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Psocid and mite pests of stored commodities: small but formidable enemies

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Abstract

In recent years, there has been a significant increase in the pest status of psocids (mainly the *Liposcelis* spp) and mites (including *Tyrophagus* spp., *Aleuroglyphus* spp. and *Acarus* spp.) in stored commodities around the world. Unlike beetles, these pests do not cause significant quantitative damage to commodities. However, their presence is no more acceptable due to the increasing demand for insect- and mite-free commodities by the consumers. Infested commodities can incur heavy economic losses through rejection by both domestic and international markets.

Managing psocids and mites has always been difficult due to the fact that they do not respond to management tactics that have been developed primarily to control beetle pests. Strong resistance to phosphine has been detected in several psocid populations from Australia, China and Indonesia. Moreover, research shows that commonly used grain protectants cannot control all major *Liposcelis* psocids together or the most common mite pest, *Tyrophagus putrescentiae*. This research, however, showed that phosphine fumigation in a sealed environment can still control this mite as well as psocids. An integrated approach with a greater emphasis on hygiene is needed to manage infestations of psocids and mites in stored commodities.

Key words: psocids, mites, pests of stored

grain, control.

Introduction

Psocids and mites are two of the smallest pests of stored commodities. Until recently, they have always been viewed by the storage authorities as nuisance pests or contaminants of low economic importance. This ignorance has mostly been due to the fact that damage to bulk commodities by these pests has always been overshadowed by major pests, such as beetles. Over the last decade, however, there has been significant enhancement in their pest status, for two main reasons. Firstly, markets are becoming increasingly sensitive to these pests as contaminants. Secondly, as this paper will show, these pests do not respond to management tactics that have been developed for beetle pests.

Among psocids, members of genus *Liposcelis* are the most frequently encountered pests in grain storages on farm, export terminals, warehouses with bagged commodities and even in kitchen pantries. A comprehensive review by Lienhard and Smithers (2002) suggests that four species of *Liposcelis* are the frequently reported psocid pests around the world: *L. bostrychophila* Badonnel, *L. entomophila* (Enderlein), *L. decolor* (Pearman), and *L. paeta* Pearman. For example, one or more of these spp. are reported as established pests in rice warehouses in several countries in Asia (Cao et al., 2003; Kleih and

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Pike, 1995; Rajendran, 1994; Wang et al., 1999); in farm and central storages in Australia (Champ and Smithers, 1965; Nayak et al., 1998; Rees, 1994); Africa (Lale and Yusuf, 2000; Mashaya, 1999) and the Americas (Arbogast et al., 2000; Mockford, 1991; Sinha, 1988) and domestic environment in Europe (Turner, 1998; Baz and Monserrant, 1999). Serious contamination problem with psocids is quite evident in a report from USA by Arbogast et al. (2000), which showed that in Florida, *L. entomophila* accounted for 88 % of the captured insects in stored oats. In another report, Rees (1994) noted that for one bulk grain handler in Australia, liposcelidid psocids have gone from being the cause of less than 1 % of pest control operations to more than 40 % over a period of 8 years.

Several species of mites have been reported as causing serious economic damage to packaged and processed food commodities (Chambers, 2003; Champ, 1966; Nayak, 2006; Olsen, 1983; Sinha, 1979; Wildey et al., 1998; Zdarkova, 1991) and are also implicated as the cause of human and livestock allergies (Haines, 1991; Hughes, 1976; Zdarkova, 1991). For example, in the UK, mites were reported in 72 % of farm stores, 81 % of commercial grain stores, 89 % of animal feed mills and 89 % of oilseed rape stores (Wildey et al., 1998), whereas an inspection by Olsen (1983) in the USA reported 22 mite species in 149 imported products. The mould mite, *Tyrophagus putrescentia* (Schrank) is the most commonly occurring mite pest, followed by *Acarus siro* (L.), *Aleuroglyphus ovatus* (Troupeau), *Glycyphagus destructor* (Shrank) and the straw itch mite, *Pymotes tritici* (Lagrange-Fossat and Montagne) (Hughes, 1976; Chambers, 2003). For example, the mould mite, *T. putrescentiae* has been reported to be the most prevalent mite in animal feed in Queensland Australia (Champ, 1966; Nayak, 2006).

Information on management of psocids and mites is limited and scattered, and specific recommendations are needed. This paper aims

to review the research on control of these pests, and attempts to integrate the most effective control options.

Damage caused by psocids and mites

Both psocids and mites compensate for their small size by causing significant damage to stored commodities through population explosions when the storage environment is hot and humid. The unique attributes of psocids, including the adult longevity (72-144 days), ability to survive for considerable periods of time in adverse conditions and without food and high degree of population growth through short life cycle (2-3 weeks) and parthenogenetic mode of reproduction of *L. bostrychophila* (all off springs are females) (Turner and Maude-Roxby, 1988), have made these pests extremely difficult to control. Under optimal conditions of 30 °C and 75 % relative humidity, psocids will multiply by 25 times a month compared with 500 times a month for the mould mites (Hughes, 1976; Haines, 1991; Leong and Ho, 1995, Turner, 1994). Outbreaks of psocids and mites, apart from causing serious damage to the stored commodities (Kleih and Pike, 1995; Rajendran, 1994), appear as moving carpets of brown dust on the commodities, silos and sheds causing discomfort to workers. In heavy infestations, *T. putrescentiae* emit a damp and pungent smell, earning them the local name of 'lemon-scented mite' in Australia (Nayak, 2006). Moreover, this mite alongside the straw-itch mite *P. tritici* has been implicated in causing allergic reactions in humans and livestock (Hughes, 1976; Haines, 1991).

Both domestic and international markets reject commodities infested with psocids and mites and the economic loss varies depending on the situation. For example, if infestation is detected in a shipment of Australian wheat export, it will cost the exporter approximately AU\$ 1.2 to 1.8 millions depending on the infestation level (ABARE, 2000). The longer the shipment is delayed, the more expensive the infestation becomes. Moreover, it costs an extra \$ 330,000 to clean up the infestation if it is

discovered before the grain is loaded. Recently, an export feed company risked losing its business, because of heavy mite infestations in its processed animal feed (Nayak, 2006).

Control strategies

Grain Protectants

Psocids

Wherever studied, *L. bostrychophila* and *L. decolor* were found to be more susceptible to grain protectants than *L. entomophila* and *L. paeta* (Leong and Ho, 1994; Nayak et al., 1998; Nayak et al., 2002b, Daghli et al., 2003). Moreover, these studies have established organophosphates to be much more successful against psocids than the other groups of chemicals such as pyrethroids, carbamates and insect growth regulators (IGRs). Nayak et al. (1998, 2002b) bioassayed numerous Australian field strains and concluded that *L. bostrychophila* and *L. decolor* were susceptible to the currently registered rates of fenitrothion (12 ppm), chlorpyrifos-methyl (10 ppm) and pirimiphos-methyl (4 ppm), and *L. entomophila* and *L. paeta* were highly tolerant. These results are similar to those reported earlier by Leong and Ho (1994).

Natural pyrethrins synergised with piperonyl butoxide (pb) (6 ppm) provided 3 months protection against all four *Liposcelis* spp. (Nayak, unpublished data). This rate was also found to have potential as a quick disinfestant yielding complete adult mortality within 6 hours, and where the grain surface was sprayed at a rate of 530 ml/L per 20 m² all life stages of all spp. were controlled (Nayak, unpublished data). Among the pyrethroids, bioresmethrin (1 ppm) synergised with pb (8 ppm) controlled only *L. bostrychophila* and *L. decolor*, but deltamethrin (1 ppm) both alone and synergised with pb (8 ppm) failed to achieve complete mortality of any of the four *Liposcelis* spp. studied (Nayak et al., 1998; 2002b). Bifenthrin (0.5 ppm) plus pb (7 ppm) plus chlorpyrifos-methyl (10 ppm) provided up

to 3 months protection against *L. bostrychophila*, *L. decolor* and *L. paeta*, but failed against *L. entomophila* (Daghli et al., 2003).

Nayak et al. (1998, 2002b) observed that the juvenile hormone analogue methoprene (1 ppm) failed to suppress populations of any of the four *Liposcelis* spp. Likewise, working only on *L. bostrychophila*, Buchi (1994) and Kucerova and Zuska (1991) noted that very high concentrations of methoprene (up to 190 ppm) and fenoxycarb (up to 16 ppm) were required to substantially reduce the population growth of this species. The carbamate carbaryl has poor efficacy against all four *Liposcelis* spp. (Nayak et al., 1998; 2002b; Leong and Ho, 1994). The overall inefficacy of deltamethrin, carbaryl and methoprene against a range of field strains of four *Liposcelis* spp. (Nayak et al., 1998, 2002b), supports earlier views that psocids have a natural tolerance to these chemicals (Turner et al., 1991; Rajendran, 1994).

In recent research, the newly developed bacterium-derived spinosad (1 ppm) controlled only *L. entomophila* (Nayak et al., 2005); but mixed with chlorpyrifos-methyl (10 ppm), controls all four *Liposcelis* spp. (Nayak and Daghli, in press). Furthermore, a neonicotinoid compound imidacloprid was also found to be effective against all four *Liposcelis* spp., but at a very high rate (10 ppm), which is highly unlikely to get registered (Nayak and Daghli 2006).

Mites

The most recent report on control of mites by using grain admixtures was from Nayak (2006), who evaluated seven grain protectants against *T. putrescentiae* including chlorpyrifos-methyl (10 ppm), pirimiphos-methyl (4 ppm) fenitrothion (12 ppm), deltamethrin (5 ppm), pyrethrin plus pb (4.5 ppm), s-methoprene (3 ppm) and the newly developed bacterium-derived chemical spinosad (1 ppm). Among these, only pyrethrin plus pb, s-methoprene and spinosad controlled the mite population after at least 3 weeks of exposure to treated wheat. The failure of organophosphates to control *T. putrescentiae*, contrasts with several

earlier reports showing the high degree of success of a range of organophosphates such as fenitrothion (Hartmannova et al., 1973); pirimiphos-methyl (4 ppm) (Chmielewski, 1987), etrimfos (20 ppm) and profenofos (10 ppm) (Stables, 1980), and methacrifos (5 ppm) (Pagliarini and Hrlec, 1982). It is suspected that mite strains tested by Nayak (2006) might have developed resistance to organophosphates. Several mite spp., including *T. putrescentiae*, *T. longior*, *A. siro*, and *G. destructor* were also controlled by etrimfos and profenofos (Stables, 1980). Among some other pyrethroids studied, phenothrin, fenopropathrin and permethrin were shown to be effective against *T. putrescentiae*, but at a very high rate of 500 ppm (Chisaka et al., 1985). Treating the wheat surface (top 0.3 m) with 2 % dust of etrimfos and pirimiphos-methyl at a rate of 50 g/m² in aerated commercial stores significantly reduced the numbers of *A. siro* and *G. destructor* (10/kg in treated bins compared with 1500/kg in untreated bins) (Armitage et al., 1994). In another field trial, mixed infestations of *A. siro*, *G. destructor*, and *T. longior* (Gervais) in farm-stored barley were controlled for 3 months with application of lindane (2 ppm) plus malathion (8.9 ppm) or pirimiphos-methyl (4 ppm) dust (Wilkin, 1975).

Only two reports are available on efficacy of plant extracts against *T. putrescentiae*. Sanchez-Ramos and Castanera (2001) tested 13 natural monoterpenes against *T. putrescentiae* and concluded that of these, pulegone, menthone, linalool and fenchone had high acaricidal activity, yielding LC₉₀ values of 14 µl/l or below. Lee et al. (2006) studied the acaricidal activity (direct contact application) of 12 fennel seed oil extracts against *T. putrescentiae* and found naphthalene (4.28 µg/cm²) and Carvone (4.62 µg/cm²) to be the most toxic.

There is only one report available on development of resistance in mites to contact insecticides (Wilkin 1973), which showed *A. siro* collected from an English Cheese store to have developed high level of resistance to lindane.

Fabric Treatments

Psocids

Numerous studies have been undertaken on potential of fabric treatments against *Liposcelis* spp. Generally, these treatments persisted for a much shorter period on porous surfaces such as concrete and plywood compared with non-porous surfaces such as galvanised steel and glass (Collins et al., 2000; Nayak et al., 2002a, 2002b, 2003a; Turner et al., 1991). On steel, azamethiphos (5 to 10 g/L), chlorpyrifos-methyl (20 ml/L) and pirimiphos-methyl (11 ml/L) combined with carbaryl (20 ml/L) at a rate of 1 L/20 m² provided 8-10 months protection from all four *Liposcelis* spp. (Nayak et al., 2003a); whereas permethrin provided 9-10 months protection against all spp. except *L. entomophila* (Nayak et al., 2002a, 2002b). On concrete, however, azamethiphos plus carbaryl provided long-term protection only against *L. bostrychophila* (7 months) and *L. paeta* (4 months) (Nayak et al., 2003a). Turner et al. (1991) reported that pre-treating *L. bostrychophila* with the synergist piperonyl butoxide dramatically increases the efficacy of permethrin.

Mites

Research on fabric treatments against mites is limited. The most recent report was from Collins and Cook (2006), which suggested that dust application of a diatomaceous earth (Silico-sec®) 0.5 g/m² on plastic and glass surfaces controlled *A. siro* and *L. destructor* mites after a 24 h exposure. Nayak (2006) reported the failure of chlorpyrifos-methyl (20 ml/L/20 m²) to control *T. putrescentia* infestations on a conveyer belt and storage floors of a food processing plant in Queensland, Australia. In some earlier studies, Hirakoso et al. (1971) observed long-term control of *T. putrescentiae* on straw mats covered with paper impregnated with 5 % fenthion (12 months) or 5 % fenitrothion (7 months) at a rate of 100 ml/m².

Fumigants

Psocids

Few reports available on efficacy of fumigants against psocids, and most are on phosphine (Cao et al., 2003; Ho and Winks, 1995; Nayak et al., 1998; 2002c, 2003b, 2003c; Pike, 1994). The most important finding among them is the detection of high level of resistance to phosphine in *L. bostrychophila* in Australia (Nayak et al., 2002c), and *L. entomophila* in China (Cao et al., 2003) and Indonesia (Pike, 1994). These findings contradicts earlier perceptions that all four *Liposcelis* spp. were highly susceptible to phosphine (e.g. to as low as a concentration of 0.1 mg/L (72 ppm)) (Ho and Winks, 1995; Nayak et al, 1998; Rajendran, 1994). Eggs of psocids were found to be much more tolerant than the adults. A concentration as high as 1.7 mg/L (1,225 ppm) over 5 days was required to control eggs of *L. entomophila* (Pike, 1994) and 2 mg/L (1,440 ppm) over 6 days for *L. bostrychophila* (Nayak et al., 2002c), which were much higher than the rates recommended for controlling resistant beetle pests in Australia and Indonesia. Nayak et al. (2003c) discovered an interesting phenomenon that when exposed to high concentrations of phosphine, egg hatching in strongly resistant *L. bostrychophila* was delayed greatly enabling them to survive the fumigation. These researchers suggested this mechanism as a key factor in failure of phosphine fumigation to control psocid infestations in several central storages and grain terminals in Australia. In addition, they established that the most successful strategy to control this resistant psocid is to apply relatively low concentrations of phosphine for extended exposure periods (e.g., 0.05 mg/L or 35 ppm for 16 days) that allows all eggs to hatch to the much less tolerant nymphal stage. In another study, Nayak et al. (2003b) investigated the influence of fumigation temperature on the efficacy of phosphine and found that, at any fixed concentration, time to population extinction decreased as temperature increased from 15 to 35 °C.

Among other fumigants, only a couple of reports are available on efficacy of methyl bromide. Pike (1994) tested a strain of *L. entomophila*, which showed strong resistance to phosphine and reported that, all life stages of this strain were controlled at 50 mg/L of methyl bromide over a 4 hour exposure. Rajendran (1994) reported that eggs of a field strain of *L. bostrychophila* were controlled with a 24 hours exposure of methyl bromide at 1.3 mg/L.

Mites

Few reports are available on the efficacy of fumigants against mites. Most recently, Nayak (2006) reported that phosphine at 1 mg/L (720 ppm) at 25 °C controlled all life stages of *T. putrescentiae* in six days. In some earlier studies, it was established that eggs of this mite were more tolerant than adults and although both phosphine and methyl bromide could control this mite; the later being more effective than the former (Jalil et al., 1970; Barker, 1967; Bowley and Bell, 1981). Bowley and Bell (1981) studied the efficacy of another ten fumigants along with methyl bromide and phosphine at 10 °C against *A. siro*, *T. longior*, *G. destructor*. Based on the CT (concentration x time) products, their efficacy were established in the following ascending order: acrylonitrile, carbon tetrachloride, ethyl bromide, ethyl formate, ethylene dibromide, ethylene dichloride, ethylene oxide, methallyl chloride, methyl bromide, methyl chlorform, methyl formate and phosphine.

Controlled atmosphere

Psocids

Knowledge on the efficacy of controlled atmosphere against psocids is limited. The earliest report was by Bell et al. (1990), who noted that at a concentration of 40 %, CO₂ controlled all stages of *L. bostrychophila* after 2 weeks exposure at 10 or 15 °C. Leong and Ho (1995) observed that *L. bostrychophila* was 2.4 times more tolerant to CO₂ treatment than *L.*

entomophila at both 45 and 60 % CO₂. Moreover, they established that an increase in exposure time rather than CO₂ concentration is more efficacious in control of adult psocids, and these two species were quite susceptible to the dosages of either 60 % CO₂ for 11 days or 40 % for 17 days. These results were quite close to that of Newton (1993), who established that, 60 % CO₂ over 14 days was sufficient to control *L. bostrychophila*. In some recent research Wang et al. (2000) showed steady development of resistance to CO₂ in *L. bostrychophila* at 35 and 55 % through selection and also observed that controlled atmospheres (12 % CO₂ + 9 % O₂ and 10 % CO₂ + 5 % O₂) significantly enhanced the toxicity of six plant oils against this psocid (Wang et al., 2001). In another study, Ding et al (2002) established that alternating exposure to CO₂ and diclorvos provided significant increase in mortality in this psocid compared with those exposed to CA or diclorvos alone.

Mites

A literature survey revealed only one publication on the influence of CA under a range of temperatures on growth and reproduction of *T. putrescentiae* (LungShu et al., 1998). This report suggests that a CA of 10 % CO₂ and 5 % O₂ had stronger inhibition on growth and reproduction than an atmosphere of 16 % CO₂ and 9 % O₂, and the inhibition was enhanced at higher temperatures (e.g., 30 and 32 °C).

Physical and other control methods

Psocids

The earliest report on physical control was by Back (1939), who observed that applying dry heat with temperatures of 50-60 °C controlled *L. bostrychophila* populations within an hour. At the other end, Turner (1988) suggested that freezing rapidly kills all stages of *L. bostrychophila*, and limited infestations can be controlled by placing commodities in a deep freeze (sub-zero temperature) for a few days.

Recently, Beckett and Morton (2003) observed that one day exposure to 46 °C controlled *L. bostrychophila*, *L. decolor* and *L. paeta*. Attempts to control Liposcelids using entomopathogenic fungi (e.g., *Metarhizium anisopliae* (Metchnikoff)) or bacteria (e.g., *Bacillus thuringiensis* Berliner) have been unsuccessful (Turner, 1988).

Mites

A number of studies have been undertaken on physical control of mites, including manipulation of temperature. Arnau and Guerrero (1994) successfully controlled all life stages of *T. putrescentiae* in dry-cured ham within 24 h at 45 °C, and all stages except eggs at -28 °C. Similarly, Mourier and Poulsen (2000) achieved complete disinfestations of *A. siro* and *T. putrescentiae* populations at 400-450 °C within 6 s, and Zdarkova and Voracek (1993) achieved the same result within 0.5 h by exposing these mites to either -15 or >55 °C. Contrary to these reports, Sinha (1964) reported much longer exposure periods for control of *G. destructor* (1 d) and *A. siro* (3 d) at -18 °C. Among other physical methods of control, Zdarkova and Voracek (1993) reported that a vacuum pressure of 190 mm Hg would control a range of mites including *A. siro* and *T. putrescentiae*, whereas White et al. (1997) reported 100 % mortality of mite *Aeroglyphus robustus* (Banks) through pneumatic movement of wheat, and 98 % mortality through augering. Recently, Nayak (2006) observed that reducing the moisture content of processed animal feed from 15 % to 12 % and reprocessing of infested feed resulted in complete eradication of *T. putrescentiae* infestations. Some research was undertaken on biological control of *A. siro* with predatory mite *Cheyletus eruditus* (Scrank) (Burnett, 1977; Zdarkova and Horak, 1990; Zdarkova and Felt, 1999; Pekar and Zdarkova, 2004; Lukas et al., in press), however, as the biocontrol agents are considered as contaminants themselves, their application in the field may never be a serious option.

Development of an IPM program against *T. putrescentiae*

Nayak (2006) successfully developed and implemented an IPM strategy against *T. putrescentiae* in a feed processing mill in Queensland Australia. Developed in a step-wise manner over a period of 2 years, this strategy involved upgrading of hygiene in the processing and storage area, reduction of the moisture content of the feed to 12 % from 15 %, addition of 2 % vegetable oil (w/w) to the feed, weekly moving of packaged pellets from storage area, rejection of mite infested grain at the receival point and reprocessing of infested products. Successful implementation of this IPM program has regained the export business of the animal feed company (Nayak, 2006).

Conclusion

Psocids and mites have the ability to successfully survive outside the storage environment with small amount of available food, and reinfest the stored commodities under favourable conditions, specifically when it is hot and humid (Turner and Maude-Roxby, 1988; Nayak, 2002b, Nayak, 2006). This review suggests that there is a great deal of variability among different spp. of *Liposcelis* and mites in their response to different chemical treatments. In a field situation, generally we find more than one species together (Nayak et al., 1998; Haines, 1991). A control strategy, therefore, should be aimed at achieving control of all major species together to avoid reinfestation from tolerant spp. The following key aspects are suggested for their appropriate integration for management of mite and psocid pests:

- Strict hygiene practices in and around grain or produce storage and handling areas including removal and destruction of unwanted residues, steam blowing of dust, cleaning of grain storages and handling equipments before handling new uninfested produce etc.
- Spraying the walls and floors of warehouses and sheds with azamethiphos or grain with

spinosad or pyrethrin plus pb, only if the commodities are destined for markets accepting residual treatments.

- Fumigation of commodities with phosphine only in sealed and gas-tight storages.
- Use of CA if the commodities are destined for organic market.
- Reduction of temperature below 20 °C, for example by aeration and moisture content of commodities below 12 %, for example by drying.
- Quick disinfestation of population outbreaks through fogging, for example by applying pyrethrins synergised with pb.
- Monitoring of pest populations (including resistant populations) in 'hot spots' within the storage environment and adoption of strict regulation in confining and rejecting infested materials at receival points.

It is also important that future research should focus on development of new biologically-derived grain protectants (such as spinosad) and fumigants for controlling mites and psocids in stored commodities.

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