abamectin resistance. J. Econ. Entomol., 89 (3) : 594-601.

Carner, G. R. and Canerday, T. D. (1968). Field and laboratory investigations with *Entomophthora fresenii*, a pathogen of *Tetranychus* spp. J. Econ. Entomol., 61 (4) : 956-959.

Castagnoli, M., Liguori, M., Nanelli, R. and Simoni, S. (1996). Effectiveness of benzyl alcohol in the control of house dust and stored crops mites (Acari : Astigmata). Proc. XX Int Cong. Entomol., Firenze, Italy. p. 577.

Cerepanova, N. P. (1964). (1964). Bot. Zh, Kiev, 49 : 696-699. (In Russian).

Chambers, C. M., Dotson, E. M. and Oliver, J. H. (1996). Ecdysteroid titers during postembryonic development of *Dermanyssus gallinae* (Acari, Dermanyssidae). J. Med. Entomol., 33 (1) : 11-14.

Chapman, M. H. and Hoy, M. A. (1991). Relative toxicity of *Bacillus thuringiensis* var. tenebrionis to the two-spotted mite (*Tetranychus urticae* Koch) and its predator *Metaseiulus occidentalis* (Nesbitt) (Acari, Tetranychidae and Phytoseiidae). J. Appl. Entomol., 111 : 147-154.

Cherry, L. M. (1969). Cholesterol in the cuticular wax of *Boophilus microplus*. Nature, 222 : 777.

Chhabra, K. S. (1971). Influence of certain phytocides and antibiotics on the reproduction and development of *Tetranychus* mites. Proc. 3rd Int. Congr. Acarology, 1971. pp. 645-647.

Chisaka, K., Minamite, Y., Ohgami, H. and Katsuda, Y. (1985). Efficacy of various types of pyrethroid compounds against *Tyrophagus putrescentiae* and *Dermatophagoides farinae*. Japanese Journal of Sanitary Zoology, 36 (1) : 7-13.

Cline, L. D., Press, J. W. and Flaherty, B. R. (1986). Protecting uninfested packages from attack by *Cadra cautella* with the parasitic wasp *Venturia canescens*. J. Econ. Entomol., 79 : 418-420.

Coats, J. R., Karr, L. L. and Drewes, C. D. (1991). Toxicity and neurotoxic effects of monoterpenoids. In insects and earthworms. In : Hedin, P. A. (Ed.) Naturally occurring pest bioregulators. ACS, Washington DC. pp. 305-316.

Collins, D. A. and Binns, T. J. (1996). Efficacy of different formulations of pirimiphos-methyl and etrimfos when admixed with oilseed rape, against susceptible storage insect and mite species. Crop Protection, 15 (8) : 707-714.

Conyers, S. T., Bell, C. H., Llewellin, B. E. and Savvidou, N. (1996). Strategies for the use of modified atmospheres for the treatment of grain. HGCA report no. 125. 122 pp.

Cook, D. A. and Armitage, D. M. (1996). The efficacy of an inert dust on the mites *Lepidoglyphus destructor* Schrank and *Acarus siro* L. Int. Pest Control, 38 (6) : 197-199.

Cook, D. A. and Armitage, D. M. (1999). The efficacy of 'Dryacide', an inert dust, against 2 species of Astigmatid mites, *Lepidoglyphus destructor* (Schrank) and *Acarus siro* L., at 9 temperature and moisture content combinations on stored grain. Exp. Appl. Acarol., 23 : 51-63.

Coombs, C. W. and Woodroffe, G. E. (1968). Changes in the arthropod fauna of an experimental bulk of stored wheat. J. Appl. Ecol., 5 : 563-574.

Cox, P. D. and Wilkin, D. R. (1996). The potential use of biological control of pests in stored grain. HGCA Research Review No. 36., HGCA, London. 53 pp.

Cunnington, A. M. (1976). The effect of physical conditions on the development and increase of some important storage mites. Ann. Appl. Biol., 82 : 175-201.

Cunnington, A. M. (1984). Resistance of the mite *Acarus siro* L. (Acarina, Acaridae) to unfavourable physical limits beyond the limits of its development. Agric. Ecosystems Environ., 11 : 319-339.

Cunnington, A. M. (1985). Factors affecting oviposition and fecundity in the grain mite *Acarus siro* (Acarina : Acaridae), especially temperature and relative humidity. Exp. Appl. Acarol., 1 : 327-344.

Czaja-Topinska, J., Stepien, Z. and Sterzycki, R. (1979). The effect of some juvenile hormone analogs on *Tyrophagus putrescentiae*. In : Rodriguez J. G. (Ed). Recent Advances in Acarology Volume 1. Academic Press, New York. pp. 231-242.

Czajkowska, B. (1971). The influence of some active substances of medicinal herbs on stored product mites (Acaroidea). Proc. 3rd Int Congr. of Acarology, pp. 365-369.

Davies, D. A. (1997). Organophosphates and the brain. In : Speakers abstracts from Organophosphates, Agriculture and the Environment Conference, 17-19 September 1997, Edinburgh.

Dees, W. H., Sonenshine, D. E. and Breidling, E. (1984). Ecdysteroids in *Hyalomma dromedarii* and *Dermacentor variabilis* and their effects on sex pheromone activity. In : Griffiths, D. A. and Bowman, C. E. (Eds) Acarology VI Volume 1. Ellis Horwood, Chichester, U K. pp. 405-413.

Dekeyser, M. A. and Downer, R. G. H. (1994). Biochemical and physiological targets for miticides. Pestic. Sci., 40 : 85-101.

Desmarchelier, J. M. and Dines, J. C. (1987). Dryacide treatment of stored wheat : its efficacy against insects, and after processing. Aust. J. Exp. Agric., 27 : 309-312.

Diehl, P. A., Connat, J. L. and Dotson, E. (1986). Chemistry, function and metabolism of tick ecdysteroids. In : Sauer, J. R. and Hair, J. A. (Eds) Morphology, Physiology and Behavioural Biology of ticks., Ellis Horwood, Chichester. pp. 165-193.

Dimetry, N. Z., Amer, S. A. A. and Momen, F. M. (1994). Laboratory trials of two neem seed extracts on the predatory mites *Amblyseius barkeri* (Hughes) and *Typhlodromus richteri* Karg. Boll. Zool. Agr. Bachic., 26 (1) : 127-137.

Dimetry, N. Z., Amer, S. A. A. and Reda, A. S. (1993). Biological activity of two neem seed kernel extracts against the two-spotted spider mite *Tetranychus urticae* Koch. J. Appl. Ent., 116 : 308-312.

Downing, A. S., Wright, C. G. and Farrier, M. H. (1990). Effects of five insect growth regulators on laboratory populations of the North American house-dust mite, *Dermatophagoides farinae*. Exp. Appl. Acarol., 9 : 123-130.

Downing, A. S., Wright, C. G. and Farrier, M. H. (1993). Population-growth of *Dermatophagoides farinae* Hughes (Acari, Epidermoptidae) suppressed by methoprene and hydroprene. J. Med. Entomol., 30 (3) : 531-536.

Drummond, J. and Pinnock, D. E. (1994). Host spectrum of *Bacillus thuringiensis*. Agric. Ecosystems & Environ., 49 : 15-19.

Drummond, R. O. and Miller, J. A. (1984). Control of ticks systemically with sustained-release implants of Ivermectin. In : Griffiths, D. A. and Bowman, C. E. (Eds) Acarology VI Volume 2. Ellis Horwood, Chichester, U K. pp. 1274-1279.

Eaton, J. L. (1985). Nervous systems : functional role. In : Blum, M. S. (Ed). Fundamentals of insect physiology. Wiley Interscience, New York.

Ebeling, W. (1960). Control of the tropical rat mite. J. Econ. Entomol., 53 (3) : 475-476.

Ebeling, W. (1971). Sorptive dusts for pest control. Ann. Rev. Entomol., 16 :123-158.

Eggenberger, L. R., Lamoreaux, W. J. and Coons, L. B. (1990). Hemocytic encapsulation of implants in the tick *Dermacentor variabilis*. Exp. Appl. Acarol., 9 : 279-287.

El-Atrouzy, N. A., Iskander, N. G. and Wahba, M. L. (1989). Efficacy of (Cascade) on some biological aspects of *Tetranychus arabicus* Attiah. Agric. Res. Rev., 67 : 79-86.

El-Banhawy, E. M. (1979). Comparison between the response of the predacious mite *Amblyseius brazilli* and its prey *Tetranychus desertorum* to the different IGRs methoprene and dimilin (Acari : Phytoseiidae, Tetranychidae). Acarologia, 21 : 221-227.

El-Kady, M. H., Ibrahim, G. A., El Halawany, M. E., Ebrahim, H. M., Abd El-Samed, M. A. and El-Ghobashy, M. S. (1996). The effect of an insect growth regulator (Andalin 25% E.C.) on *Tetranychus urticae* Koch (Tetranychidae). In : Mitchell, R., Horn, D. J., Needham, G. R. and Welbourn, W. C. (Eds). Proc. Acarology IX Volume 1., Ohio, USA, 1996, pp. 173-175.

Elixmann, J. H., Bischoff, E., Jorde, W. and Linskens, H. F. (1991). Changements during 2 years in populations of different mite species in house dust before and after a single acaricidal treatment. Acarologia, 32 : 385-398.

Ellis, B. J. and Obenchain, F. D. (1984). *In vivo* and *in vitro* production of ecdysteroids by nymphal *Amblyomma variegatum* ticks. In : Griffiths, D. A. and Bowman, C. E. (Eds) Acarology VI Volume 1. Ellis Horwood, Chichester, U K. pp. 400-404.

Errampalli, D. D. and Knowles, C. O. (1990). Cholinesterase inhibition in the bulb mite *Rhizoglyphus echinopus* (Acari : Acaridae) in relation to the acaricidal action of organophosphates and carbamates. Exp. Appl. Acarol., 9 : 19-30.

Evans, D. E. (1984). Biological control of stored grain pests. In : Champ, B. R. and Highley, E. (Eds). Proceedings of the Australian development assistance course on the preservation of stored cereals. Volume 2. CSIRO, Canberra. pp. 574-582.

Evans, G. O. (1992). Principles of Acarology. CABI, Wallingford, UK.

Fairhall, D. (1996). Flea treatments linked to Gulf War Syndrome. The Guardian. 31 October 1996.

Ferron, P. and Robert, P. H. (1975). Virulence of entomopathogenic fungi (Fungi imperfecti) for the adults of *Acanthoscelides obtectus* (Coleoptera : Bruchidae). J. Invert. Pathol., 25 : 379-388.

Fields, P. and Timilick B. (1995). Efficacy assessment of super insecolo. Report for Hedley Pacific Ventures Ltd. Vancouver, Canada.

Fisher, F. E. (1950). Entomogenous fungi attacking scale insects and rust mites on citrus in Florida. J. Econ. Entomol., 43 (3) : 305-309.

Fisher, F. E. (1951). An entomophthora attacking citrus red mite. Florida Ent., 34 : 83-88.

Flinn, P. W., Hagstrum, D. W. and McGaughey, W. H. (1996). Suppression of beetles in stored wheat by augmentative releases of parasitic wasps. J. Econ. Entomol., 25 (2) : 505-511.

Frances, S. P. (1988). Response of a chigger, *Eutrombicula hirsti* (Acari : Trombiculidae) to repellent and toxicant compounds in the laboratory. J. Med. Entomol., 31 (4) : 628-630.

Gangrade, G. A. and Pant, N. C. (1970a). Egg viability in *Cadra cautella* - I. Effect of competition between normal and apholate-sterilised males. PANS, 16 (2) : 370-372.

Gangrade, G. A. and Pant, N. C. (1970b). Egg viability in *Cadra cautella* - II. Effect of sequential mating with normal and apholate-sterilised males. PANS, 16 (2) : 373-376.

Gaugler, R. (1987). Entomogenous nematodes and their prospects for genetic improvement. In : Maramorosch, K. (Ed.) Biotechnological advances in invertebrate pathology and cell culture. Academic Press, New York. pp. 457-484.

Gaugler, R. and Boush, G. M. (1979). Nonsusceptibility of rats to the entomogenous nematode, *Neoaplectana carpocapsae*. Environ. Entomol., 8 : 658-660.

Gaugler, R., LeBeck, L., Nakagaki, B and Boush, G. M. (1980). Orientation of the entomogenous nematode *Neoaplectana carpocapsae* to carbon dioxide. Environ. Entomol., 9 : 649-652.

Gerson, U., Kenneth, R. and Muttah, T. I. (1979). *Hirsutella thompsonii*, a fungal pathogen of mites. II. Host pathogen interactions. Ann. Appl. Biol., 91: 29-40.

Glancy, B. M., Lofgren, C. S. and Williams, D. F. (1982). Avermectin $B1_a$ : effects on the ovaries of red imported fire ant, *Solenopsis invicta*, (Hymenoptera : Formicidae) queens. J. Med. Entomol., 19 : 743-747.

Glazer, I. and Samish, M. (1993). Suitability of *Boophilus annulatus* replete female ticks as hosts of the nematode *Steinernema carpocapsae*. J. Invert. Pathol., 61 : 220-222.

Golob, P. (1997). Current status and future perspectives for inert dusts for control of stored product insects. J. Stored Prod. Res., 33 (1) : 69-79.

Golob, P. and Webley, D. J. (1980). The use of plants and minerals as traditional protectants of stored products. Report of the Tropical Products Institute, G138.

Goulet, H. and Huber, J. T. (1993). Hymenoptera of the world : An identification guide to families. Agriculture Canada.

Graham, M. W. R. de V. (1987). The European Tetrastichinae (Hymenoptera : Eulophidae). Bull. Brit. Museum (Nat. History) Entomology, 55 : 1-392.

Grainge, M. and Ahmed, S. (1988). Handbook of plants with pest-control properties. Wiley Interscience.

Griffiths, D. A., Hodson, A. C. and Christensen, C. M. (1959). Grain storage fungi associated with mites. J. Econ. Entomol., 52 : 514-518.

Grosscurt, A. C. (1978). Diflubenzuron : some aspects of its ovicidal and larvicidal mode of action and an evaluation of its practical possibilities. Pestic. Sci, 9 : 373-386.

Grosscurt, A. C., ter Haar, M., Jongsma, B and Stoker, A. (1988). PH 70-23: A new acaricide and insecticide interfering with chitin deposition. Pestic. Sci., 22 : 51-59.

Grossman, J. (1993). Botanical pesticides in Africa. The IPM Practitioner, 15 (1) : 1-9.

Grubhoffer, L., Veres, J. and Dusbabek, F. (1991). Lectins as the molecular factors of recognition and defence reaction of ticks. In : Dusbabek, F. and Bukva, V. (Eds.). Modern Acarology Volume 2. Academia, Prague. pp. 381-388.

Guillot, F. S. and Wright, F. C. (1984). Reduced fecundity of *Psoroptes ovis* (Hering) (Acari : Psoroptidae) on calves treated with ivermectin. Bull. Ent. Res., 74 : 657-662.

Gulati, R. (1998). Inhibitory action of neem products on *Tyrophagus putrescentiae* (Schrank) (Acarina : Acaridae) in wheat during storage. Annals Agri-bio res., 3 (2) : 227-230.

Gulati, R. and Mathur, S. (1995). Effect of *Eucalyptus* and *Mentha* leaves and *Curcuma* rhizomes on *Tyrophagus putrescentiae* (Schrank) (Acarina : Acaridae) in wheat. Exp. App. Acarol., 19 : 511-518.

Hagdorn, H. H. (1983). The role of ecdysteroids in the adult insect. In : Downer, R. G. H and Laufer, H. (Eds). Endocrinology of insects. Alan R. Liss, New York. pp 271-304.

Hall, I. M., Hunter, D. K. and Arakawa, K. Y. (1971). The effect of the β-exotoxin fraction of *Bacillus thuringiensis* on the citrus red mite. J. Invertebr. Pathol., 18 : 359-362.

Haq, M. A. (1991). Nematode parasitism in vector Oribatid mites. In : Dusbabek, F. and Bukva, V. (Eds.). Modern Acarology Volume 2. Academia, Prague. pp. 623-627.

Hassanain, M. A., El Garhy, M. F., Abdel-Ghaffar, F. A., El-Sharaby, A. and Abdel Megeed, K. N. (1997). Biological control studies of soft and hard ticks in Egypt I. The effect of *Bacillus thuringiensis* varieties of soft and hard ticks (Ixodidae). Parasitol. Res., 83 : 209-213.

Heidelberger, C., Chaudhuri, N. K., Danneberg, P., Mooren, D. and Griesbach, L. (1957). Fluorinated pyrimidines, a new class of tumour-inhibitory compounds. Nature, 179 : 663-666.

Helle, W. (1984). Aspects of pesticide resistance in mites. In : Griffiths, D. A. and Bowman, C. E (Eds) Acarology VI Volume 1. Ellis Horwood, Chichester, U K. pp. 122-131.

Henderson, S. (1987). A mean moisture content-equilibrium relative humidity relationship for nine varieties of wheat. J. Stored Prod. Res., 23 (3) : 143-147.

Highland, H. A. (1975). Tricalcium phosphate as an insect suppressant in flour and CSM. J. Econ. Entomol., 68 (2) : 217-219.

Hluchy, M. and Samsinakova, A. (1989). Comparative study on the susceptibility of adult *Sitophilus granarius* (L.) (Coleoptera : Curculionidae) and larval *Galleria mellonella* (L.) (Lepidoptera : Pyralidae) to the entomogenous fungus *Beauvaris bassiana* (Bals.) Vuill. J. Stored Prod. Res., 25 (2) : 61-64.

Hodges, R. J. (1984a). Biological methods for integrated control of insects and mites in tropical stored products. IV : The use of insect diseases. Trop. Stored Prod. Inf., 48 : 27-31.

Hodges, R. J. (1984b). Biological methods for integrated control of insects and mites in tropical stored products. V : The use of sterile insects. Trop. Stored Prod. Inf., 48 : 33-36.

House, H. L. and Graham, A. R. (1967). Capric acid blended into foodstuff for control of an insect pest, *Tribolium confusum* (Coleoptera : Tenebrionidae). Can. Ent., 99 : 994-999.

Hoy, M. A. and Cave, F. E. (1985). Laboratory evaluation of avermectin as a selective acaricide for use with *Metaseilus occidentalis* (Nesbitt) (Acarina : Phytoseiidae). Exp. App. Acarol., 1 : 139-152.

Hoy, M. A. and Conley, J. (1987). Selection for abamectin resistance in *Tetranychus urticae* and *T. pacificus* (Acari : Tetranychidae). J. Econ. Entomol., 80 : 221-225.

Hoy, M. A. and Ouyang, Y-L. (1987). Toxicity of the β-exotoxin of *Bacillus thuringiensis* to *Tetranychus pacificus* and *Metaseiulus occidentalis* (Acari : Tetranychidae and Phytoseiidae). J. Econ. Entomol., 80 : 507-511.

Hughes, A. M. (1976). The mites of stored food and houses. MAFF Tech. Bull. 9. HMSO, London.

Hurlock, E. T., Armitage, D. M. and Llewellin, B. E. (1980). Seasonal changes in mites (Acari) and fungal populations in aerated and unaerated wheat stored for threee years. Bull. Ent. Res., 70 : 537-548.

Ignatowicz, S. (1980). Effect of inorganic salts upon biology and development of acarid mites. IV. Effects of calcium phosphate surplus in food upon fecundity, life span and development of copra mite, *Tyrophagus putrescentiae* (Schrank) (Acarina, Acaridae). Polskie Pismo Entomologiczne, 50 : 289-298.

Ignatowicz, S. (1981). Effect of inorganic salts upon biology and development of Acarid mites. VII. Rapid desiccation of the copra mite, *Tyrophagus putrescentiae*, (Schrank), and other mites with tricalcium phosphate and ferric phosphate. Polskie Pismo Entomologiczne, 51 (3) : 471-482.

Ignatowicz, S. (1982a). Chemosterilisation of Acarid mites (Acarida : Acaridae). Part I. Infecundity induced in females of the flour mite, *Acarus siro* L., by potassium iodide. Roczniki Nauk Rolniczych, 12 : 11-21.

Ignatowicz, S. (1982b). Chemosterilisation of Acarid mites (Acarida : Acaridae). Part II. Boric acid and sodium borate effects on fecundity and longevity of *Tyrophagus putrescentiae* (Schrank). Roczniki Nauk Rolniczych, 12 : 23-35.

Ignatowicz, S. (1983a). Chemosterilisation of Acarid mites (Acarida : Acaridae). Part III. Doses of sodium fluoride affecting fecundity of *Tyrophagus putrescentiae* (Schrank). Roczniki Nauk Rolniczych, 13 : 9-16.

Ignatowicz, S. (1983b). Effect of inorganic salts upon biology and development of Acarid mites. I. Effect of mineral salts on fecundity and egg viability of "copra mite", *Tyrophagus putrescentiae* (Schrank) (Acarina : Acaridae). Zeszyty Problemowe Postepow Nauk Rolniczych, 252 : 207-229.

Ignatowicz, S. (1986). Chemosterilisation of Acarid mites (Acarida : Acaridae). Part IV. Potassium iodate and tin iodide as chemosterilants of the mold mite, *Tyrophagus putrescentiae* (Schrank). Roczniki Nauk Rolniczych, 16 : 9-16.

Ignatowicz, S. (1987a). Chemosterilisation of Acarid mites (Acarida : Acaridae). Part V. Chemosterilant activity and toxicity of thiourea against the mold mite, *Tyrophagus putrescentiae* (Schrank) and the flour mite, *Acarus siro* L. Roczniki Nauk Rolniczych, 17 : 47-60.

Ignatowicz, S. (1987b). Chemosterilization of Acarid mites (Acarida : Acaridae). Part VI. Chemosterilant effect of 5-fluorouracil on the flour mite *Acarus siro* L., and the mold mite *Tyrophagus putrescentiae* (Schrank). Roczniki nauk Rolnicych, 17 : 149-159.

Ignatowicz, S. (1987c). Chemosterilization of acarid mites (Acarida : Acaridae). Part VII. Effect of colchicine against the flour mite *Acarus siro* L., and the mold mite *Tyrophagus putrescentiae* (Schrank). Roczniki nauk Rolnicych, 17 : 161-167.

Ignatowicz, S. and Boczek, J. B. (1979). Sterility induced in 'Copra Mite' *Tyrophagus putrescentiae* by iodine salts. In : Rodriguez J. G. (Ed), Recent Advances in Acarology 1 Academic Press, New York. pp. 285-290.

Intervention Board (1996). Support buying of cereals. Leaflet no. IM (C) 15.

Iqbal, M., Verkerk, R. H. J., Furlong, M. J., Ong, P. C., Rahman, S. A. Wright, D. J. (1996). Evidence for resistance to *Bacillus thuringiensis* (*Bt*) subsp. *kurstaki* HD-1, *Bt* subsp. *aizawai* and abamectin in field populations of *Plutella xylostella* from Malaysia. Pestic. Sci., 48 : 89-97.

Jackson, K. and Webley, D. (1994). Effects of Dryacide on the physical properties of grains, pulses and oilseeds. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 635-637.

Jacobson, M. (1984). Control of stored-product insects with phytochemicals. In : Proc. 3rd Int. Working Conf. Stored Prod. Entomol. Kansas State University Manhattan, Kansas, October, 1983. pp 183-195.

Jacobson, M. (1986). The neem tree : natural resistance par excellence. In : Green, M. G. and Hedin, P. A. (Eds). Natural resistance of plants to pests : Roles of alleochemicals. American Chemical Society, Washington DC. pp 220-

Jacobson, M. (1989). Botanical Pesticides, Past, Present, and Future. In : Arnason, J. T., Philogene, B. J. R. and Morand, P. (Eds.) Insecticides of plant origin. American Chemical Society, Washington DC. pp. 1-10.

Johnson, D. E. and McGaughey, W. H. (1996). Natural mortality among Indian meal moth larvae with resistance to *Bacillus thuringiensis*. J. Invertebr. Pathol., 68 : 170-172.

Kaaya, G. P. (1992). Non-chemical agents and factors capable of regulating tick populations in nature : a mini review. Insect Sci. Applic., 13 (4) : 587-594.

Kalpaklioglu, A. F., Ferizli, A. G., Misirligil, Z., Demirel, Y. S. and Gurbuz, L. (1996). The effectiveness of benzyl benzoate and different chemicals as acaricides. Allergy, 51 (3) : 164-170.

Kaufman, W. R. (1988). The effects of steroids and azadirachtin on the salivary gland and ovary in ixodid ticks. J. Insect Physiol., 34 (7) : 721-723.

Kaufman, W. R. (1991). Further investigations on the action of ecdysteroids on the salivary glands of the female tick *Amblyomma americanum*. Exp. App. Acarol., 10 : 259-265.

Kaya, H. K. (1985). Entomogenous nematodes for insect control in IPM systems. In : Hass, M. A. and Herzog, D. C. (Eds). Biological control in agricultural IPM systems. Academic Press, New York. pp. 283-302.

Kellen, W. R. and Lindgren, J. E. (1971). Modes of transmission of *Nosema plodiae* Kellen and Lindgren, a pathogen of *Plodia interpunctella* (Hübner). J. Stored Prod. Res., 7 : 31-34.

Keller, B. and Langenbruch, G-A. (1993). Control of Coleopteran pests by *Bacillus thuringiensis*. In : Entwistle, P. F., Cory, J. S., Bailey, M. J. and Higgs, S. (Eds) *Bacillus thuringiensis*, an Environmental Biopesticide : Theory and Practice. John Wiley & Sons, Chicester, U.K. pp. 171-191.

Kettle, D. S. (1990). Medical and Veterinary Entomology. CAB International, Wallingford, U.K.

Khan, A. R. and Selman, B. J. (1989). *Nosema* spp. (Microspora : Microsporida : Nosematidae) of stored product Coleoptera and their potential as microbial control agents. Agric. Zool. Revs., 3 : 193-223.

Kneist, F. M. and Bischoff, E. R. C. (1995). Efficacy and safety of mite management by a new benzyl benzoate containing wash additive. In : Basomba, A. and Hernandez F. de Rojas, M. D. (Eds). XVI European congress of allergology and clinical immunology. 24-25 June 1995, Madrid, Spain. Monduzzi Editore, Bologna

Kneist, F. M., Blank, K. U. and Bischoff, E. R. C. (1996). Domestic mites as a cause of allergic diseases; a method for management in the home environment. Proc. XX Int Cong. Entomol. p 569.

Kneist, F. M., Wolfs, B. J., Vos, H., Ducheine, B. O. I., Van Schayk-Bakker, M. J., De Lange, P. J. P. Vos, E. M. P. and Van Bronswijk, J. E. M. H. (1992). Mechanisms and patient compliance of dust-mite avoidance regimens in dwellings of mite-allergic rhinitic patients. Clinical and Experimental Allergy, 22 : 681-689.

Koren, L. G. H. (1995). Long-term efficacy of acaricides against house dust mites (*Dermatophagoides pteronyssinus*) in a semi-natural test system. In : Koren, W. (Ed.) Allergen avoidance in the home environment a laboratory evaluation of measures against mite, fungal and cat allergens. Kerckebosch BV, Zeist. pp. 105-113.

Korunic, Z. (1996). Protect It. Improved diatomaceous earth in home and garden field. Report for Hedley Technologies Ltd, Vancouver, Canada.

Korunic, Z. (1997). Rapid assessment of the insecticidal value of diatomaceous earths without conducting bioassays. J. Stored Prod. Res., 33 : 219-229.

Kramer, K. J., Hendricks, L. H., Wojciak, J. H. and Fyler, J. (1985). Evaluation of fenoxycarb, *Bacillus thuringiensis*, and malathion as grain protectants in small bins. J. Econ. Entomol., 78 : 632-636.

Kreig, A. (1968). Effectiveness of *Bacillus thuringiensis* exotoxin on *Tetranychus telarius* (Acarina : Tetranychidae). J. Invertebr. Pathol., 12 : 478.

Krinsky, W. L. (1977). *Nosema parkeri*, sp. n., a microsporidian from the argasid tick *Ornithodorus pakeri* Cooley. J. Protozool., 24 : 52-56.

Lackie, A. M. (1988). Haemocyte behaviour. Adv. Insect Physiol., 21 : 85-178.

LaHue, D. W. (1970). Evaluation of malathion, diazinon, a silica aerogel and a diatomaceous earth as protectants on wheat against lesser grain borer attack in small bins. USDA, Agricultural Research Service, Marketing Research Report No 680.

Lasota, J. A. and Dybas, R. A. (1991). Avermectins, a novel glass of compounds : Implications for use in arthropod pest control. Ann. Rev. Entomol., 36 : 91-117.

Leahy, M. G. and Booth, K. S. (1980). Precocene induction of tick sterility and ecdysis failure. J. Med. Entomol., 17 (1) : 18-21.

Leal, W. S. and Kuwahara, Y. (1991). Cuticle wax chemistry of Astigmatid mites. In : Dusbabek, F. and Bukva, V. (Eds). Modern Acarology Vol. 2. Academia, Prague. pp. 419-423.

Leatherdale, D. (1965). Fungi infecting rust and gall mites (Acarina : Eriophyidae). J. Invertebr. Pathol., 7 : 325-328.

Le Patourel, G. N. J. (1986). The effect of grain moisture content on the toxicity of a sorptive silica dust to four species of grain beetle. J. Stored Prod. Res., 22 (2) : 63-69.

Li, L., Zhang, X. and Guo, Y. (1994). The influence of temperature and modified atmosphere on effectiveness of *Lavandula angustifolia* Mill. oil for controlling *Tyrophagus putrescentiae*. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 817-818.

Lipa, J. J. (1962). A review of diseases and microbial control of mites. Biuletyn Inst. Ochrony Roslin, 18: 175-202. (In Polish, summary in English)

Lipa, J. J. (1971). Microbial Control of mites and ticks. In : Burges, H. D. and Hussey, N. W. (Eds). Microbial Control and Insects and Mites. Academic Press, London pp. 357-373.

Lipa, J. J. and Chmielewski, W. (1976). Effect of insect growth regulator Dimilin W.P. 25 on development of *Tyrophagus putrescentiae* (Schrank) (Acarina : Acaridae). Bulletin de L'academie Polonaise des Sciences, 24 (7) : 381-384.

Liu, T. P. (1995). Controlling tracheal mites in colonies of honey bees with neem (Margosan-O) and flumethrin (Bayvarol). American Bee Journal, 136 : 562-566.

Longstaff, B. C. and Desmarchelier, J. M. (1983). The effects of the temperature-toxicity relationships of certain pesticides upon the population growth of *Sitophilus oryzae* (L.) (Coleoptera : Curculionidae). J. Stored Prod. Res., 19 (1) : 25-29.

Loschiavo, S. R. (1976). Effects of the synthetic insect growth regulators methoprene and hydroprene on survival, development or reproduction of six species of stored-product insects. J. Econ. Entomol., 69 (3) : 395-399.

Lozzia, G. C., Rigamonti, I. E. and Ottoboni, F. (1994). Chemical control testing on foodstuff mites. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 809-816.

Lunke, M. D. and Kaufman, W. R. (1992). Effects of the avermectin analogue MK-243 on vitellogensis and reproduction in the ixodid tick, *Amblyomma hebraeum*. Exp. Appl. Acarol., 13 : 249-259.

Lynch, S. M., Muggleton, J. and Starzewski, J. C. (1991). The distribution of mites in commercial grains stores In : Prickett A. J. and Muggleton, J. (Eds) Commercial grain stores 1988/89 England and Wales. Pest incidence and storage practice - part I and II. London, U.K. HGCA Project Report No. 29. pp. 41-44.

Maddox, J. V. (1975). Use of diseases in pest management. In : Metcalf, R. L. and Luckman, W. (Eds). Introduction to insect pest management. John Wiley & Sons, New York.

Majumder, S. K. and Bano, A. (1964). Toxicity of calcium phosphate to some pests of stored grain. Nature, 202 : 1359-1360.

Mango, C. K. A. and Moreka, L. (1979). Moulting hormone activity in the fifth nymphal instar of the tick *Ornithodoros porcinus porcinus*. In : Rodriguez J. G. (Ed.), Recent Advances in Acarology Volume I. Academic Press, New York. pp. 435-437.

Mansour, F. A., Ascher, K. R. S. and Abo-Moch, F. (1993). Effects of Margosan-O, Azatin and RD9-Repelin on spiders, and on predacious and phytophagous mites. Phytoparasitica, 21 (3) : 205-211.

Mauleon, H., Barre, N. and Panoma, S. (1993). Pathogenicity of 17 isolates of entomophagous nematodes (Steinernematidae and Heterorhabditidae) for the ticks *Amblyomma variegatum* (Fabricus), *Boophilus microplus* (Canestrini) and *Boophilus annulatus* (Say). Exp. Appl. Acarol., 17 : 831-838.

McCoy, C. W. (1981). Pest control by the fungus *Hirsutella thompsonii*. In : Burges, H. D. (Ed) Microbial Control of Pests and Plant Diseases 1970-1980. Academic Press, London. pp. 499-512.

McCoy, C. W., Samson, R. A. and Boucias, D. G. (1988). Entomogenous Fungi. In : Ignoffo, C. M. and Mandava, N. B (Eds). Handbook of Natural Pesticides. Volume V Microbial Insecticides. Part A Entomogenous Protozoa and Fungi.. CRC Press. pp. 151-236.

McGaughey, W. H. (1975a). A granulosis virus for Indian meal moth control in stored wheat and corn. J. Econ. Entomol., 68 (3) : 346-348.

McGaughey, W. H. (1975b). Compatability of *Bacillus thuringiensis* and granulosis virus treatments of stored grain with four grain fumigants. J. Invert. Pathol., 26 : 247-250.

McGaughey, W. H. (1980). *Bacillus thuringiensis* for moth control in stored wheat. Can. Ent., 112 : 327-331.

McGaughey, W. H. (1985). Insect resistance to the biological insecticide *Bacillus thuringiensis*. Science, 229 : 193-195.

McGaughey, W. H. (1994a). Implications of cross-resistance among *Bacillus thuringiensis* toxins in resistance management. Biocontrol Sci. Technol., 4 : 427-435.

McGaughey, W. H. (1994b). Problems of insect resistance to *Bacillus thuringiensis*. Argic. Ecosystems & Environ., 49 : 95-102.

McGaughey, W. H. and Beeman, R. W. (1988). Resistance to *Bacillus thuringiensis* in colonies of Indianmeal moth and almond moth (Lepidoptera : Pyralidae). J. Econ. Entomol., 81 (1) : 28-33.

McGaughey, W. H. and Dicke, E. B. (1980). Methods of applying *Bacillus thuringiensis* to stored corn for moth control. J. Econ. Entomol., 73 : 228-229.

McLaughlin, (1994). Laboratory trials on desiccant dust insecticides. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 638-645.

McLean, K. A. (1989). Drying and storing combinable crops. Farming Press, Ipswich U.K.

McMurty, J. A. (1984). A consideration of the role of predators in the control of acarine pests. In : Griffiths, D. A. and Bowman, C. E (Eds) Acarology VI Volume 1. Ellis Horwood, Chichester, U K. pp. 109-121.

Megalov, A. A. (1934). The mechanical method of controlling grain mites under the conditions of elevators and mechanized granaries. Grain Prod. J., 4 : 96-101.

Melicher, B. and Willomitzer, J. (1967). Bewerting der physikalischen insektizide. Sci. Parmaceut., 2 : 589-597.

Mietkiewski, R., Balazy, S. and van der Geest, L. P. S. (1993). Observations of a mycosis of spider mites (Acari : Tetranchyidae) caused by *Neozygites floridana* in Poland. J. Invert. Pathol., 61 : 317-319.

Morris, O. N. (1985). Susceptibility of 31 species of agricultural insect pests to the entomogenous nematodes *Steinernema feltiae* and *Heterorhabiditis bacteriophora*. Can. Entomol., 117 : 401-407.

Mothes-Wagner, U. (1984). Effects of the chitin synthesis inhibitor complex nikkomycin on oogeneis in the mite *Tetranychus urticae*. Pestic. Sci., 15 : 455-461.

Mothes-Wagner, U. (1986). Comparative histopathology of the chitin synthesis inhibitors Nikkomycin X/Z, Nikkomycin Z and Polyoxin D. I : Effects on moulting, reproduction and digestion in the spider mite *Tetranychus urticae*. Pestic. Sci., 17 : 607-620.

Muma, M. H. (1955). Factors contributing to the natural control of citrus insects and mites in Florida. J. Econ. Entomol., 48 : 432-438.

Mummigatti, S. G., Raghunathan, A. N. and Karanth, N. G. K. (1994). *Bacillus thuringiensis* variety *tenebrionis* (DSM-2803) in the control of coleopteran pests of stored wheat. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 1112-1115.

Mwangi, E. N., Dipeolu, O. O., Newson, R. M., Kaaya, G. P. and Hassan, S. M. (1991). Predators, parasites and pathogens of ticks : a review. Biocontr. Sci. Techn., 1 : 147-156.

Mwangi, E. N., Kaaya, G. P., Essuman, S. and Kimondo, M. G. (1994). Parasitism of *Amblyomma variegatum* by a Hymenopteran parasitoid in the laboratory, and some aspects of its basic biology. Biol. Contr., 4 : 101-104.

Mwangi, E. N., Shawgi, M. H., Kaaya, G. P. and Essuman, S. (1997). The impact of *Ixodiphagus hookeri*, a tick parasitoid, on *Amblyomma variegatum* (Acari : Ixodidae) in a field trial in Kenya. Exp. Appl. Acarol., 21 : 117-126.

Narahashi, T. (1976). Nerve membrane as a target of pyrethroids. Pestic. Sci., 7 : 267-272.

Navarro, S. and Donahaye, E. (1990). Generation and application of modified atmospheres and fumigants for the control of storage insects. In : Champ, B. R., Highley, E. and Banks, H. J. (Eds). Fumigation and controlled atmosphere storage of grain. ACIAR Proceedings No. 25 Singapore, 14-18 February, 1989. ACIAR, Canaberra, Australia. pp. 56-69.

Navarro, S., Lider, O. and Gerson, U. (1985). Response of adults of the grain mite *Acarus siro* L. to modified atmospheres. J. Agric. Entomol., 2 : 61-68.

Nawrot, J. and Harmatha, J. (1994). Natural products as antifeedants against stored product insects. Postharvest News and Information, 5 (2) : 17N-21N.

Neal, J. W., Lindquist, R. K., Gott, K. M. and Casey, M. L. (1987). Activity of the thermostable β-exotoxin of *Bacillus thuringiensis* on *Tetranychus urticae* and *T. cinnabarinus.* J. Agric. Entomol., 4 (1) : 33-40.

Nelson, R. D. and Show, E. D. (1974). A novel group of miticides containing the cyclopropane moiety : Laboratory experiments and field studies in strawberries on the twospotted spider mite. J. Econ. Entomol., 68 (2) : 261-266.

Nemec, V., Kahovcova, J. Peroutka, M. and Vesely, V. (1990). Precocenes : Possible means to control the bee mite, *Varroa jacobsoni* (Oudemans). Folia Parasitol., 37 : 157-163.

Niber, B. T. (1994). The ability of powders and slurries from ten plant species to protect stored grain from attack by *Prostephanus truncatus* Horn (Coleoptera : Bostrichidae) and *Sitophilus oryzae* L. (Coleoptera : Curculionidae). J. Stored Prod. Res., 30 (4) : 297-301.

Nickson, P. J., Desmarchelier, J. M. and Gibbs, P. (1994). Combination of cooling with a surface application of Dryacide to control insects. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 638-645.

Noble, R. M., Hamilton, D. J. and Osborne, W. J. (1982). Stability of pyrethroids on wheat in storage. Pestic. Sci., 13 : 246-252.

Nolan, J. and Roulston, W. J. (1979). Acaricide resistance as a factor in the management of Acari of medical and veterinary importance. In : Rodriguez J. G. (Ed), Recent Advances in Acarology Volume II. Academic Press, New York. pp. 3-13.

Norris, J. D. (1958). Observations on the control of mite infestations in stored wheat by *Cheyletus* spp. (Acarina, Cheyletidae). Ann. Appl. Biol., 46 (3) : 411-422.

Oberlander, H., Silhacek, D. L., Shaaya, E. and Ishaaya, I. (1997). Current status and future perspectives of the use of insect growth regulators for the control of stored product insects. J. Stored Prod. Res., 33 : 1-6.

O'Connor, B. M. (1984). Acarine-Fungal relationships : the evolution of symbiotic associations. In : Wheeler, Q. and Blackwell M. (Eds) Fungus-Insect Relationships Perspectives in Ecology and Evolution, Columbia University Press, New York. p. 375-381.

Oliver, J. H. and Dotson, E. M. (1993). Hormonal control of molting and reproduction in ticks. American Zoologist, 33 (3) : 384-396.

Oliver, J. H. Jr., Pound, J. M . and Severino, G. (1985). Evidence of a juvenile-hormone-like compound in the reproduction of *Dermanyssus gallinae* (Acari : Dermanyssidae. J. Med. Entomol., 22 : 281-286.

Ottoboni, F., Rigamonti, I. E. and Lozzia, G. C. (1992). House dust mites prevention in Italy. Boll. Zool. agr. Bachic., 24 (2), 113-120.

Parkinson, C. L., Barron, C. A., Barker, S. M., Thomas, A. C. and Armitage, D. M. (1991a). Longevity and fecundity of *Acarus siro* on four field and eight storage fungi. Exp. Appl. Acarol., 11 : 1-8.

Parkinson, C. L., Jamieson, N., Eborall, J. and Armitage, D. M. (1991b). Comparison of the fecundity of three species of grain store mites on fungal diets. Exp. Appl. Acarol., 12 : 297-302.

Perrucci, S. (1995). Acaricidal activity of some essential oils and their constituents against *Tyrophagus longior*, a mite of stored food. J. Food Prot., 58 (5) : 560-563.

Perugia, G., Inglesfield, C. and Tipton, J. D. (1986). The evaluation of a novel acylurea (flufenoxuron) on top fruit and citrus in Italy. Proc. 1986 Brit. Crop Prot. Conf. - Pests and Diseases, 3 : 315-322.

Pezowicz, E. and Sandner, H. H. (1983). Laboratory experiments on the use of nematodes for the control of pests of stored products. Ochrona Roslin, 27 (11/12) : 36. (In Polish, English abstract)

Piccardi, P., Massardo, P., Bettarini, F. and Longoni, A. (1980). New chlorinated juvenile hormone analogues and their biological activity. Pestic. Sci. 11 : 423-431.

Pinniger, D. B., Simmonds, M., Cox, P. D., Walters, K. and Watson, E. (1996). Natural pesticides for organic farming. MAFF, CSL, Slough. 61 pp.

Pitman, R. M. (1971). Transmitter substances in insects : A review. Comp. Gen. Pharm., 2 : 347-371.

Podboronov, V. M. (1991). Antibacterial protective mechanisms of Ixodoid ticks. In : Dusbabek, F. and Bukva, V. (Eds.). Modern Acarology Volume 2. Academia, Prague. pp. 375-380.

Poinar, G. Jr. and Poinar, R. (1998). Parasites and pathogens of mites. Ann. Rev. Entomol., 43 : 449-469.

Potts, M. F. and Rodriguez J. G. (1978). Effects of spice oils on *Tyrophagus putrescentiae*. Proc. of the entomological soc. of America - North Central branch 57th Annual Con., 33 : 27-28.

Press, J. W., Phillips, R. H., Lum, P. T. M. and Miller, A. M. (1972). Tricalcium phosphate as an additive to CSM and all-purpose wheat flour for control of insect infestations. J. Econ. Entomol., 65 (1) : 254-257.

Prickett, A. J. (1991). Results from part A of the fact sheet - sites visited. In : Prickett, A. J. and Muggleton, J. (Eds). Commercial grain stores 1988/89 England and Wales. Pest incidence and storage practice - part I. London, U.K. HGCA Project Report No. 29. pp 11-17.

Prickett, A. J. (1994). Animal feed mills 1992, England and Wales, Pest Management MAFF, CSL Report.

Prickett, A. J. (1997). Oilseed stores 1995, England. Pest management. MAFF, CSL Report No. 102. pp.

Prickett, A. J. and Buckland A. (1997). Resistance to organophosphorus pesticides in stored-product mites in the UK. Proc. Resistance '97, 14-16 April, Harpenden, UK

Pulpan, J. and Verner, P. H. (1965). Control of Tyroglyphoid mites in stored grain by the predatory mite *Cheyletus eruditus* (Schrank). Can. J. Zool., 43 : 417-432.

Putter, I., MacConnell, J. G., Preiser, F. A., Haidri, A. A., Ristich, S. S. and Dybas, R. A. (1981). Avermectins : novel insecticides, acaricides and nematicides from a soil microorganism. Experentia, 37 : 963-964.

Qadri, S. S. H., Usha, G. and Jabeen, K. (1984). Sub-acute dermal toxicity of Neemrich-100 (tech.) to rats. Int. Pest Control, 26 : 18-20.

Quarles, W. (1992a). Botanical pesticides from *Chenopodium* ?. The IPM Practitioner, 14 (2) : 1-11.

Quarles, W. (1992b). Diatomaceous earth for pest control. The IPM Practitioner, 14 (5/6) : 1-11.

Quicke, D. L. J. (1997). Parasitic wasps. Chapman and Hall, London.

Reed, D. K. (1981). Control of mites by non-occluded viruses. In : Burges, H. D. (Ed). Microbial Control of pests and plant diseases 1970-1980. Academic Press, New York. pp. 427-432.

Reed, D. K., Tashiro, H. and Beavers, J. B. (1975). Determination of mode of transmission of the citrus red mite virus. J. Invertebr. Path., 26 : 239-246.

Regev. S and Cone, W. W. (1976). Evidence of gonodotropic effect of farnesol in the twospotted spider mite, *Tetranychus urticae*. Environ. Entomol., 5 : 517-519.

Rehacek, J., Kovacova, E. and Kocianova, E. (1996). Isolation of *Nosema slovaca* (Microsporidiae) from *Dermancentor reticulatus* ticks (Acari : Ixodidae) collected in Hungary. Exp. Appl. Acarol., 20 : 57-60.

Renwrantz, L. (1983). Involvement of agglutins (lectins) in invertebrate defense reactions : the immuno-biological importance of carbohydrate-specific binding molecules. Dev. Comp. Immunol., 7 : 603-608.

Rizvi, S. J. H., Pandey, S. K., Mukerji, D. and Mathur, S. N. (1980). 1,3,7-trimethylxanthine, a new chemosterilant for stored grain pest *Callosobruchus chiensis*. Z. ang. Ent., 90 : 378-381.

Rodriguez, J. G. (1972). Inhibition of acarid mite development by fatty acids. In : Rodriguez, J. G. (Ed.) Insect and mite nutrition, North Holland Publishing Company, Amsterdam, pp 637-650.

Rodriguez, J. G., Potts, M. F. and Patterson, G. (1979). Allelochemic effects of some flavoring components on the acarid, *Tyrophagus putrescentiae*. In : Rodriguez J. G. (Ed), Recent Advances in Acarology, 1 Academic Press, New York. pp. 251-262.

Rodriguez, J. G., Potts, M. F. and Patterson, C. G. (1984). Mycotoxin-producing fungi : effects on stored product mites. In : Griffiths, D. A. and Bowman, C. E (Eds) Acarology VI Volume 1. Ellis Horwood, Chichester, U K. pp. 343-350.

Rodriguez, J. G., Potts, M. F. and Rodriguez, L. D. (1980). Mycotoxin toxicity to *Tyrophagus putrescentiae*. J. Econ. Entomol., 73 : 282-284.

Roulston, W. J., Schuntner, C. A. and Schnitzerling, H. J. (1966). Metabolism of coumaphos in larvae of the cattle tick *Boophilus microplus*. Aust. J. Biol. Sci., 19 : 619-633.

Roush, R. T. and Wright, J. E. (1986). Abamectin : toxicity to house flies (Diptera : Muscidae) resistant to synthetic organic insecticides. J. Econ. Entomol., 79 : 562-564.

Royalty, R. N., Hall, F. R. and Taylor, R. A. J. (1990). Effects of thuringiensin on *Tetranychus urticae* (Acari : Tetranychidae) mortality, fecundity and feeding. J. Econ. Entomol., 83 : 792-798.

Saint Georges-Gridelet, D. de (1987). Destruction of eggs of *Dermatophagoides pteronyssinus* (Acari: Pyroglyphidae) by natamycin and imidazoles in vitro. Int. J. Acarol. 13 (1) : 5-14.

Sakagami, Y., Taki, K., Matsuhisa, T. and Marumo, S. (1992). Identification of 2-deoxyecdysone from the mite *Tyrophagus putrescentiae*. Experientia, 48 : 793-795.

Saleh, S. M., El-Helaly, M. S., Rawash, I. A. and El-Gayar, F. H. (1976). Effects of the JH-analogue altosid and altozar on the North American house dust mite, *Dermatophagoides farinae* Hughes (Acarina, Pyroglyphidae). Acarologia, 18 : 345-350.

Salt, G. (1970). The cellular defence reactions of insects. Cambridge Mongraphs in experimental biology No. 16. Cambridge University press, Cambridge, UK.

Samish, M. and Glazer, I. (1991). Pathogenicity of parasitic nematodes to ticks. In : Dusbabek, F. and Bukva, V. (Eds.). Modern Acarology Volume 2. Academia, Prague. pp. 629-632.

Samish, M., Glazer, I. and Alekseev, E. (1996). The susceptibility of the developmental stages of ticks (Ixodidae) to entomopathogenic nematodes. In : Mitchell, R., Horn, D. J., Needham, G. R. and Welbourn, W. C. (Eds) Proc. Acarology IX Volume 1. Ohio Biological Survey, Ohio. pp. 121-123.

Sanguanpong, U. and Schmutterer, H. (1992). Laboratory trials on the effects of neem oil and neem seed based extracts against the two spotted spider mite *Tetranychus urticae* Koch (Acari : Tetranychidae). Zeischrift fur Pflanzenkrankheiten und Pflanzenschutz, 99 (6) : 637-646.

Saxena, R. C., Jilani, G. and Kareem, A. A. (1989). Effects of neem on stored grain insects. In : Jacobson, M. (Ed.). 1988 Focus on Phytochemical Pesticides Vol. 1. The Neem Tree. CRC Press, Boca Raton. pp. 97-111.

Schober, G., Wetter, G, Bischoff, E., Van Bronswijk, J. E. M. H. and Kneist, F. M. (1987). Control of house-dust mites (Pyroglyphidae) with home disinfectants. Exp. Appl. Acarol., 3 : 179-189.

Schooneveld, H. and Veenstra, J. A. (1988). Immunocytochemistry. In : Gilbert, L. I. and Miller, T. A. (Eds) Immunological techniques in insect biology. Springer-Verlag, New York.

Schmit, A. R. and Ratcliffe, N. A. (1977). The encapsulation of foreign tissue implants in *Galleria mellonella* larvae. J. Insect Physiol., 23 : 175-184.

Schmutterer, H. (1988). Potential of azadirachtin-containing pesticides for integrated pest control in developing and industrialised countries. J. Insect Physiol., 34 (7) : 713-719.

Schmutterer, H. (1990). Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. Ann. Rev. Entomol., 35 : 271-297.

Schwalbe, C. P., Burkholder, W. E. and Boush, G. M. (1974). *Mattesia trogodermae* infection rates as influenced by mode of transmission, dosage and host species. J. Stored Prod. Res., 10 : 161-166.

Scott, J. G. (1989). Cross-resistance to the biological insecticide abamectin in pyrethroid-resistant house flies. Pestic. Biochem. Physiol., 34 : 27-31.

Searle, T. and Doberski, J. (1984). An investigation of the entomogenous fungus *Beauvaris bassiana* (Bals.) Vuill. as a potential biological control agent for *Oryzaephilus surinamensis*. J. Stored Prod. Res., 20 (1) : 17-23.

Secoy, D. M. and Smith, A. E. (1983). Use of plants in control of agricultural and domestic pests. Economic Botany, 37 (1) : 28-57.

Shapas, T. J., Burkholder, W. E. and Boush, G. M. (1977). Population suppression of *Trogoderma glabrum* by using pheromone luring for protozoan pathogen dissemination. J. Econ. Entomol., 70 (4) : 469-474.

Shaw, J. G., Moffitt, C. and Scriven, G. T. (1967). Biotic potential of Phytoseiid mites fed on virus-infected citrus red mites. J. Econ. Entomol., 60 (6) : 1751-1752.

Sigrianskii, A. M. (1940). Granary mites as vectors of diseases of agricultural plants. Uchen. Zap. gosud. Univ. no. 42 Zool. 167-177. (In Russian, abstract in RAE, 31 : 71).

Simpson, W. F. (1973). The effect of propionic acid on insect and mite infestation in grain. Combining the Report of the Infestation Control Laboratory 1968-70 and Pest Infestation Research 1970, HMSO p. 31.

Sinha, R. N. (1964). The effect of low temperature on survival of some stored product mites. Acaralogia, 6 : 336-341.

Smith, C. N., LaBrecque, G. C. and Borkovec, A. B. (1964). Insect Chemosterilants. Ann. Rev. Entomol., 9 : 269-284.

Smith, K. M. and Cressman, A. W. (1962). Birefringent crystals in virus-diseased citrus red mites. J. Insect Pathol., 4 : 229-236.

Smith, K. M., Hills, G. J., Munger, F. and Gilmore, J. E. (1959). A suspected virus disease of the citrus red mite *Panonychus citri* (McG.). Nature, 184 : 70.

Smitley, D. R., Kennedy, G. G. and Brooks, W. M. (1986). Role of the entomophagous fungus, *Neozygites floridana*, in population declines of the twospotted spider mite, *Tetranychus urticae*, on field corn. Entomol. Exp. Appl., 41 : 255-264.

Snelson, J. T. (1987). Grain Protectants. ACIAR, Canberra.

Soloman, K. R. and Evans, A. A. (1977). Activity of juvenile hormone mimics in egg-laying ticks. J. Med. Entomol., 14 (4) : 433-436.

Soloman, K. R., Mango, C. K. A. and Obenchain, F. D. (1982). Endocrine mechanisms in ticks : effects of insect hormones and their mimics on development on development and reproduction. In : Obenchain, F. D. and Galun, R. (Eds) Physiology of Ticks. Pergamon Press, Oxford UK. pp. 399-438.

Solomon, M. E. (1946a). Tyroglyphid mites in stored products. Nature and amount of damage to wheat. Ann. Appl. Biol., 33 : 280-289.

Solomon, M. E. (1946b). Tyroglyphid mites in stored products. Ecological studies. Ann. App. Biol., 33 : 82-97.

Solomon, M. E. (1961). Interactions of a predator and physical factors in the control of a grain mite. Verh. Int. Kongr. Ent. Wien 1960, 1 : 768-772.

Solomon, M. E. (1962). Notes on the extraction and quantitative estimation of the Acaridae (Acarina). Progress in soil zoology. Proceedings of a colloquium on research methods in soil zoology, Rothampstead, 1 : 305-307.

Solomon, M. E. (1969). Experiments on predator-prey interactions of storage mites. Acarologia, 11 : 484-503.

Solomon, M. E., Hill, S. T., Cunnington, A. M., Ayerst, G. (1964). Storage fungi antagonistic to the flour mite (*Acarus siro* L.). J. Appl. Ecol., 1 : 119-125.

Sonenshine, D. E. (1991). Biology of Ticks Volume 1. Oxford University Press, Oxford.

Staal, G. B. (1975). Insect growth regulators with juvenile hormone activity. Ann. Rev. Entomol., 25 : 165-169.

Stables, L. M. (1984). Effect of pesticides on three species of *Tyrophagus*, and detection of resistance to pirimiphos-methyl in *T. palmarum* and *T. putrescentiae*. In : Griffiths, D. A. and Bowman, C. E. (Eds) Acarology VI Volume 2. Ellis Horwood, Chichester, U K. pp. 1026-1033.

Starzewski, J. C. (1991). The incidence of resistance to pirimiphos-methyl in stored product mites collected from commercial grain stores in the United Kingdom. In : Prickett, A. J. and Muggleton, J. (Eds). Commercial grain stores 1988/89 England and Wales. Pest incidence and storage practice - part I. London, U.K. HGCA Project Report No. 29. pp 11-17.

Statutory Instruments No. 1985. The Pesticides (Maximum Residue Levels in crops, food and feeding stuffs) Regulation 1994, HMSO, London, 1994 p. 18.

Steinhaus, E. A. (1959). Possible virus disease in European red mite. J. Insect Path., 1 : 435-437.

Stengard Hansen, L., Herling, C. and Danielson, C. (1996). Densities of *Lepidoglyphus destructor* and levels of its major allergen Lep d 1 in grain and flour. Proc. XX Int. Congr. Entomol. p. 569.

Stephens, R., Spurgeon, A. and Berry, H. (1996). Organophosphates : The relationship between chronic and acute exposure effects. Neurotoxicity and Teratology, 18 : 449-453.

Stepien, Z. (1974). Effect of carbon dioxide on *Tyrophagus putrescentiae* (Schr.) (Acarina : Acaridae). Proc. 4th Int. Congr. Acarol., Budapest. pp. 249-255.

Subramanyam, Bh. and Cutkomp, L. K. (1985). Moth control in stored grain and the role of *Bacillus thuringiensis* : An overview. Residue Reviews, 94 : 1-47.

Subramanyam, Bh. and Cutkomp, L. K. (1987). Influence of posttreatment temperature on toxicity of pyrethroids to five species of stored-product insects. J. Econ. Entomol., 80 (1) : 9-13.

Subramanyam, B., Swanson, C. L., Madamanchi, N. and Norwood, S. (1994). Effectiveness of Insecto, a new diatomaceous earth formulation in suppressing several stored-grain insect species. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 650-659.

Summers, F. M. and Witt, R. L. (1972). Nesting behavior of *Cheyletus eruditus*. The Pan-Pacific Entomologist, 48 : 261-269.

Sundaram, K. M. S. and Sloane, L. (1995). Effects of pure and formulated azadirachtin, a neem based biopesticide, on the phytophagous spider mite, *Tetranychus urticae* Koch. J. Environ. Sci. Health, B30 (6) : 801-814.

Szlendak, E. (1998). Influence of folic acid, methionine and riboflavin on population parameters of *Tyrophagus putrescentiae* (Schr.). Ochrona Srodowiska, 2 : 105-114.

Takiguchi, Y., Mishima, H., Okuda, M, Terao, M., Aoki, A. and Fukuda, R. (1980). Milbemycins, a new family of macrolide antibiotics : fermentation, isolation and physiochemical properties. J. Antibiotics, 33 : 1120-1127.

Tarshis, I. B. (1960). Control of the snake mite (*Ophionyssus natricis*), other mites and certain insects with the sorptive dust, SG 67. J. Econ. Entomol., 53 (5) : 903-908.

Tarshis, I. B. (1964). A sorptive dust for control of the Northern fowl mite, *Ornithonyssus sylviarum*, infesting dwellings. J. Econ. Entomol., 57 (1) : 110-111.

Thaung, M. and Collins, P. J. (1986). Joint effects of temperature and insecticides on mortality and fecundity of *Sitophilus oryzae* (Coleoptera : Curculionidae) in wheat and maize. J. Econ. Entomol., 79 : 909-914.

Thind, B. B. (1991). Assessment of some of the physical changes occurring in grain following treatment with caustic soda and the effects of these changes on the infestability of the grain by *Calogyphus* sp. MAFF CSL Report 19 pp.

Thind, B. B. and Edwards, J. P. (1990). Stimulation of egg production in the grain mite *Acarus siro* by the juvenile-hormone analogue fenoxycarb. Exp. Appl. Acarol., 9 : 1-10.

Thind, B. B., Muggleton, J., Bedi, A. and Buckland, A. (1996). A new technique for detecting pesticide resistance in the stored product mite *Lepidoglyphus destructor* (Schrank) (Glycyphagidae). In : Mitchell, R., Horn, D. J., Needham, G. R. and Welbourn, W. C. (Eds). Proc. Acarology IX Vol. 1., Ohio, USA, 1996, pp. 645-650.

Thuy, P. T., Dien, L. D. and Van, N. G. (1994). Research on multiplication of *Beauveria bassiana* fungus and preliminary utilisation of Bb bioproduct for pest management in stored products in Vietnam. In : Highley E., Wright, E. J., Banks, H. J. and Champ, B. R. (Eds). Proc. 6th Int. Working Conf. Stored-prod. Prot., Canberra, Australia 1994, pp. 1132-1133.

Vail, P. V., Tebbets, J. S., Cowan, D. C. and Jenner, K. E. (1991). Efficacy and persistence of a granulosis virus against infestations of *Plodia interpunctella* (Hubner) (Lepidoptera : Pyralidae) on raisins. J. Stored Prod. Res., 27 (2) : 103-107.

Vial, T., Nicolas, B. and Descotes, J. (1996). Clinical immunotoxicity of pesticides. J. Toxicol. Environ. Health, 48 : 215-229.

Vollinger, M. (1987). The possible development of resistance against neem seed kernel extract and deltamethrin in *Plutella xylostella*. In : Schmutterer, H. and Ascher, K. R. S. (Eds). Natural pesticides from the neem tree and other tropical plants. Proc. 3rd Int. Neem Conf., Nairobi, 1986. Eschborn : GTZ. pp. 543-554.

Warden, J. (1996). Pesticide link with Gulf War Syndrome. British Medical Journal, 313 : 897.

Watanabe, F., Tadaki, S-I, Takaoka, M., Ishino, M and Morimoto, I. (1989). Killing activities of the volatiles emitted from essential oils for *Dermatophagoides pteronyssinus*, *Dermatophagoides farinae* and *Tyrophagus putrescentiae*. Japanese J. of Pharmacology, 43 (2) :163-168.

Watters, F. L., White, N. D. G. and Cote, D. (1983). Effect of temperature on toxicity and persistence of three pyrethroid insecticides applied to fir plywood for the control of the red flour beetle (Coleoptera : Tenebrionidae). J. Econ. Entomol., 76 : 11-16.

Weiser, J. (1956). *Nosema steinhausi* n. sp. Nova mikrosporidie z roztoce *Tyrophagus noxius* (Acarina, Tyroglyphidae). Ceskoslovenska parasitologie, 3 : 187-192. (In Czech).

Wester, R. C., Quan, D. and Maibach, H. I. (1996). *In vitro* percutaneous absorption of model compounds glyphosphate and malathion from cotton fabric into and through human skin. Food Chem. Toxicol., 34 : 731-735.

White, G. D., Berndt, W.L., Schesser, J. H. and Fifield, C. C. (1966). Evaluation of four inert dusts for the protection of stored wheat in Kansas from insect attack. USDA Agric. Research Service Report ARS-51-8.

White, N. D. G. (1984). Residual activity of organophosphorus and pyrethroid insecticides applied to wheat stored under simulated Western Canadian conditions. Can. Ent., 116 : 1403-1410.

White, N. D. G. and Jayas, D. S. (1991). Control of insects and mites with carbon dioxide in wheat stored at cool temperatures in non airtight bins. J. Econ. Entomol., 84 : 1933-1942.

Whitehead, R. (Ed.) (1997). The U.K. Pesticide Guide 1997. CABI and BCPC.

Wilkin, D. R. (1975a). The control of stored product mites by contact acaricides. Proc. 8th Br. Insectic. Fungic. Conf. 1975, pp. 355-364.

Wilkin, D. R. (1975b). The effects of mechanical handling and the admixture of acaricides on mites in farm-stored barley. J. Stored Prod. Res., 11 : 87-95.

Wilkin, D. R. and Hope, J. A. (1973a). Evaluation of pesticides against stored product mites. J. Stored Prod. Res., 8 : 323-327.

Wilkin, D. R. and Hope, J. A. (1973b). The effects of grain conveyance on mite populations. Pest Infestation Control Report 1968-70. HMSO, London. p. 116.

Wilkin, D. R. and Stables, (1985). The effects of dusts containing etrimfos, methacrifos or pirimiphos-methyl on mites in the surface layers of stored barley. Exp. Appl. Acarol., 1 : 203-211.

Wilkin, D. R. and Thind, B. B. (1984). Stored product mites detection and loss assessment in animal feed. Proc. 3rd Int. Working Conf. Stored Prod. Prot. 1983, Kansas State University, Manhattan KS, pp. 608-620.

Wilkin, D. R., Binns, T. J. and Dawson, B. (1988). The assessment of a new formulation of cypermethrin as a grain protectant. Brighton Crop Protection Conference. Pests and Diseases - 1988, 3 : 965-970.

Williams, G. C. and Hurlock, E. T. (1969). Insecticidal and acaricidal activity of propionic acid as a mould inhibitor on grain. Report of the Infestation Control Laboratory for 1965-67, HMSO p. 16.

Wisniewski, H. M., Sigurdarson, S., Rubenstein, R., Kascsak, R. J. and Carp, R. I. (1996). Mites as vectors for scrapie. The Lancet, 347 : 1114.

Wright, D. J. (1986). Biological activity and mode of action of avermectins. In : Ford, M. G., Lunt, G. G., Reay, R. C. and Usherwood, P. N. R. (Eds). Neuropharmacology and pesticide action. Ellis Horwood, Chichester. pp 174-202.

Wright, J. E. (1969). Hormonal termination of larval diapause in *Dermacentor albiptus*. Science, 163 : 390-391.

Yamaguchi, I. (1996). Pesticides of microbial origin and application of molecular biology. In : Copping L. G. (Ed.). Crop protection agents from nature. Natural products and analogues. The Royal Society of Chemistry , Cambridge UK. pp 27-49.

Zaki A. M., Darwish, E. T. E. and Abdella, M. M. H. (1990). Bio-efficacy of certain chitin synthesis inhibitors on dipterous flies and mites inhabiting dung of farm animals. Anz. Schadlingskde Pflanzenshutz Umweltschutz, 63 : 69-73.

Zdarkova, E. (1986). Mass rearing of the predator *Cheyletus eruditus* (Schrank) (Acarina : Cheyletidae) for biological control of acarid mites infesting stored products. Crop Protection, 5 (2) : 122-124.

Zdarkova, E. (1991). Application of the bio-preparation 'Cheyletin' in empty stores. In : Dusbabek, F. and Bukva, V. (Eds.). Modern Acarology Volume 1. Academia, Prague. pp. 607-610.

Zdarkova, E. (1994). The effectiveness of organophosphate acaricides on stored product mites interacting in biological control. Exp. Appl. Acarol., 18 : 747-751.

Zdarkova, E. (1997). The susceptibility of different strains of *Cheyletus eruditus* (Acarina : Cheyletidae) to organophosphate acaricides. Exp. Appl. Acarol., 21 : 259-264.

Zdarkova, E. and Horak, E. (1990). Preventative biological control of stored food mites in empty stores using *Cheyletus eruditus* (Schrank). Crop Protection, 9 : 378-382.

Zdarkova, E. and Pulpan, J. (1973). Low temperature storage of the predatory mite *Cheyletus eruditus* (Schrank) for future use in biological control. J. Stored Prod. Res., 9 : 217-220.

Table 1 - Summary of efficacy of different admixture compounds against storage mites

| COMPOUND | MITE SPECIES | DOSE (mg kg $^{-1}$ )* (TEMP / RH ) | APPLICATION | MORTALITY * | REFERENCE |
|---|---|---|---|---|---|
| **Growth Regulators** | | | | | |
| Fenoxycarb | *A. siro* | 10<br>100<br>(20°C / 80%) | Food | + 43 % eggs +<br>99 % eggs | Thind & Edwards (1990) |
| Fenoxycarb | *A. siro* | 0.5 - 8 | Food | Adults 37% - 99%<br>Larvae 35% - 95% | Buchi (1990) |
| Methoprene | *A. siro* | 47.5 - 190 | Food | Adults 53% - 88%<br>Larvae 54% - 84% | Buchi (1990) |
| 56 JHAs | *T. putrescentiae* | 0.0001% - 10%<br>(25°C / 85 %) | Topically | Ovicidal, morphogenetic & sterilising effects | Czaja-Topinska et al (1979) |
| Diflubenzuron (Dimilin) | *T. putrescentiae* | 1000 & 100,000<br>(25°C / 85 %) | Wheat | 60-70% of larvae reached adulthood | Lipa & Chmielewski (1976) |
| **Inert Dusts** | | | | | |
| Dryacide | *A. siro* & *L. destructor*<br>*A. siro* | 1000 & 3000<br>(17.5°C / 60 %)<br>3000<br>(17.5°C / 75 %) | Wheat<br><br>Wheat | 100% at 14% mc<br><br>100% at 16% mc | Cook & Armitage (1996) |
| Dryacide | *A. siro*<br><br>*L. destructor* | 3000 & 5000<br>(10, 17.5 & 25°C)<br>5000<br>(10, 17.5 &25°C) | Wheat<br><br>Wheat | 100% at 14.5 % mc<br><br>100% at 14.5 % mc | Cook & Armitage (1999) |
| Super Insecolo | Astigmata & Prostigmata | 50<br>(Field) | Wheat | 98% | Fields & Timlick (1995) |
| Dri-die 67 | *Tyrophagus* sp. | 20 mg<br>(24-26°C/75&100%)<br>50 mg<br>(25-26°C / 25,50,75 & 100 %) | Dishes<br><br>With/without culture media | No effect on eggs, larvae desiccated<br>Killed mixed stages in 3 hours | Tarshis (1960) |
| **Pyrethroids** | | | | | |
| Cypermethrin | *A. siro* | 2, 4 & 8<br>(22°C / 100 %) | Wheat | 5%, 45% & 66% after 4 weeks | White (1984) |
| | *A. siro* | 0.125 - 2<br>(17°C / 75 %) | Wheat | Ineffective after 1 day - 6 months | Wilkin et al (1988) |
| | *A. siro* | 2 %<br>(25°C / 75 %) | Potter Tower | 83 % after 24 hours | Lozzia et al (1994) |
| | *L. destructor* | 2 %<br>(25°C / 75 %) | Potter Tower | 96.2 % after 24 hours | Lozzia et al (1994) |
| | *L. destructor* | 0.25 - 2<br>(17°C / 75 %) | Wheat | 75 % after 1 day - 6 months<br>100 % after 4 months | Wilkin et al (1988) |
| | *G. domesticus* | 2%<br>(25°C / 75 %) | Potter Tower | 97.6 % after 24 hours | Lozzia et al (1994) |
| | *T. putrescentiae* | 2%<br>(25°C / 75 %) | Potter Tower | 64% after 24 hours | Lozzia et al (1994) |
| Permethrin | *A. siro* | 2, 4 & 8<br>(22°C / 100 %) | Wheat | 0%, 20% & 54% after 4 weeks | White (1984) |

Table 1 - Continued

| COMPOUND | MITE SPECIES | DOSE (mg kg $^{-1}$)* (TEMP / RH) | APPLICATION | MORTALITY * | REFERENCE |
|---|---|---|---|---|---|
| Permethrin | *T. putrescentiae* | 500 | Culture | 98% after 3 weeks | Chisaka et al (1984) |
| Bioresmethrin | *A. siro* *L. destructor* *T. putrescentiae* | 2 (17.5$^o$C / 75 %) | Wheat | 100% after 14 days 100% after 14 days > 75 % after 14 days | Wilkin and Hope (1973a) |
| Bioresmethrin + piperonyl butoxide | *A. siro* *L. destructor* *T. putrescentiae* | 2 + 20 (17.5$^o$C / 75 %) | Wheat | 100% after 14 days > 75 % after 14 days > 75 % after 14 days | Wilkin and Hope (1973a) |
| Bioresmethrin + piperonyl butoxide | *T. longior* *T. palmarum* *T. putrescentiae* | 10 + 10 (17.5$^o$C / 80 %) | Wheat | ~ 75 % after 14 days ~ 75 % after 14 days ~ 75 % after 14 days | Stables (1984) |
| Bioresmethrin + piperonyl butoxide | *A. siro* | 4+20, 2+20 & 2+2 (15$^o$C) | Wheat | ~ 100 % after 14 days | Wilkin (1975a) |
| Bioresmethrin + piperonyl butoxide | *Acarus* sp. | 0.5% + 0.5% (14$^o$C / 90 %) | Cheese | 'Large numbers' after 3 weeks | Anderson & Wilkin (1984) |
| Bioallethrin | *A. siro* *L.. destructor* *T. putrescentiae* | 2 (17.5$^o$C / 75 %) | Wheat | Ineffective | Wilkin and Hope (1973a) |
| Bioallethrin + piperonyl butoxide | *A. siro* *L. destructor* *T. putrescentiae* | 2 + 20 (17.5$^o$C / 75 %) | Wheat | Ineffective | Wilkin and Hope (1973a) |
| Pyrethrins | *A. siro* *L. destructor* *T. putrescentiae* | 2 (17.5$^o$C / 75 %) | Wheat | Ineffective | Wilkin and Hope (1973a) |
| Pyrethrins + piperonyl butoxide | *A. siro* *L. destructor* *T. putrescentiae* | 2 + 20 (17.5$^o$C / 75 %) | Wheat | 100 % after 14 days > 75 % after 14 days ~ 50% after 14 days | Wilkin and Hope (1973a) |
| Phenothrin | *T. putrescentiae* | 500 | Culture | 99.7 % after 3 weeks | Chisaka et al (1984) |
| Fenopropathrin | *T. putrescentiae* | 500 | Culture | 99.5 % after 3 weeks | Chisaka et al (1984) |
| Bifenthrin | *A. siro* | 1 & 0.5 | Wheat | 100 % & 75% after 1 day | Binns (1989) |
| Bifenthrin | *A. siro* | 1 (17.5$^o$C / 75 %) | Wheat | 50 % after 4 weeks, ineffective after 12 weeks | Binns (1989) |
| Deltamethrin | *A. siro* | 1 & 0.5 | Wheat | 75% & 25% after 1 day | Binns (1989) |
| Deltamethrin | *A. siro* | 1 (17.5$^o$C / 75 %) | Wheat | 50% after 4 weeks, ineffective after 12 weeks | Binns (1989) |
| **Botanicals** | | | | | |
| Lavender oil | *T. longior* | 1.00 % (25$^o$C / 70 %) | Petri dishes | 100 % | Perrucci (1995) |
| Almond bitter oil, caraway oil, dill oil spearmint oil, ho oil, wintergreen oil | *T. putrescentiae* | (25$^o$C / 75 %) | Petri dishes | 100 % with 1-5 µl | Watanabe et al (1989) |

Table 1 - continued

| COMPOUND | MITE SPECIES | DOSE (mg kg $^{-1}$)* (TEMP / RH) | APPLICATION | MORTALITY * | REFERENCE |
|---|---|---|---|---|---|
| Essential oils of Eugenia & Garlic | *G. domesticus* | 1% (25°C / 75 %) | Potter tower | 41% & 36% after 24 hours | Lozzia et al (1994) |
| Parsley oil | *A. siro* | 16.80 % | ) | ) | Czajkowska (1971) |
| | *T. putrescentiae* | 8.40 % | ) | ) | |
| Caffeine | *A. siro* | 2 % | ) | ) | |
| | *T. putrescentiae* | 8 % | ) | ) | |
| Ergotamine | *A. siro* | 2 % | ) rye germs | ) 100 % | |
| Quinine | *A. siro* | 10 % | ) | ) | |
| | *T. putrescentiae* | 40 % | ) | ) | |
| Arbutine | *A. siro* | 40 % | ) | ) | |
| Colchicine | *T. putrescentiae* | 0.6 % | ) | ) | |
| Digitoxine | *T. putrescentiae* | 0.4 % (25°C / 85-89 %) | ) | ) | |
| Spice oils of : | | | | | |
| Sassafras | ) | 0.001 % | ) | Moderately Inhibitory | Potts & Rodriguez (1978) |
| Vaniprox | ) | 0.001 % | ) | Moderately Inhibitory | |
| Bitter almond < sage | ) | ) | ) | ) | |
| < onion < clove < | ) *T. putrescentiae* | ) 0.01 % & 0.1 % | ) Diet | ) | |
| Oleoresin black | ) | ) | ) | ) High to low inhibition | |
| pepper < mace < | ) | ) | ) | ) | |
| Black pepper | ) | ) | ) | ) | |
| Curry powder, | ) | ) | ) | ) | Rodriguez et al (1979) |
| Lemon/pepper | ) *T. putrescentiae* | ) 2 % | ) Pet food | ) Feeding deterrent effects | |
| seasoning, mace, | ) | ) | ) | ) | |
| Sage | ) | ) | ) | ) | |
| Oleoresin black pepper | *T. putrescentiae* | 0.1 % | Pet food | 76 % growth inhibition | |
| Clove | ) | 0.1 % | ) | 92 % growth inhibition | |
| Almond | ) | 0.01 % | ) | 82 % growth inhibition | |
| Sassafras | ) *T. putrescentiae* | 0.01 % | ) Pet food | 96 % growth inhibition | |
| Oil of black pepper | ) | 0.001% | ) | 74 % growth inhibition | |
| Sassafras | ) | 0.001% | ) | 94 % growth inhibition | |
| Caraway extracts | ) | 12 | ) | 100 % after 48 hours | Afifi & Hafez (1988) |
| Fenugreek extracts | ) | 12 | ) | 100 % after 72 hours | |
| Caraway extracts | ) *T. putrescentiae* | 100 | ) Flour | 100 % after 24 hours | |
| Fenugreek extracts | ) | 100 | ) | 100 % after 24 hours | |
| Lupin extracts | ) | 100 (28°C / 85 %) | ) | 100 % after 48 hours | |
| Eucalyptus powder | ) | 5 % | ) | Eggs ↓ to 52 / female | Gulati & Mathur (1995) |
| Mentha powder | ) *T. putrescentiae* | 5 % | ) Flour | Eggs ↓ to 25 / female | |
| Curcuma rhizomes | ) | 0.1 % (27°C / 80-85 %) | ) | Eggs ↓ to 8 / female | |
| **Novel Compounds** | | | | | |
| Chemosterilants | | | | | |
| Potassium iodide | *A. siro* | > 0.25 % (25°C / 85 %) | Wheat germ | Egg laying suppressed, | Ignatowicz (1982a) |
| Potassium iodate & tin iodide | *T. putrescentiae* | > 0.25 % (85 %) | Wheat germ | permanent sterility | Ignatowicz (1986a) |
| | | | | Egg laying suppressed | |
| Boric acid | *T. putrescentiae* | > 0.5 % | Food | | Ignatowicz (1982b) |
| Sodium fluoride | *T. putrescentiae* | 2 % | Food | 100 % | Ignatowicz (1983) |
| | | 0.25 % or 0.5 % | Food | 58% did not lay eggs | |
| Thiourea | *A. siro* | 1-2 % | Food | 6-8% did not lay eggs | Ignatowicz (1987a) |
| 5-fluorouracil | *T. putrescentiae* | 0.25 % - 0.5 % | Food | High mortality & sterility | Ignatowicz (1987b) |
| | *A. siro* | 2 % | | Partial sterility | |
| | | (85 %) | | Permanent sterility | |

Table 1 - continued

| COMPOUND | MITE SPECIES | DOSE (mg kg $^{-1}$)* (TEMP / RH) | APPLICATION | MORTALITY * | REFERENCE |
|---|---|---|---|---|---|
| Colchicine | *T. putrescentiae* | 0.01 % | Food | Fecundity ↓ 89 % | Ignatowicz (1987c) |
| | *A. siro* | 0.01 % (25°C / 85 %) | Food | Fecundity ↓ 24 % | |
| Fatty Acids | | | | | |
| Capric acid | *T. putrescentiae* | 1 % | Dog food | No eggs | Rodriguez (1972) |
| Propionic, butyric, caproic & caprylic acids | *T. putrescentiae* | 2 % (27 °C / 80 %) | Dog food | No eggs | |
| Propionic acid | *A. siro* | 0.5 - 0.8 % | Wheat | 100 % | Simpson (1973) |
| Inorganic salts | | | | | |
| Tricalcium phosphate | *T. putrescentiae* | 18 %<br>31.5 %<br>0.5 - 1mm<br>(25°C / 85 %) | Food<br>Food | 50 % ↓ fecundity<br>84 % ↓ fecundity<br>100 % after 3-5 hours | Boczek & Ignatowicz (1979) |
| $Ag_2So_4$, $AgNO_3$ | *T. putrescentiae* | 1 %<br>> 3 %<br>(25°C / 85 %) | Food | Suppressed egg laying<br>↓ adult longevity | Boczek et al (1984) |
| Antibiotics | | | | | |
| Benzyl alcohol | *T. putrescentiae* | 3.25 %<br>(15-19°C / > 80 %)<br>(22°C / > 80 %) | Direct | 87 % after 24 hours of motile stages<br>56 % egg hatch | Castagnoli et al (1996) |
| **Biological control**<br>Predators | | | | | |
| *Cheyletus eruditus* | Astigmata | 2000-3000 predators / 100m$^2$ (Field) | Empty store | Markedly reduced mites | Zdarkova & Horak (1990) |
| | Astigmata | 1 : 100 & 1 : 1000 (Predator : Prey) (Field) | Grain surface | Successful control | Pulpan & Verner (1965) |
| Cheyletin | Astigmata | 2000-3000 predators / 100m$^2$ (Field) | Empty store | Population ↓ by 8.4 x | Zdarkova (1991) |
| Pathogens<br>Protozoa | | | | | |
| *Nosema steinhausi* | *T. putrescentiae*<br>*A. siro* | (22-24°C / ~ 90 %) | | | Weiser (1956)<br>Beerling et al (1993) |
| *Pleistophora* sp. | *T. putrescentiae*<br>*A. siro* | (22°C / ~ 90 %) | | | Beerling & van der Geest (1991) |
| Fungi<br>*Hirsutella thompsonii* | *A. siro*<br>*A. chaetoxysilos*<br>*A. farris*<br>*L.. destructor*<br>*T. putrescentiae* | 1.0 x 10$^7$ spores / ml (20°C / 70, 90 & 100 %) | Wheat, cheese & filter papers | No detectable effect | Anon (1983) |
| *Verticillium lecanii* | *A. siro*<br>*A. chaetoxysilos*<br>*A. farris*<br>*L. destructor*<br>*T. putrescentiae* | 1.4 x 10$^7$ spores / ml (20°C / 70, 90 & 100 %) | Wheat, cheese & filter papers | No detectable effect | Anon (1983) |

Table 1 - continued

| COMPOUND | MITE SPECIES | DOSE (mg kg $^{-1}$)* (TEMP / RH) | APPLICATION | MORTALITY * | REFERENCE |
|---|---|---|---|---|---|
| *Aspergillus versicolor* *Aspergillus flavus* *Aspergillus nidulans* *Pencillium rubrum* | *T. putrescentiae* | (27$^{o}$C / 85 %) | Culture | Females did not develop or lay eggs, longevity shortened | Rodriguez et al (1984) |
| *Aspergillus ochraceus* *Aspergillus versicolor* *Aspergillus nidulans* *Fusarium popae* *Pencillium rubrum* | *T. putrescentiae* | (27$^{o}$C / 85 %) | Culture | Most toxic | Rodriguez et al (1984) |
| *Sporendonema sebi* *Aspergillus restrictus* | *A. siro* | (20$^{o}$C / 75 %) | Food | ↓ reproduction, high mortality & retarded dev. | Solomon et al (1964) |
| aflatoxin, citrinin, ochratoxin, pencillic acid | *T. putrescentiae* | (27$^{o}$C / 85 %) | Culture | Mild acute toxicity in developing generation Lethal to $F_1$s | Rodriguez et al (1980) |
| *Cladosporium cladosporiodes,* *Aspergillus repens* *Aspergillus ruber* *Pencillium cyclopium* | *A. siro* *L. destructor* *T. longior* | (20$^{o}$C / 90 %) | Food | Fewer eggs produced Male longevity ↓ | Parkinson et al (1991 a & b) |

* - Unless otherwise indicated

Table 2 - Advantages and disadvantages in the use of some alternative compounds for the control of storage mites

| COMPOUND / TYPE | ADVANTAGES | DISADVANTAGES |
| --- | --- | --- |
| **Growth regulators** | • Specific for target pests<br>• Low toxicity to beneficial organisms and mammals<br>• Persistant<br>• Effective against insects<br>• Commercial compounds available | • Vary in efficacy against mites<br>• Cross resistance in OP resistant insects |
| **Inert dusts** | • Resistance will not occur<br>• Persistant<br>• Effective against insects<br>• Large particle formulations safe<br>• No toxic residues<br>• Low mammalian toxicity<br>• Commercial compounds available<br>• Cost effective<br>• Registered for storage use in some countries | • Behavioural avoidance may occur<br>• Less effective at high r.h.<br>• Small particle dusts are a respirable hazard<br>• Slow-acting<br>• Affects grain flow |
| **Botanicals** | | |
| Azadirachtin | • Effective against insects<br>• Possible increased persistance in store.<br>• Quite selective<br>• Low mammalian toxicity<br>• Resistance not detected<br>• Commercial compounds available | • Delayed effect<br>• No information on efficacy against storage mites |
| Others | • Vast array of products<br>• Efficacy against mites varies | • Some extracts may taint grain |
| **Pyrethroids** | • Multiple modes of action<br>• Reduced resistance threat<br>• Degrade slowly under UK conditions<br>• Toxicity increased at lower temperatures<br>• Effective against mites and insects<br>• Commercial compounds available<br>• Registered for use in some countries | • Toxic residues<br>• Resistance potential<br>• Degradation increases as temperature increases |
| **Novel compounds** | | |
| Chemosterilants | • Efficacy against storage mites well known<br>• Used with attractants to target pest | • Usually highly toxic<br>• Activity not specific to target pest |
| Fatty acids | • Effective against storage mites | • Short-lived protection<br>• Grain killed |
| Inorganic salts | • May be food additives<br>• Some effective against mites<br>• Resistance unlikely | • Efficacy against mites varies<br>• High doses required |
| Antibiotics | • Avermectins effective at low doses against phytophagous mites<br>• Commercial compounds available | • Resistance potential |

Table 2 - continued

| COMPOUND/TYPE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| **Biological control**<br>Parasitoids, nematodes and predators | • No toxic residues<br>• Predators already used in storage overseas<br>• Predators more tolerant of OPs than pests | • Predators considered contaminants<br>• Parasitoids of storage mites unknown<br>• Storage conditions too dry for nematodes<br>• Slow to act at low temperatures |
| Pathogens | • Harmless to non-target organisms<br>• Compatible with pesticides<br>• Cheap and easy to culture<br>• Longevity enhanced in grain storage<br>• Suitable for admixture<br>• Invisible<br>• Effective against storage insects | • Specicifity may limit usefulness<br>• Careful application timings needed<br>• Virulence depends on climate<br>• Control achieved slowly |
| *Bacteria* | • Pest feeding halted rapidly<br>• Easy to use<br>• Commercial compounds available | • Resistance potential<br>• Not evaluated against storage mites<br>• β-exotoxins toxic to bees, poultry & mammals |
| *Viruses* | | • Few mite viral diseases<br>• Resistance potential |
| *Protozoa* | • Large number of species available<br>• Many modes of transmission | • Sub-lethal effects<br>• Slow-acting<br>• Difficult to produce |
| *Fungi* | • Some effective against storage mites<br>• Mycotoxins may be toxic to mites | • Storage too dry for fungal growth<br>• Mycotoxins also toxic to mammals |