Pesticide Resistance in Stored Grain Pests in Brazil: Strategies for Management

Maria Regina Sarton¹ and Irineu Lorini²

Abstract

Management of resistance to pesticides in stored grain pests is one of the most important subjects to be understood and practiced in the post harvest grain system. Resistance has already been reported in Brazil by Rhyzopertha dominica (F.), Sitophilus oryzae, Cryptolestes sp. and Tribolium castaneum to the recommended pesticides for stored grain, such as phosphine, malathion, pirimiphos-methyl, fenitrothion, chlorpyrifos-methyl and deltamethrin. An efficient program for the management of resistance requires coordination of efforts amongst the various sectors involved in grain storage and protection, marketing and legislation. The main strategies are: (1) Detection and monitoring systems for pesticide resistance; (2) Collection, updating and analysis of pesticide resistance data by working groups, including, at least, representatives of the grain storage, protection and transportation sectors; (3) Training and extension in post harvest pest management, stressing the importance of preventive methods of control such as inspection, housekeeping and physical and mechanical methods of control; (4) Intensive training in the correct use of pesticides; (5) Establishment of IPM programs adapted to each situation, including preventive as well as corrective methods; (6) Evaluation of the spectrum of possible cross resistance problems to other pesticides to be used. The implementation of these strategies would keep resistance under control, help to reduce post harvest losses in quantity and quality, and increase the availability of more healthy and wholesome grain for internal consumption and exportation.

Introduction

Management of resistance to pesticides in stored grain pests is one of the most important subjects to be understood and practiced in the post harvest grain system.

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Status of Resistance

Resistance to phosphine, malathion, pirimiphos-methyl, fenitrothion, as evaluated by the Food and Agricultural Organization (FAO) discriminating dose methods (FAO, 1975), has been reported in Brazil for Sitophilus oryzae, Rhyzopertha dominica (F.), Tribolium castaneum and Cryptolestes sp. (Sarton et al., 1990; Pacheco et al., 1990; Sartori, 1993; Pacheco et al., 1994; Sarton, 1996). Resistance to chlorpyrifos-methyl was detected by Guedes (Guedes et al., 1996, Guedes et al. 1997) who also reported resistance to malathion and pirimiphos methyl. Resistance of Rhyzopertha dominica (Lonni and Galley, 1996; Lorini 1997) and of Sitophilus zeamais (Guedes et al., 1993; 1994; 1995) to deltamethrin has also been reported.

In the FAO Global survey carried out in 1972/73 (Champ & Dyte, 1976) resistance to malathion had already been detected in brazilian strains of R. dominica, T. castaneum, T. confusum and Oryzaephilus surinamensis. In this survey, resistance to malathion was not detected in brazilian strains of S. oryzae and S. zeamais. In addition, no resistance to phosphine was detected in stored grain insects from Brazil.

Preliminary results of a second survey in the southern part of the country, indicate that the strategies used for management of resistance to phosphine have been effective. Management of resistance to contact insecticides has been more difficult to achieve. Difficulties are related to poor sanitation practices, storage structures, lack of training of those who apply the insecticides and the small number of products registrated for use in stored grain. Training courses to implement the use of IPM in storage units, with initial emphasis on inspection and housekeeping, have been started.
almost total lack of residues and its great capacity for penetration certainly contributed to its wide acceptance, with the consequent decrease in the use of other fumigants, especially methyl bromide.

In the worldwide survey of pesticide susceptibility carried out by FAO in the period 1972–1973 (Champ and Dyte, 1976), no resistance to phosphine was detected in stored grain insects from Brazil. However, in a country-wide survey on resistance carried out by the ITAL research group, which covered eight brazilian states, resistance to phosphine in stored grain insects, as evaluated by the FAO standard method (FAO, 1975), was detected in 100% of the populations of Cryptolestes spp., 98.2% of R. dominica, 80% of S. oryzae and 84.9% of T. castaneum. (Sartori, 1996) Populations of R. dominica collected in the central and northern parts of the country were more difficult to control, requiring up to 10 times the discriminating dose and 168 hours of exposure (Sartori et al., 1990).

In a second survey, started recently in Rio Grande do Sul by EMBRAPA/CNPT in collaboration with ITAL, results have indicated, so far, that resistance to phosphine is under control. Average mortality at the discriminated dosages (FAO, 1975) for S. oryzae and R. dominica, reported in 1990 as being, respectively, 28% and 27% (Sartori et al., 1990) has changed to 37% and 34% (Sartori et al., unpublished) Increasing the exposure to the discriminated dose from 20 to 40 hours, made the average mortality change from 50% and 57% (Sartori et al., 1990) to 71% and 70% (Sartori et al., unpublished).

Resistance to insecticides

Organophosphates

In the survey on resistance which covered eight brazilian states, with sampling carried out in 1989–91 to detect resistance to malathion, pirimiphos-methyl and fenitrothion, as evaluated by the FAO filter paper technique (FAO, 1975), the following results were obtained: (1) resistance to malathion was detected in 90% of the populations of S oryzae, 73.3% of R. dominica and 100% of T. castaneum.; (2) resistance to pirimiphos methyl was detected in 20% of the populations of S. oryzae and 53.8% of T. castaneum; no resistance to this insecticide was detected in R. dominica; (3) resistance to fenitrothion was detected in 10% of the populations of S. oryzae, 27% of R. dominica and 39% of T. castaneum; (4) no resistance was detected to any of the insecticides tested in S. zeamays; (5) T. castaneum showed the greatest ability to develop resistance to these insecticides, exhibiting the highest frequency of resistant individuals, mainly to malathion (Pacheco et al., 1994). Resistance of brazilian populations of Rhizopertha dominica to chlorpyrifos-methyl has also been reported (Guedes et al., 1996; Guedes et al., 1997).

Pyrethroids

Resistance to DDT and Pyrethroids was detected in six strains of S. zeamays collected from four brazilian states (Guedes, 1993) Resistance of Rhizopertha dominica to deltamethrin was also reported (Guedes, 1996; Lorini and Galley, 1996).

Cross resistance in 10 Brazilian deltamethrin resistant strains of R. dominica was evaluated with permethrin, pirimiphos-methyl and chlorphosph-methyl. The results indicated cross-resistance to permethrin in two strains, but no clear evidence of cross resistance to pirimiphos-methyl and chlorphosph-methyl was found in any of the strains tested (Lorini and Galley, 1996).

Control of Immature Stages of Sitophilus Oryzae and Rhysopertha Dominica

All developmental stages of strains of with a higher frequency of resistance to phosphine, were used for a study of their control using commercial doses and extended exposure periods. The tests were conducted using the Mills and Price methodology (Mills and Price, 1988) and the results are indicated in Tables 1 and 2.

Table 1. Average mortality of eggs and young larva (Y) and old larva and pupae (O) of resistant strains of S. oryzae and of R. dominica, in relation to their control, after fumigation with 1.5 and 3.5g PH3/m3 for 72 hours.

<table>
<thead>
<tr>
<th>Species/strain</th>
<th>1.5 gPH3/m3</th>
<th>3.5 gPH3/m3</th>
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<tbody>
<tr>
<td></td>
<td>O</td>
<td>Y</td>
</tr>
<tr>
<td>S oryzae/stram 200</td>
<td>99.2</td>
<td>99.5</td>
</tr>
<tr>
<td>S oryzae/stram 226</td>
<td>96.6</td>
<td>90.0</td>
</tr>
<tr>
<td>R. dominica/stram 320</td>
<td>96.3</td>
<td>99.6</td>
</tr>
<tr>
<td>R. dominica/stram 312</td>
<td>88.3</td>
<td>100</td>
</tr>
</tbody>
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1 Sartori et al 1996; 2 Sartori et al , unpublished data
Table 2. Average mortality of eggs and young larva (Y) and old larva and pupae (O) of resistant strains of S. oryzae and of R. dominica, in relation to their control, after fumigation with 1.5 and 3.5 g PH₃/m³ for 120 hours

<table>
<thead>
<tr>
<th>Species/strain</th>
<th>1.5 gPH₃/m³</th>
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<td></td>
<td>O</td>
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<tr>
<td>S. oryzae/strain 200</td>
<td>99.6</td>
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<tr>
<td>S. oryzae/strain 226</td>
<td>100</td>
<td>99.7</td>
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<tr>
<td>R. dominica/strain 320</td>
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<tr>
<td>R. dominica/strain 312</td>
<td>97.3</td>
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1 Sarton et al., 1996; 2 Sarton et al., unpublished data

Management of resistance

Research Institutions

ITAL- Instituto de Tecnologia de Alimentos (Institute of Food Technology) and FAO-Food and Agriculture Organization

Based on preliminary results obtained in the country-wide survey, an alert to the users of phosphine was published in July 1987, by sending letters to official and private organizations involved in grain storage all over the country, recommending better sealing during fumigation and extension of the exposure period from 72 to 120 hours.

In August 1991, problems of resistance of stored grain insects to pesticides in Latin America were discussed in the Symposium on Post Harvest Management of Pests and Microorganisms carried out during the XII International Plant Protection Congress, Rio de Janeiro, Brazil. A talk was given based on results of a rapid survey conducted as part of the project PFL/RLA-002 PFL (Apoio a la Cooperacion Tecnica entre Paises de America Latina y del Caribe) which included 44 replies from 15 Latin American countries (Schulten, G., FAO Plant Protection Service, Rome, personal communication, 1991) and the results of the survey conducted in Brazil by ITAL research workers (Sarton et al., 1990 a; Sarton et al., 1990 b; Sarton et al., 1990 c; Pacheco et al., 1990 a; Pacheco et al., 1990 b). The main conclusions of this symposium as related to the resistance of stored grain insects to the pesticides in use were:

1. Very little factual information existed on the use of pesticides in post harvest production in Latin America.
2. The available information showed, however, that, in particular, fumigation practices were often inadequate due to poor sealing, underdosing and too short exposure periods.
3. There were strong indications that the resistance of stored product insects was developing in Latin America. There was, however, almost no factual information except for Brazil.
4. In Brazil there was widespread resistance to malathion with a cross resistance developing to pirimiphos methyl and fenitrothion.
5. In Brazil, phosphine resistance was demonstrated in S. oryzae, Rhyzopertha dominica and Tribolium castaneum from 6 states.
6. Inadequate pest management combined with poor application techniques were the underlying causes of resistance development.
7. The number of pesticides for post harvest was limited and all efforts should be made to maintain their usefulness.
8. Improved fumigation techniques referred, in particular, to improved sealing, recirculation of gases, CO₂ fumigation and improved apparatus to measure phosphine concentrations.
9. Effective sealing was considered essential to maintain the gas at the required concentration.
10. Improved techniques such as CO₂ fumigation and recirculation of gas could only be used in certain well-defined situations.
11. In the foreseeable future, fumigation would be conducted with the same products and technologies that were, at that date, most commonly in use.
12. There was an urgent need to improve fumigation practices through effective training and extension.

The principal recommendations of the Symposium related to the resistance problem were:

1. Monitoring systems for pesticide resistance needed to be established at national levels.
2. The information on pesticide resistance should be centrally collected, regularly updated, analysed and interpreted by national work groups (or similar bodies). In the light of the observed resistances, pest
management recommendations would have to be formulated for different post harvest situations.

3. Intensive training in the correct use of fumigants was required for different target groups, such as the pest control personnel of: terminals, transit depots, collection points, fumigation companies and farmers.

4. To this effect a ‘code of practice’ for fumigation should be developed and nationally accepted as the obligatory procedure for fumigation in the various situations.

5. Government should give more attention to training and extension on post harvest pest management, through the allocation of adequate funds and the nomination of post harvest extension specialists who, in turn, would train the front line extension workers.

6. International cooperation in post harvest pest management should be actively promoted, for example by the establishment of networks among countries which face similar post harvest problems and by support and participation of international technical assistance organizations in national training courses.

Following the recommendation for the establishment of a national work group, in November of 1991, the first meeting for ‘Management of Resistance in Stored Grain Insects to the Pesticides in Use’ took place at ITAL. There were nine participants: five manufacturers and distributors of equipment, insecticides and fumigants, three research workers from two research institutions and one representative of the state company responsible for grain storage. The objectives were to examine the data of the ongoing survey on resistance being carried out by the ITAL group and analyse recommendations and potential solutions, contributing in this way to make the kind of action expected from each sector very clear. The importance of cooperative work involving the various sectors, beyond immediate commercial interests, was emphasized, since control of resistance was, in the long run, of interest to everyone. The second meeting took place three months later with the participation of 22 individuals from various sectors. Three other meetings were held at three monthly intervals, with an increasing participation of other segments, since the discussions made the necessity for their presence very clear. Very important for the process was the participation of the three ministers: Agriculture, Health and Environment, which, together, function as a regulatory body as far as pesticides are concerned. Their participation was required due to the fact that the Brazilian legislation for the registration of pesticides was considered too strict. One of the recommendations for management of resistance was the use of pesticides with different forms of action. In addition, for effective simultaneous control of S. oryzae and R. dominica, it was necessary to use an organophosphate and a pyrethroid. Mixtures in the tank, on the other hand, were unforeseen by the legislation and results from research carried out in other countries, not accepted. The knowledge of the difficulties being faced due to the development of resistance helped to change the attitude of the Ministers.


During 1992, a document was also sent to phosphine manufacturers and to the Ministers of Agriculture, Health and Environment, recommending changes in the instructions on the labels of commercial products, increasing from 72 to 120 hours the period of exposure (M. R. Sartori and I. A. Pacheco, unpublished data).

Chemical companies and distributors started including the question of resistance in training courses on grain storage given in different areas of the country. An important improvement was observed in their attitude towards not only selling the product, but also in transferring technology for the correct usage.

A paper relating the situation on pesticide resistance of stored grain insects in Brazil, was presented at the workshop ‘Pesticide Resistance of Stored Product Insects: Status, Evaluation, Management and Education’, organized by FAO and the National University of Mexico-UNAM/PUAL-University Food Program, Mexico City, November 26-28, 1996 (M. R. Sartori, unpublished data). The main recommendations of this workshop, to be pursued during the following years were:

Group 1: Situation and Evaluation of Resistance
1. To develop instructions for the correct usage of pesticides.
2. To conduct a survey of the requirements concerning the conduction of tests on detection/monitoring of resistance in each country.
3. To develop protocols for the evaluation of resistance of insect-pests.
4. To develop a catalogue of specialists and experts working in the area of resistance of stored product insects.

Group 2: Integrated Pest management and Education on Resistance to Pesticides
1. To develop specific programs for the education and training on the control of stored product insects.
2. To conduct research and find simple solutions for pest control, implementing this research in the rural areas.
3. To evaluate the progress of the implemented educational programs.

Universidade Federal de Viçosa, Minas Gerais: The parasitic relation which exists between R. dominica and its natural enemy Acarophenax lacunatus (acari: Acarophenacidae) was verified (Padilha and Fonon, 1993). Acarophenax lacunatus is a mite which feeds on R. dominica. The immature phases of this mite developed in the eggs of R. dominica and dried them out, causing a 90% reduction in the population of this insect, in only one generation (idem).
A thesis has been published on the subject in which, among other aspects, the behavior and potential for parasitism of *A. lacunatus* against *R. dominica*, and the influence of temperature on the development and fecundity of the female mites were studied (Matioli, A. L., Departamento de Engenharia Agricola, Universidade Federal de Víçosa, 1997).

**EMBRAPA/wheat**: A project on the reduction of losses in wheat after harvesting is in progress, studies being carried out on: (1) efficiency of pesticides applied alone or in mixtures, (2) distribution of insects, (3) sampling and identification of agents for the biological control of stored grain insects. Studies conducted on the efficacy of inert dust as silica dioxide on the control of the main pest were successful. Improvement in detection and monitoring systems for the detection of infestation using grain traps, such as Burkholder Grain Probe traps (Cogburn et al., 1984; Burkholder & Ma, 1985; Subramanyan & Haren, 1990), with or without aggregation pheromones, inserted in the grain mass at different locations according to the structure of the grain storage unit, and examined once or twice a month, as well as sticker traps to pick up flying insects. The detection and monitoring of the resistance of stored grain insects to pesticides as well as training courses to implement the use of IPM techniques in grain storage facilities in the southern part of Brazil has been started in collaboration with ITAL and the Federal University of Paraná. To begin with, emphasis has been given to inspection and housekeeping and the improvement of pesticide application techniques. An important point to emphasize is that all efforts should concentrate on not carrying resistant insects from one harvesting season to another.

**ESALQ/Department of Entomology** is well known for its research on testing the efficiency of pesticide mixtures. They have also studied the control of residual resistant populations of stored grain insects using pathogenic fungi. **Federal Government**

The Ministry of Agriculture published a Decree (n° 67, of May 30, 1995) authorizing and regulating the mixture of pesticides in the tank. Mixture in the tank, means the practice of associating immediately before application, pesticides or related products necessary for the control of biological targets which occur simultaneously, for which it is not possible to achieve the desired efficacy with only one product. **Pesticide Manufacturers**

Casa Bernardo Ltda., in order to promote the adequate use of the product Gastoxin, the manufacturer has elaborated a detailed Technical Manual, produced videos on fumigation techniques and a practical manual on good fumigation practices in the form of an illustrated booklet (cartoon book). The firm has also been promoting training courses for distributors and clients. They have changed the instructions on the label regarding exposure periods, and have requested registration of a product for sealing junctions or fissures in metal and concrete silos, in order to reduce or eliminate leakage of phosphine gas during fumigation procedures.

Fersol, in collaboration with Fugran from Argentine, have worked on the introduction of a device for the recirculation of phosphine gas in silos. They also started importing an apparatus for the measurement of phosphine concentration in the air for dosage purposes and for the safety of personnel. Ihara Bras, is submitting for registration a mixture of fenitrothion + s-fenvarelate for the control of *Sitophilus oryzae* and *Rhizopertha dominica* (H. Kawanami, personal communication, 1998).

FMC, is testing a new pesticide with a different form of action **Grain Storage Operation**

Operational factors are an important tool for management of resistance, mainly for their potential in lowering the selection pressure and minimising the problem of residual infestations.

In grain storage units, management of resistance through changes in operational factors in grain storage units, include:

Factors related to the elimination of infestation focus and residual infestations.

The importance of the cleanliness of the equipment and premises used for storing, cleaning and moving the grain as well as that of the vehicles used for transportation, has been known for a long time. However, in Brazil the awareness of the extreme importance of this factor is only starting.

Factors that affect the temperature and the humidity of the grain.

It is known that a reduction in temperature and humidity affect the development rate of insects by reducing the generations selected and the number of insects in each generation. Temperature also affects the speed of degradation of pesticides during storage. In addition, some pesticides are more efficient at lower temperatures (pyrethroids), while others are more efficient at higher temperatures (organophosphates). Lower moisture contents are beneficial for both groups of pesticides (Heather, 1981).

In spite of the fact that most storage units in Brazil do have aeration systems, in most cases they are used in a curative rather than in a preventive way. A better use of aeration to lower the temperature enough to control or even prevent the multiplication of insects, as well as using this in conjunction with chemical treatments in an integrated approach, is the next issue to be presented in the training program being carried out by EMBRAPA/wheat in collaboration with ITAL.
Factors related to the application of pesticides

It is important to know the exact location of the infestation, the species present and the requirements for their control, directing the treatment with the objective of achieving complete control. Good sealing in the case of application of contact insecticides and training of personnel is different modes of action is advised. However, this is frequently overlooked. Alternation of pesticides with fumigation, adjustment of equipment for the correct application, directing the treatment with the objective of infestation, the species present and the requirements for their control, must be considered in deciding the type of treatment to be applied.

Training to improve pesticide application practices has been carried out by chemical companies and distributors and by EMBRAPA/wheat in collaboration with ITAL. Selling the pesticide applied, mainly to new customers, is another technique that has been used by pesticide distributors.

Cross Resistance Problems

Some work has been done in Brazil regarding the evaluation of the spectrum of possible cross resistance problems with other pesticides to be used.

Non-specific type of resistance to malathion, indicating the probability of resistance to other pesticides of the same group, was detected in 9 out of 14 (67%) populations of T castaneum collected in the State of São Paulo, Brazil (Sartori et al., 1990). In a survey that covered 8 states of Brazil it was observed that 20% of the populations of S. oryzae and 53.8% of T. castaneum showed indications of resistance to pirimiphos-methyl (Pacheco et al., 1994). Resistance to this insecticide was not detected in R dominica (Idem). Resistance to fenitrothion was detected in 10% of the populations of S. oryzae, 27% of R. dominica and 39% of T. castaneum (Idem). All the populations resistant to either pirimiphos-methyl and/or fenitrothion were also resistant to malathion. It was not detected resistance to any pesticide in S. zeamays.

Some cross-resistance of deltamethrin resistant strains of R. dominica (F) with pyrethroid, permethrin and the two organophosphate insecticides, pirimiphos-methyl and chlorpyrifos-methyl has been found. After laboratory selection, deltamethrin selected strains increased their tolerance to permethrin and vice versa. However, the strains selected with these pyrethroids exhibited a decreased or unchanged tolerance to the two organophosphate insecticides, pirimiphos-methyl and chlorpyrifos-methyl, after three generations of selection. This pattern of cross-resistance in R. dominica (F) probably involves different genes, which confer resistance to the different insecticides tested. This is an important aspect to be considered when managing pesticide use, particularly where resistant strains are detected in the stored grain environment, since the lack of this knowledge may result in pest control failures and losses in grain (Lorini, 1997).

Conclusions and Recommendations

1. Detection and monitoring of resistance of the most common stored product insects to the pesticides in use in Brazil must be implemented at a national level, using standardized methodology.
2. A catalog of specialists working in the area of resistance of grain storage insects must be prepared, to allow for ample exchange of information on this subject.
3. Directions for the correct use of each pesticide must be developed.
4. Programs of education and training directed specifically towards the control of stored product insects, including cost/benefit considerations and ambiental safety, must be developed.
5. Due to the fact that grain storage units most commonly in use in the country are open structures, the cost involved in the modification of existing units and available know-how, in the foreseeable future the control of stored grain insects in Brazil will continue relying mainly on contact insecticides, with fumigation being used in specific situations where the absence of chemical residues is important or when the failure of control by contact insecticides has been detected.
6. Research on new and old pesticides must be continued in order to maintain viable alternatives for control.
7. Research and implementation of the use of non-chemical methods of control, as inert dusts and cooling, are recommended to lower selection pressure for resistance.
8. Government institutions must provide technical support to grain storage operators to implement the use of integrated pest management techniques adequate for each situation, to reduce pesticide application and lower the selection pressure for resistance.
9. Improvement in housekeeping and inspection in grain storage units is the first goal to be attained in order to reduce infestation problems.
10. Resistance of stored grain insects to the discriminating dosages of all pesticides in use in Brazil has been detected, so measures to preserve the useful life of these pesticides as well as grain quality are urgently needed.

References


Resistance to phosphine in stored grain insects in Brazil

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