Bridgeman B, Collins P (2012) Resistance management in stored products fumigation. In: Navarro S, Banks HJ, Jayas DS, Bell CH, Noyes RT, Ferizli AG, Emekci M, Isikber AA, Alagusundaram K, [Eds.] Proc 9th. Int. Conf. on Controlled Atmosphere and Fumigation in Stored Products, Antalya, Turkey. 15 – 19 October 2012, ARBER Professional Congress Services, Turkey pp: 633-637

RESISTANCE MANAGEMENT IN STORED PRODUCTS FUMIGATION

Barry Bridgeman[1]* and Pat Collins[2]

[1]Forsure Pty Ltd, Toowoomba, Australia
[2]DEEDI, Brisbane Qld. Australia
*Corresponding author's e-mail: *barry.bridgeman@bigpond.com*

ABSTRACT

Various resistance management strategies were successfully implemented across the Qld and NNSW Grain Growing areas during 2009 to 2011 seasons, to minimise the effects of high resistance to phosphine in target species, specifically *Cryptolestes ferrugineus*. The resistance levels studied determined this strain was able to survive fumigation at current label rates with a dose of 700 ppm phosphine for 20 days at 20°C being required to achieve control (Nayak and Collins 2011). This strain Fumigation, phosphine, resistance, grain, bunker, rotation, management, *Cryptolestes*, PRF, selection was detected predominantly in the large bunker storages of the area where achieving this C/T is not practical with currently available processes.

Several of the issues which may have provided a selection pressure resulting in the manifestation of these control failures and development of this resistance are discussed.

This paper outlines several of the strategies tested in a PRF "Pesticide Residue Free" Storage system and the circumstances in which they were employed. The common theme is a focus on the basics, such as, management rather than control. Specific issues discussed include the use of chemical/fumigant rotations /substitutions, which were critical in the ultimate control of this strain in particular, as well as the effect of hygiene, monitoring, storage sealing and fumigation basics on the potential development of this resistance. The resistance development minimisation strategies utilised to mitigate development of resistance in any storage situation and how that may relate to operations of PRF storage facilities is also discussed.

Key words: Fumigation, phosphine, resistance, grain, bunker, rotation, management, *Cryptolestes*, PRF, selection

INTRODUCTION

The development of the phosphine resistant *Cryptolestes ferrugineus* strains in grain storages throughout the eastern grain growing areas of Australia, has resulted in numerous control failures within that area. The resistant populations were detected predominantly in the larger bunker storages, which are commonly used in the area.

Initially bunkers were designed for temporary storage. Bunkers provide a harvest receival buffer system, which enables ballooning of storage capacity at specific sites. The strategy is a cost effective alternative to construction expensive permanent storage in areas where they may not be cost justified. These bunker storages have continued to evolve, becoming the preferred long term storage type in Australia generally. The low cost construction and ability to store large and variable volumes economically, has relieved the need for extensive construction of more permanent storage facilities. The well built bunker presents as a very well sealed/gastight enclosure, which can be fumigated very cost effectively. Insect control is achieved through an IPM plan heavily reliant on phosphine fumigation. The bunker storage system has provided the industry with the ability to provide PRF storage facilities which is a preference in an increasing number of markets.

Customer bias against chemical residues on food commodities has driven the focus for Pesticide Residue Free (PRF) grain storage. Bunkers are used extensively to provide residue free storage. Phosphine fumigation is used to maintain insect free status on out-turn. The use of contact pesticides at anytime within the grain path in a PRF facility is not an option.

The resistant stains were and still are under study by various Australian Departments of Agriculture and Qld DEET is particular. The studies have determined that the level of resistance exhibited within this stain enabled the individuals to survive label rates of phosphine. The control of this strain was found to require dose rates of 700 ppm for 20 days at 20^{o}C (Nayak and Collins 2011).

The research has also developed an opinion on how the resistance is selected. It is the considered opinion that this selection process required repeat, sub lethal phosphine doses on a single population. Data indicates a approximately 4-7 repeat selection fumigations would be required (Collins 2009).

The questions must be asked. Has this resistance developed because existing bunker storage insect control has been ineffective over a long period? or Is resistance development within a population inevitable when a single chemical is used over a long period? What can be done to minimise resistance development?

THE ISSUES

The storage system

The development of this resistant strain must be considered a wakeup call to the grain industry in Australia, particularly in the PRF sites. It has highlighted the vulnerability to any strategy which is dependent on a single chemical for successful control of insects. The industry has been forced to review all procedures and compliance with basic IPM principles. All previously uncontested assumptions on Bunker sealing and fumigation practice in bunkers are being tested.

It is however difficult to guarantee that all bunkers are effectively sealed for fumigation. Bunkers also present several grain husbandry issues, which may have contributed to the development of this resistant strain in particular, as well as add significantly to the complexity of the fumigation. Two of these anomalies are the degree of moisture migration within the bunker and the effect of wind currents on the distribution of fumigant within the storage.

The significance of the presence of a wet area on the crest of bunkers is well documented. The peak or crest is commonly affected by wet, mouldy crust of spoiled commodity due to the presence of this wet area, which is due to the moisture migration from within the bulk. The presence of this wet area in the context of understanding the development resistance within this species is an obvious concern. The resistant insect populations have been detected primarily in this area and have most likely developed by a continuous selection process, which has been facilitated by this wet area. Areas of wet commodity are either not permeated by the fumigant at all or receive sub lethal concentrations.

Studies have detailed the significance of the wind on the bunker and the distribution of fumigant within the bunker. It is apparent that the effect of wind on the bunker fumigant distribution is arguably the single most critical element ensuring the success of fumigations within bunkers. Subsequent and current studies into the significance of the wind on distribution within bunkers and the effect of fumigation effectiveness suggest that it is not providing the selection pressures exhibited by the wet areas on the crest of the bunkers. The effect of wind on the fumigation of these storages is not discussed here.

Operations and logistics

It is evident that some operational processes and logistical realism of the grain industry also affects the resistance selection processes. The most perplexing of these operational realities is the preference for prophylactic scheduled (3 monthly), routine fumigation with phosphine.

This practice is usually a directive from the grain exporters who are looking to manage the risk of insect detection on the way to or at the market place. The market has realised that the risk of detecting insects increases with time since last fumigation. After 3 months the risk is considered unacceptable and fumigation prior to out-turn is demanded. This is often despite the fact the grain may well be fumigated at Port in any case, as a Phyto-sanitary request from the importing country. With this fact in mind the grain storage management will schedule fumigation to ensure out-turn program predictability and control of the fumigation timing.

The practice results in each bulk of grain that is being kept for 12 months will be fumigated 3 – 4 times with phosphine fumigant (depending on location). If the grain is to be held over for the next season, it is possible the bulk could be fumigated a further 3 -4 times with phosphine. Some of the bulks exhibiting large populations of resistant insects had been held for 3-4 years. At 3-4 fumigations per bunker, per year, that is between 9 and 16 fumigations with the same phosphine fumigant on the single population. This selection pressure on this population is enhanced when there is moisture present in the bulk.

Another operational issue is the reality of commodity being held as carry over from last season. Ideally under an IPM the storage and complete site would be emptied for some time prior to harvest to allow thorough hygiene and disinfestations of residual insects from the previous season. The unfortunate reality as that this practise needs to continue and as such needs to be carefully managed.

The other issue worthy of mention with logistics and operations in regards to resistance development risk is the practice of cutting fumigations short. This happens more often than it should and becomes an annoyance when only a single train load is taken from the bunker. So the bunker with a compromised fumigation must be then resealed and scheduled for re-fumigation. Again, apart from just managing the practice, there is little else to be done when the client demands out-turn of their own grain regardless of the forward scheduling of fumigation agreed or otherwise.

Operationally, bunker covers are reused from season to season. The assumption is that a visual inspection of the bunker cover provides a satisfactory measure of its integrity. Such assumptions need to be tested and a standard provided for the industry. An empirical test could be developed but results would need to be collated over a period.

Commodity issues

Moisture content of commodity stored within a bunker is the most critical quality consideration in regards to the risk of resistance development in target species. During harvest (spring to summer) moisture migration issues are fairly minimal however in the autumn, the cooler evenings will drive the condensation on the underside of the tarps particularly along the peaks. Once the commodity is wet, the risk of fumigation failure and resistance selection is a very real possibility. Fumigants will not penetrate these wet areas and the survivors will remain protected from fumigation to fumigation. It is probable that those insects existing in the wetter areas, at the edge of the area where fumigant is at a lethal concentration, such as the *Cryptolestes* sps are going to provide the population most likely to develop selection to phosphine resistance in this scenario.

Fumigation issues
Reliance on a single chemical to achieve control has always been highlighted as a risk factor to the Australian grain Industries continued use of phosphine fumigation. The repeated use of this fumigant must be considered as a risk factor in selection of resistance regardless of how well the fumigation is conducted. Management of the pest is really a strategy to prolong its use as long as possible.

The effectiveness of the storage for fumigation, the skill of the fumigator and the efficacy of the dose rate being applied are the critical fumigation success factors. The development of resistance has caused these factors to be considered more closely.

A fumigation is only as good as its weakest point. All fumigations must be conducted in effectively sealed enclosures and be accurately monitored to ensure success. Poor results must be attended to during the fumigation process.

At the time the resistance was discovered and in current general practice, the bunker storage, if constructed correctly and checked for holes and proper closing, was considered to be effectively sealed. The data collected since then indicates this assumption is a stretch at best and often the seal is hopelessly inadequate. It is clear that a standardised test for assessing the integrity of the bunker seal prior to fumigation is a priority. While a test can be devised the data collected will need to be assessed to develop a standard measure of gas tightness with in a bunker storage.

This discussion has highlighted that current practice has increased selection pressure for the development of this resistant strain. It therefore follows that if current practice is modified the strain may be controlled.

STRATEGIES USED TO MANAGE RESISTANCE

In PRF facilities, the primary strategy has been to refocus on the basics of hygiene, sealing and fumigation practice. The use of contact pesticides is not an option in these facilities although it has been used successfully implemented in non-PRF sites. Due to the high level of phosphine required to control these resistant insects, successful fumigation at some sites became impossible. These sites required the use of an alternative fumigation or not residual strategy. The use of sulphuryl fluoride was having some success as a methyl bromide substitute and some studies on longer term fumigations had indicated although more expensive than phosphine it may provide a viable substitute in areas where phosphine was not achieving control. Trials using sulphuryl fluoride at a variety of locations and application rates were carried out and the results indicated efficacy could be achieved using much lower concentrations if the time of the fumigation could be extended to 10-12 days.

At the sites where insects had developed resistance to phosphine, sulphuryl fluoride was substituted completely for a season. No phosphine was used at any of these sites for this period. The sites were locked down and all areas disinfested using residual chemicals in non contact areas and diatomaceous earths in the grain path. Covers were replaced where they were damaged and the areas of wet grain along the peak were removed. All tarps and grain handling equipment was routinely cleaned and disinfested. All areas of refuge were eliminated or treated. The data collected on populations detected at these sites indicated that although the strategy had controlled the insects during the season the resistance was still present in most sites. Some sites did not detect insects for six nine months post fumigation.

As well as targeting the sites where resistance was known, the sulphuryl fluoride was substituted for phosphine at all sites for the fumigation of carry over grain and as such providing a break from phosphine in the selection cycle.

Apart from the significant increase in cost of this fumigant (in comparison to phosphine), several issues were highlighted from these trials. The fact that a significant increase fluoride levels were detected on the fumigated commodity is one such issue. Although the levels were low, the levels after repeat fumigations exceeded background levels. As such this is an area to be further investigated. Another issue was the significance of sorption onto the commodity was under estimated and varied significantly between products and quality.

A major observation from the substitution exercise was that the issues discussed above, which were thought to contribute to the phosphine resistance development, were significant in any control failure with sulphuryl fluoride fumigation.

The concluding comment from this observation must be that regardless of the chemical being used the basics are critical to successful control and resistance management.

CONCLUSION

The success of PRF facilities in delivering insect free and pesticide residue free grain is only possible if pest management programs are seriously implemented and monitored.

Fumigation rotation/substitution presents as a solution to current control failure due to resistance and resistance management or phosphine resistance in the future. However if the failures of the storage system and fumigation practice are not changed the risks of resistance selection will remain to challenge all fumigants utilised.

The use of rotation of fumigants can only be successful if all industry participants agree to be involved in a coordinated effort.

The discussion has highlighted several issues which still need attention.

The suitability of reused bunker covers for next season needs to be assessed against a standard in a uniform methodology.

The use of routine fumigations as a scheduling issue rather than a pest management strategy is questionable and needs to be reassessed.

The bunker as a sealed storage needs to be assessed with a pressure test or similar, prior to fumigation using a uniform comparable standard.

Systems to prevent the presence of moisture in the fumigation enclosure need to be developed urgently. Should bunkers be aerated, have vents in them or be regularly uncovered to highlight problem areas.

Fumigants may need to be recirculated within the bunker to ensure even distribution of chemical in the commodity.

The industry needs to agree to a coordinated approach to any fumigant rotation strategy.

REFERENCES

Collins P. (2009), National Working Party on Grain Protection and verified by personal communication)

Nayak M. and Collins P. (2011), National Working Party on Grain Protection and verified by personal communication