RESEARCH ON PESTICIDES AND FUTURE REQUIREMENTS FOR CHEMICALS IN THE PROTECTION OF STORED PRODUCTS FROM INSECT[1]

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ABSTRACT: The need for safer and better pesticides, greater understanding of the interrelation between pest biology and pesticide action, and the application of techniques and practices for improving the effectiveness of pest control agents will provide wide scope for future research on stored-product pesticides. The development of insect resistance to insecticides in current use as well as to insecticides not yet used on a wide scale is cause for concern and suggests that too much reliance has been placed on the effectiveness of a single control agent. The combined use of physical and chemical controls should reduce the amounts of chemicals needed for insect control and consequently reduce selection pressure which contributes to the emergence of resistant strains. Critical assessment of those control practices applied routinely as insurance against infestation may reveal instances of over-treatment which add unnecessarily to the overall chemical "load" applied to a commodity, first as a raw cereal and later as a food product during various stages of processing, transportation, and storage.

Environmental factors such as temperature, grain moisture content and availability of food, influence insect locomotor activity and, consequently, the amount of toxicant picked up by insects. Thus, toxicants which stimulate insect activity will counteract environmental effects which tend to reduce insect activity. Public concern for contamination of foods suggests that more attention should be given to extension and public relations in the safe and efficient use of stored-product pesticides to counteract the unfavorable publicity generally given to pesticides.

The importance of food conservation in a hungry world makes it abundantly clear that man will need to use every device known to him to protect his food from insect attack during storage. Pesticides are among our most effective weapons for disinfesting and protecting stored products from infestation. But optimum value from pesticide usage can only be obtained by the application of knowledge gained from continued research on all aspects of the stored product complex: ecosystems, the organisms that inhabit them, and the practices used for their control.

The tremendous potential of pesticides for increasing agricultural productivity was recognized shortly after the

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development of synthetic pesticides; since then rapid expansion of entomological research programs emphasized evaluation of these new chemicals. It has only been in the last decade, however, that the limitations of pesticides have become widely recognized and weighed against their merits. The occurrence of pesticide residues in plants, animals and foods, assessment of the toxicological significance of residues, and the development of pest resistance are but a few of the problems that have stimulated research into the development of safer pest control chemicals and safer and more effective ways of using them.

It would have been short sighted indeed, however, to have restricted pest control research to pesticides alone. Much emphasis has also been placed on research on the biology of storage pests and some studies have sought to relate these findings to improvements in overall pest control practices. Thus, emphasis on research that seeks to relate pesticide usage to pest biology provides optimism for the future.

This paper deals with various aspects of pesticide research that have a bearing on pesticide use in stored grain and the food industry and touches briefly on problems that may be encountered in the future use of pesticides.

Most chemical compounds supplied for testing have already been critically evaluated by the chemical industry or by various research institutes. Evidence concerning efficacy against stored product insects is usually derived from a limited number of laboratory tests which may form part of an overall screening program. Additional research therefore is often needed to evaluate those aspects of an insecticide's performance that are of concern for a particular climatic region, or for a special need. This usually involves tests of efficacy against one or more economically important species, and studies to determine persistence and rate of breakdown under certain environmental conditions. Comparisons with other insecticides should reveal whether candidate insecticides overcome some of the deficiencies inherent in currently used compounds.

Laboratory evaluation is relied on to a great extent for obtaining preliminary information on the efficacy of certain compounds. It is unfortunate if research on a compound is discontinued if small-scale laboratory trials show that it has little promise. For example, laboratory tests with methoxychlor by various workers [1,2,3,4] have shown that this insecticide is less effective than others for control of several species of stored-product insects. Our own field tests, however, revealed that methoxychlor applied in flour storage warehouses controlled infestations of spider beetles[5,6]. Thus, laboratory trials in which dosages, exposure times, and temperatures etc. are closely measured and controlled may not always provide a true indication of field performance. Nevertheless, laboratory tests are indispensible for rapid assessment of insecticides and investigations of important parameters which limit effectiveness.

Control or prevention of insect infestations in storages or stored products is usually attempted with insecticides that have been recommended for this purpose. Recommendations are usually based on laboratory and field trials carried out by scientists in the chemical industry, Government or university research stations. The acid test of course is whether the insecticide actually meets the expectations of a wide variety of users under a wide variety of conditions. Considering the many combinations of factors involved in the practical use of an insecticide it is little wonder that there are instances where a recommended insecticide use does not provide the control expected. Variations in dosages, application equipment, building surfaces, substrates, environmental conditions, the susceptibility of insect species, stages and strains and in the people who apply the insecticide, all contribute to wide divergencies in results. When all of these factors are considered it is indeed remarkable that there is any unanimity of opinion at all concerning the performance of an insecticide. It must not be forgotten also that of the people, who apply an insecticide to control an infestation, some are skeptical of its performance and do a slipshod job, some do a token job to conform with instructions issued by management or a regulatory agency, while others may be conscientious in trying to obtain the desired results. Thus a wide spectrum of people are involved in both applying a treatment and assessing its effectiveness.

There is also a wide range of criteria used to determine the success of a treatment. Warehousemen are often most impressed by the sight of numerous dead insects in a warehouse or commodity after treatment. They often fail to consider the potential threat of survivors. A more objective way to assess the effectiveness of chemical control measures is the use of insect traps. McFarlane and Warui[7] used trap bags, 30 x 20 cm, made from medium weight B-twill jute sackcloth containing 600 g of sieved disinfested maize grain or green coffee beans. Trap bags may be placed in premises that have been fumigated or treated with insecticides, and sieved at intervals after treatment to determine when, to what extent, and with which species, the treated premise, warehouse, or ship's hold becomes reinfested. In 1949, shortly after our laboratory had recommended certain insecticides for the control of spider beetles in flour storage warehouses in the Prairie Provinces, we provided an "indicator service" for the flour milling industry which was concerned about spider beetle infestations of bagged flour and the effectiveness of control recommendations. This service involved the placement of one-pound cotton sacks filled with flour on the floor of warehouses treated with DDT, lindane or pyrethrins-piperonyl butoxide. The sacks were returned to our laboratory at intervals throughout the summer and sieved to determine infestation levels. We assessed the effectiveness of treatments applied by various warehousemen and supplied the information to the flour milling companies to enable them to assess the effectiveness of treatments carried out by their own staff in their own warehouses. The results showed that the treatments were extremely effective. Various kinds of traps may be used[8,9] to detect insects in stored grain. Traps are particularly useful for assessing the effectiveness of grain fumigants, for determining whether or when the grain becomes reinfested and in detecting low levels of infestation which if left uncontrolled could result in extensive damage to stored grain.

INSECT TOLERANCES: Several countries have established insect tolerances in wheat and other grains, usually for grading purposes and to meet export specifications[10]. In addition, food standards in certain countries, notably the United States, may specify permissible insect fragment levels in cereal products. Such tolerances have been defined partly in accordance with the standards that are possible to meet. It is perhaps more difficult to determine threshold levels of infestation in stored grain, warehouses, and flour mills which can be tolerated without recourse to the use of chemicals or other controls. Yet regulatory enforcement officers frequently make decisions on acceptable infestation levels which are not based on scientific data.

Much confidence is placed on the experience of individuals who make decisions on infestation levels that require the application of control measures. Assuming that a treatment controls 99.9% of a heavy infestation many survivors will remain. The probability of detecting survivors will depend on the sensitivity of insect sampling methods or detection devices. The cost of control in relation to the value of the stored commodity and the consequences of insect survival will determine how far one should go to measure the effectiveness of a control measure. For example, if a small proportion of a pest population survives a stored grain fumigation, a decision must be made regarding the potential threat of the survivors to the storage quality of the grain. This decision should be based on knowledge of the possible rate of increase of the population in grain under the conditions of storage, whether the survivors are in pockets or are sparsely distributed throughout the grain, and whether the season of the year is conducive to rapid insect reproduction and growth. Decisions that are not based on these considerations may result in serious storage losses or the unnecessary reapplication of treatments.

Those who have developed integrated approaches for the control of pests of growing crops are in a much stronger position for determining when to apply pest control chemicals. Their decisions are based on knowledge of measures which cause the minimum disruption of the crop ecosystem consistent with the need to control the pest that is causing the most damage. Field crops can withstand infestations below a level often referred to as a "critical injury level". Control measures are implemented when insect counts exceed this level. The critical injury level may be easier to recognize in a two dimensional crop where damage may be confined near the top of the plant and at the periphery of the plantation. Pest damage to stored grain, a three-dimensional medium, is only readily apparent at the surface; extensive probing and sampling must be done to determine the condition of the grain throughout the bulk.

Though it is conceivable to contemplate a critical injury level being set for stored grain, it is difficult to imagine a level being set for the foods we eat although no doubt there have been times when it has been necessary to tolerate the presence of insects in foods.

The use of chemicals on or near foodstuffs for insect control or for prevention of infestations has to be considered in relation to the ultimate use of the food. Imported foods will be subjected to scrutiny both for chemical residues and for insects to comply with national standards of health and food sanitation. If the commodity is to be used immediately for processing, the requirement may be less stringent for the presence of insects but more exacting for chemical residues. By contrast, if the food is to be stored in reserve for several months or years the presence of insects will not be tolerated but there will be a longer period for the breakdown of chemical residues. High food standards in developed countries place a heavy burden on developing countries in tropical and subtropical zones, that are expected to export foods that are both uninfested and free of insecticide residues and other contaminants.

The measurement of losses due to pests and diseases is difficult in most crops but a start has been made and progress has been reported by FAO[11]. Storage losses have frequently been estimated and reviewed[12,13] and the information has often been used to justify research and programs to improve storage practices. Caswell[14] has measured the loss of weight of cow peas in Nigeria which have resulted from insect infestation. There are many aspects of storage losses such as loss of good will that cannot readily be measured. Despite these difficulties, the accumulation of reliable data and the development of techniques to measure loss will be useful for determining the emphasis of research programs as well as for providing a yardstick for measuring the success of control measures.

The use of cost-benefit studies for research as well as for assessing the economic significance of pest control programs will no doubt expand in the future. The accumulation of reliable storage loss data will be essential in any cost-benefit studies undertaken to improve storage practices and facilities.

FUTURE REQUIREMENTS: Research on pesticides must take into account the serious problems posed by the development of resistant strains of insects. The occurrence of resistance in endemic populations of stored-product insects in ships' holds is cause for concern. Several grain exporting countries require that empty holds be fumigated or sprayed to control insects prior to taking on fresh cargoes of grain. The insects that survive such treatments can readily be transported with the grain to its destination. This facilitates the dispersal of resistant insects to ports of call throughout the world. It is conceivable that in countries where resistance monitoring programs are established, cases of resistance of stored-product insects will be discovered and such instances may be due to the transportation of infested commodities from ports to inland areas. In our own program of monitoring the susceptibility of *Tribolium castaneum* (Herbst) to malathion, we have found that the LD 50's of insects collected from port areas in Vancouver and Montreal where chemical controls are frequently used were 5 to 10 X as high as those of insects collected from interior regions in the Prairie Provinces where the application of chemical control is more the exception than the rule.

The FAO global survey of resistance of stored product insects to insecticides has emphasized the importance attached to the effective control of stored food pests throughout the world. The unchecked spread of resistant strains of storage pests is cause for concern among both food exporting and food importing nations. To deal with this problem effectively it will be necessary to encourage the establishment of monitoring centers to pinpoint the countries or regions where resistant strains are developing most rapidly. Standardized test methods for resistance such as those reported by Champ and Campbell-Brown[15] and recommended by FAO[16] provide the means for achieving uniformity in resistance testing at various centers throughout the world.

The development of countermeasures to deal with resistant insects will involve increased emphasis on the screening and introduction of new compounds to replace those that have become obsolete. But care should be taken to use the new chemicals in such a way as to reduce the speed with which insects may develop new resistant strains. This will involve the use of practices that do not rely solely on chemicals to control an infestation. More emphasis must therefore be placed on combining chemical and physical controls to reduce selection pressure on populations that may become resistant.

Combined chemical and alternative methods of pest control have been the foundation stone of practical, integrated control techniques. However, it is easier to expound on this theme than to develop programs for improved pest controls. One of the difficulties in most storage pest control operations is that in most cases farmers, grain companies, government agencies and the food processing industry want quick results before the grain can be sold, consumed, or moved to another destination. However, where grain or stored processed food is to be held for long periods as a strategic reserve, it may be possible to institute combined chemical and other appropriate means of control with the object of reducing[1] the overall pesticide load on the food and[2] the chemical selection pressure on the pest populations which often leads to the emergence of resistant strains. Whichever pest control techniques are employed, however, the owners of the grain or food will expect to obtain the same degree of control or protection from pest damage as may be obtained with chemicals alone.

The timing of pesticide applications to coincide with maximum flight or locomotor activity will improve the possibility of obtaining maximum opportunity of contact between the toxicant and the pest[17]. The use of formulations that include components to excite pests and increase their frequency of contact with the toxicant should increase the efficiency of pesticides. This is especially desirable with chemicals such as bromophos that take longer to kill insects.

Insecticides are often applied to all accessible structural surfaces of food storage premises and the work areas of elevators and food processing plants, without regard to the need to treat the entire area. In addition, pesticides are sometimes applied as an insurance against infestation without any knowledge of whether or not an infestation is likely to develop. The excessive and, in some cases, unnecessary use of insecticides may result in severe selection pressure which may contribute to the development of resistant strains of insects in addition to the waste of chemicals and labor if insects are not present. More emphasis should therefore be placed on the selective application of chemicals to those places where insects are known to occur most frequently. "Spot treatment" of localized infestations in flour mills and stored grain demonstrates the value of controlling an infestation with the minimum amount of chemical consistent with good pest control practice.

A possible countermeasure against resistant strains of insects that are being transported around the world in ships' holds might involve the use of highly toxic, low vapor pressure fumigants that have been tested in the laboratory and in flour mills[18,19]. Though such fumigants have not been used commercially they may be considered for the spot treatment of confined spaces in ship's holds and premises where food residues accumulate and insect control is difficult.

The many environmental restrictions being placed on newly developed compounds will make pesticide research less profitable for the chemical industry. Therefore, it may be necessary to develop new techniques to utilize existing compounds more efficiently to overcome their deficiencies. The use of plastic polymers impregnated with an insecticide has provided a means of prolonging the effectiveness of insecticides such as malathion and pyrethrins that have limited persistence when sprayed on certain types of structural surfaces. Research on the most effective ways of utilizing slow release formulations may reveal new approaches for protecting stored products from insect attack.

Greater emphasis should be directed to the improvement of extension and public relations activities regarding the proper handling and application of agricultural chemicals to obtain maximum benefit at minimum risk to those who apply the chemical and to those who transport, store and use the treated commodity. Certain pesticides such as phosphine formulations have built-in safety features which protect personnel from exposure to toxic gases during application. Development of pesticide formulations with similar protective features should be encouraged to eliminate the hazards associated with the use of pesticides for the control of storage pests.

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