*KPS4-1*

# Resistance to chemical treatments in insect pests of stored grain and its management

***P.J. Collins*[1]**

## Abstract

Chemical insecticides, including fumigants, disinfestants and grain protectants, are essential components of grain insect pest management systems. This is particularly the case in warmer climates where insect infestation pressure is high. Because of health, safety, environmental and economic considerations, only a very limited number of chemicals is available for application to grain. A serious threat to the continued availability of these materials is the development of resistance in target pests.

World-wide, the fumigant phosphine is by far the most important insect control treatment for stored grain. There are no practical alternatives to this unique material. However, resistance to this fumigant has developed in major pest species in many regions threatening its continued viability.

Incidence of resistance to residual grain protectants is widespread. Populations of major pest species have developed resistance to organophosphates, pyrethroids, carbamates and other agents such as methoprene and *Bacillus thuringiensis*. In some regions, the situation is precarious with insect populations containing multiple resistances leaving no effective protectant options available.

Because grain protection chemicals are a rare resource, the ability to manage or reduce the impact of resistance is a priority. Effective management relies on early detection which can only be achieved with a routine monitoring system and a research capability to estimate the impact of resistance. Development of effective strategies requires understanding of the grain storage system, the ecology of the pest insects, the response of insects to various chemicals and other treatments, and some insight into resistance genetics. We need to be able to answer the questions: How is resistance selected? and, What can we do to reduce selection? Implementation requires cooperation between scientists and storage managers across the system.

*Key words:* Insect resistance, chemical, fumigant, phosphine, protectant.

## Introduction

Civilisation was founded on the ability to harvest, store and distribute grain and will only continue as long as we maintain effective supply of these foods to the world's population.

The largest natural threat to the safe storage and distribution of grains is insect infestation. This is particularly the case in warmer climates that favour insect population growth resulting in very high infestation pressure.

Grain storage managers, at all levels, implement an integrated approach to controlling insect pests using several tactics, such as cooling, drying and sanitation, in their strategy. However, currently and for the foreseeable future, the tools

[1] Department of Primary Industries and Fisheries. 80 Meiers Road, Indooroopilly QLD 4068, Australia. Fax: 61 7 3896 9433 Pat.Collins@dpi.qld.gov.au

most effective at controlling insect pests and those relied on in most integrated approaches are the chemical treatments including fumigants, disinfestants and protectants. These tools enable us to maintain food security, to access to markets, to implement effective quarantine systems, to protect the supply chain and to provide people with high quality food.

Health, safety, environmental and economic considerations severely limit the range of chemicals that can be applied to grain, and in recent years we have seen various authorities around the world reduce the number of chemicals available. Chemicals that can be applied to grain are rare and very costly to develop.

In addition to these pressures, the targets of these chemicals, the insect themselves, are rapidly developing resistance to the few alternatives we have.

In this paper, I will summarise the development and status of resistance to grain protection chemicals using my own experience in Australia as an example supported by information from other countries where available. I will also discuss our approach to managing this problem.

## Protectants

Protectants, which are applied as liquids or dusts directly to the grain stream are designed to provide long term protection. They are currently used on about 25 % grain in Australia. There are a range of protectant chemicals with various efficacies. However, none will control all species, so a mixture of two is applied to the grain.

Malathion was the first "protectant". It came into widespread use in Australia in the mid-1960 s and was responsible for ensuring that the grain industry could meet a government mandated "nil tolerance" for live insects at export and retain overseas markets. However, resistance was detected in the *Tribolium castaneum* (Herbst) in 1968 and in *Rhyzopertha dominica* (F.) by 1972 (van Graver and Winks, 1994). Resistance became so widespread that control with malathion began to collapse and the industry was forced to quickly develop alternative protectants which first came into use in the 1976/77 harvest. Malathion provided only about 12 years of widespread use before being abandoned, with the incidence of resistance increasing from zero to virtually 100 % in that time. In the same era, resistance to malathion became widespread internationally and occurred in many species (Champ and Dyte 1976)

In most species economic resistance to malathion did not extend to other potential protectants (Champ and Dyte, 1976) so that a range of organophosphorotionate materials, including fenitrothion, chlorpyrifos-methyl and pirimiphos-methyl, was introduced to replace malathion. The exception was *R. dominica*. Resistance to malathion in this species was so strong that no other chemically similar protectant could be used against this pest. However, this resistance did not extend to an insecticide group called "pyrethroids" and one or more of these has been used against this species since the loss of malathion. The pyrethroid, bioresmethrin, was used successfully for about 12 years in Australia until resistance was first detected in 1990 (Collins et al., 1993). Incidence of resistance was patchy at first, but a strong increase in the frequency of resistance is evident for the last 10 years (this includes a period where deltamethrin has replaced bioresmethrin). For example, detection of resistance to pyrethroids in the north-eastern grain belt, where data have been collected systematically, has increased steadily from a few percent in 1996 to greater than 50 % in the last few seasons.

As *R. dominica* is the most significant pest and the most difficult to control, a second protectant, the juvenile hormone analogue methoprene, was developed from another chemical group and introduced in about 1994. This material has the advantage of also being effective against *T. castaneum* and very effective against *Oryzaephilus surinamensis* (L.).

Resistance to this material was detected in *R. dominica* only two years later with the frequency continuing to increase steadily over the last 10 years. Frequency of resistant strains is currently greater than 50 %.

A simple linear trend analysis suggests that resistance to pyrethroids and methoprene will reach 100 % by 2010 and about 85 % in 2015, respectively, in the northern grain growing region of Australia (Collins 1996 – 2006). In Australia and internationally, this spectrum of resistance leaves only one protectant available for control of one of the world's most important grain pests, *R. dominica* (Nayak et al., 2005). This chemical, spinosad, is scheduled for registration in Australia and internationally in 2007. There appears to be no other protectants under serious consideration for development.

The organophosphorous protectants were more successful, and although economic resistance has been detected to these chemicals in *T. castaneum* and *Sitophilus oryzae* (L.), these incidences remain rare. However, only a few years after their introduction, populations of *O. surinamensis*, an insect previously considered a minor pest, were detected with resistance to fenitrothion (Heather and Wilson, 1983). Since that time, this resistance has become widespread in eastern Australia and broadened to include all registered OP protectants. (Collins and Wilson, 1987).

## Disinfestant

Under this heading I include dichlorvos. This chemical is a highly volatile organophosphate that is applied in the same way as a grain protectant. However, it does not provide residual protection to the grain as it has a short half-life. Resistance to dichlorvos is very common in *R. dominica* but not detected in other pest species it.

## Fumigants

Fumigants, which are applied as gases and penetrate the grain mass to exert control of insect populations. Because of various problems with other fumigants, phosphine is by far the dominant material used to protect grain world-wide. Phosphine is unique and the likelihood of finding a replacement that is as cheap, effective (when properly applied), easy to use and accepted by markets as a residue-free treatment, is extremely remote.

Although phosphine has been used by the Australian grain industry since the mid-1950 s it was generally regarded as a back-up for the grain protectants. However, from the 1980 s, both domestic and international markets began to increasingly require nil or very low chemical residues on grain. Phosphine was the only viable replacement for grain protectants and consequently its use increased dramatically through the 1990 s. Phosphine is now the primary insect control tool used on 70-80 % of grain.

Concomitant with the increased use of phosphine was an increase in the frequency of resistance in all five major target pests. Resistance at that time was referred to as weak or moderate and was not a major concern for the industry. However, from 1997, there appeared a quantitative change in resistance levels in four of the five major species. This change occurred in each species when the frequency of weak resistance reached about 80 %. Genetic analysis revealed that moderate resistance in *R. dominica* was controlled by one major gene and that it was this gene plus the selection of a second resistance gene that produced the new "Strong resistance" phenotype (Schlipalius et al., 2002).

The strong resistance phenotype has been detected in all states of eastern Australia and in all sectors of the grains value chain. Evolution of this new high level resistance is a major challenge to the grain industry. It has caused a complete re-development of phosphine protocols which have now flowed on to product registrations. Our research showed that Strong resistance levels known in Australia can be controlled with phosphine by increasing either gas concentration or fumigation period (Collins et al., 2005) but at a significant cost to industry. For example, not only is the cost of fumigant increased, silos also need to be of a high standard to maintain the gas concentrations required, and logistics of grain handling are compromised.

Through our national resistance monitoring program (Collins et al., 2003), trends for phosphine resistance are available for all of Australia. Both Weak resistance (1 gene) and Strong resistance (2 genes) in *R. dominica* are increasing. A simple linear analysis indicates that Weak resistance should reach a frequency of 100 % all over Australia in about 10 years. Currently, however, the frequency of strong resistance is relatively low. The major reason for this is that the evolution of the second resistance gene requires the widespread distribution of the first gene, which controls Weak resistance. Based on our experience in northern Australia, the Strong resistance phenotype appears once Weak resistance is found in about 80 % insect population samples. I predict that unless something is done to manage resistance, strong resistance to phosphine will become a major problem in Australia in a few years time when Weak resistance frequency reaches 80 % throughout the country.

Frequency of strong resistance is currently relatively low at around 3-5 % per year. However, the potential spread of this resistance can be illustrated by the experience of the Brazilian grain industry. In a survey of lesser grain borer population samples collected from country storages in Brazil, it was found that of the 19 samples collected, 14 (74 %) were diagnosed with strong resistance. In addition, one of these strains had a resistance level significantly higher that the highest resistance detected in Australia (Lorini et al., in press).

The threat to the future is not only frequency of resistance but its potential increase in strength. A significant concern is the question: how strong will this resistance get? Recent extensive research on a strain of rice weevil (a common grain pest in world-wide), imported under quarantine from southern China, revealed that it is about 50 % more resistant to phosphine than our most resistant strain of any species (Nayak et al., 2003). There is also further evidence from China (Wang et al., 2006) that populations of other pest species will survive long fumigations – up to 21 days at reasonably high concentrations.

The danger for Australia is that major increases in resistance, similar to those experienced overseas, will evolve with the consequence that phosphine will be either ineffective, or almost useless because effective fumigations will require such long fumigation periods and very high concentrations of gas. This concern has motivated the Australian grain industry to develop a national phosphine resistance strategy in consultation with researchers.

## Managing resistance to phosphine

The Australian strategy has four parts:

1) A **national monitoring program** to provide early detection of resistance and strategic and tactical information;

2) A **research capability** to estimate the impact of resistance and to develop effective strategies to combat resistance;

3) An **extension network** to promote fumigation best management practice;

4) **A resistance management implementation plan.**

## The plan

Because the grain industry operates within fairly strict regulatory, operational and market-driven boundaries these constraints had to be recognised and incorporated into the Australian phosphine resistance management plan. Nevertheless the strategy is based on the best scientific information on insect pest biology and resistance selection available. Very briefly, the strategy is based on tactics to 1) reduce selection pressure and 2) destroy resistant insects. Selection pressure is reduced by limiting the number of fumigations applied to any one parcel of grain to three per year and by better application of non-chemical options such as cooling and hygiene. Resistant populations are destroyed by “making every fumigation count” i.e. by only using approved rates of phosphine that are researched and known to control resistant insects, and by using alternative fumigants or protectants where available.

The Strategy is now in an implementation phase. The major bulk handling companies in Australia have agreed to the strategy and are developing implementation plans. At least part of the strategy is already in place in the northern grain-growing region and this company is seeing the benefit of significantly reduced incidences of control failures in their storages. A copy of the strategy is available from the author.

## References

Champ, B.R., Dyte, C.E., 1976. Report of the FAO global survey of pesticide susceptibility of stored grain pests. FAO Plant Production and Protection Series, No. 5, p.297.

Collins, P.J., 1996 – 2006. Unpublished annual reports to the National Working Party on Grain Protection, Australia.

Collins, P.J., Wilson, D., 1987. Efficacy of current and potential grain protectant insecticides against fenitrothion-resistant strain of the sawtoothed grain beetle, *Oryzaephilus surinamensis, L.* Pesticide Science 20, 93-104.

Collins, P.J., Daglish, G.J., Pavic, H., Kopittke, K.A., 2005. Response of mixed-age cultures of phosphine-resistant and susceptible strains of the lesser grain borer, *Rhyzopertha dominica*, to phosphine at a range of concentrations and exposure periods. Journal of Stored Products Research 41, 373-385.

Collins, P.J., Emery, R.N., Wallbank, B.E., 2003. Two decades of monitoring and managing phosphine resistance in Australia. In: Proceedings of the 8th International Working Conference on Stored Product Protection, July 2002, York, UK, pp 570-575.

Collins, P.J., Lambkin, T.M., Bridgeman, B.W., Pulvirenti, C., 1993. Resistance to grain-protectant insecticides in coleopterous pests of stored cereals in Queensland, Australia. Journal of Economic Entomology 86, 239-245.

Heather, N.W., Wilson, D., 1983. Resistance to fenitrothion in *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) in Queensland. Journal of Australian Entomological Society 22, 210.

Lorini, I., Collins, P.J., Daglish, G.J., Nayak, M.K., Pavic, H., in press. Detection and Characterisation of strong resistance to phosphine in Brazilian *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae). Pest Management Science.

Nayak, M.K., Collins, P.J., Pavic, H., 2003. Developments in phosphine resistance in China and possible implications for Australia. In: Stored grain in Australia 2003, proceedings of the Australian Postharvest Technical Conference, Canberra 25-27 June 2003.

Nayak, M.K., Daglish, G.J., Byrne, V.S., 2005. Effectiveness of spinosad as a grain protectant against resistant beetle and psocid pests of stored grain in Australia. Journal of Stored Products Research 41, 455-467.

Schlipalius, D.I., Cheng, Q., Reilly, P.E.B., Collins, P.J., Ebert, P.R., 2002. Genetic linkage analysis of the lesser grain borer *Rhyzopertha dominica* identifies two loci that confer high-level resistance to the fumigant phosphine. Genetics 161, 773-782.

Van Graver, J., Winks, R.G., 1994. A brief history of the entomological problems of wheat storage in Australia. In: Highley, E., Wright, E.J., Banks, H.J., Champ, B.R. (Eds). Stored Products Protection, Proceedings of the 6th International Working Conference on Stored-product Protection, 17-23 April 1994, Canberra, pp. 1250-1258.

Wang, D., Collins, P.J., Gao, X., 2006. Optimising indoor phosphine fumigation of paddy rice bag-stacks under sheeting for control of resistant insects. journal of stored products research 42, 207-217.