GENETIC CONTROL OF INSECTICIDE-RESISTANCE IN STORED PRODUCTS INSECTS: PROSPECTS AND PRELIMINARY INVESTIGATION

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ABSTRACT: Insecticide resistance rapidly becomes a control factor in the control of insect pests.

Control of stored products insects by conventional methods is more difficult, than control of other insects, but the fact that they live in confined spaces makes the use of some control measures more successful than with other pests.

Genetic control measures, which were successfully used with some insects of agricultural and medical importance, should be particularly useful against stored products pests. Specifically, a procedure is suggested for the genetic control of insecticide resistance.

Preliminary investigations with *Tribolium castaneum* have indicated that it may be possible to reduce the level of resistance despite continuous exposure by the periodical release of susceptible males. However, these results require further confirmation.

Most, if not all, major agricultural pests and disease vectors are now resistant to at least one, more frequently to several of the chemicals used for their control. When resistance is detected in a given population, the usual solution is first to increase the dose (in some cases even 100-fold) and when this fails to kill the insects, to replace the chemical by another, usually more potent insecticide. The chemical industry is constantly being kept busy producing new and more effective chemicals, so that agriculture could stay in the race with the developing resistance in the insect populations, but the latter is gradually winning [1].

For stored-products insects the problem is more serious than for other pests. Because they live inside food or fodder commodities, direct application of the insecticides is impossible, and periodical spraying of warehouses, storage tanks, or empty bags is often used. The kinds of insecticides and the applicable doses are more restricted than for open-field insects, and the range of alternatives to an insecticide is much narrower. Moreover, world trade in grain and grain products serves to spread insecticide resistance very quickly. Port warehouses are a major source of insect infestations in shipped grain [2]. Once a resistant strain has developed somewhere in the world, it cannot be expected to remain localized for long, as shown, for example, by the spread of resistance in the flour beetle *Tribolium* [3].

However, compared with other pests (agricultural and medical), stored-products insects have one characteristic which helps in controlling them: the fact that they live within a more or less confined space, within human warehouses and other storage facilities. This makes possible the use of control measures inapplicable to other insects, such as fumigation with ethylene dibromide. Saturation with pure oxygen [4] and massive gamma irradiation [5,6] have been investigated as possible means of control.

Radiation resistance was reported in *Drosophila* recently [7]. Although the phenomenon was not detected in *Tribolium* by Brower and his associates [5] the danger of its developing in the future exists. Resistance to ethylene dibromide fumigation was recently reported by Bond [8]. So we may be confronted with resistance problems to these control measures also.

The limitations on conventional spraying or dusting procedures due to their living inside food commodities, and their occupying more or less confined spaces, justify in my opinion the exploration with other control means for stored products insects, which may prove to be more effective for these insects than for any others. I refer to genetic techniques, which have been tried in many insects in the last 15 years or so.

The ultimate objective of genetic control methods is to interfere with the reproductive process in the pest population, and cause its decline and final eradication.

A few cases of impressive success with such methods have been reported. The first method to be used successfully (although, historically, not the first one suggested) was the well known sterile male technique, suggested by Knipling [9,10], which was successfully used in eradication of the screw-worm fly in the United States and of the melon fly on the Island of Rota. The use of this technique for control of disease vectors is reviewed by Rai [11]. Laven [13] has reported successful eradication of a population of Culex from a village in Burma through the release of strains carrying cytoplasmic incompatibility factors resulting in infertile eggs when mated with the local strain. The prospects of using this and other genetic methods against mosquitoes was reviewed by Knipling et al. [13]. Successful replacements of a harmful strain by a harmless one were recently reported by Foster and Galun [14, 15] with the Hessian fly, a pest of wheat.

The dominant Great Plains race, which is unable to develop on resistant varieties of wheat, was released in large numbers in field cages and greenhouses (both confined spaces) infested by the harmful but recessive B strain. In a few generations the population growth of the B strain was suppressed with a release ratio of 4:1, and complete replacement and eradication of B was achieved with a ratio of 9:1. These ratios are very low compared to those used with the sterile male technique.

As of now, however, such cases of success in the field are rare. Much more has been done in theory and in the laboratory.

Serebrouskii's [16] suggestion to use strains carrying chromosomal translocations for eradication of pests was examined theoretically for applicability to the Tse Tse fly control, by

Curtis and Mill ([17, 18]). Whitten [19] suggested that the genetic "driving force" leading to fixation of translocation homozygotes when they are released in appropriate proportions, can be used to insert desirable genes into the population, such as susceptibility, to insecticides or to cold. He calculated that theoretically, few generations are required for such a replacement.

Translocation have been produced in houseflies [20] by irradiation, and also have been considered and tried in mosquitoes [21,22]. But irradiation adversely affects fitness. Of more than 300 translocations produced by Wagoner et al. [20] in houseflies, only few were viable enough to give rise to laboratory strains carrying inherited reduced fertility when tried in the laboratory.

When released in the field, a translocation carrier house fly strain did not affect the local population at all despite large scale releases, apparently because the released files migrated away from the release area [23]. This report illustrates that even strains producing very good results in the laboratory, may not do so in the field for reasons which cannot always be predicted.

More recently Foster et al. [24, 25, 26] suggested the use of strains carrying compound chromosomes. The driving force created by the release of such a strain is stronger than with ordinary translocations, because no offspring are produced from a mating of a compound chromosome homozygote and a normal organism. When both sexes of such a strain are released in high enough proportion, it will replace the normal strain quickly - if it is competitive under field conditions. However, only in *Drosophila* there are known strains carrying compound chromosomes, and they have very poor fitness (fertility of these strains is expected to be 25% of the normal).

We must accept, therefore, that genetic methods available at present cannot replace pesticides in controlling pests. This is just as true for other biological control measures, which are beyond the scope of this paper.

GENETIC CONTROL OF INSECTICIDE RESISTANCE: If we accept as realistic, (perhaps to the disappointment of many) that pesticides will have to be used in the future (in fact, that no alternative is available for modern agricultural) then we must concentrate on solving the problem of insecticide resistance, which rapidly becomes a key issue in insect control. Genetic methods may be useful for this purpose.

In a 1971 paper I presented the following argument [27]. Resistance develops in an insect population when by applying a pesticide, we remove from it those genotypes which respond "positively" to the treatment, i.e., those which die, and thus allow those genotypes which do not die to multiply and constitute a higher proportion of the next generation. If we could compensate for the loss of genes contributing to susceptibility and keep the genetic composition of the population unchanged, then the pesticide will remain effective despite continuous use. This can be achieved by releasing in the field susceptible males, produced in large numbers in the laboratory. A susceptible stock of insects can be obtained either from a field source in which resistance has not been demonstrated or by selecting for sensitivity from a resistant field source. Release of males only will not cause an increase in population size. Benson [28] discussed in detail the possibility of replacing a resistant by a susceptible strain, and calculated that this may be done in few generations if the desirable strain is released in appropriate numbers.

This idea seems particularly attractive for use with stored products insects, first because genetic methods do not suffer from the limitations on the use of poisons with food products. The released males will penetrate the grain bulk and find their mates just as easily as the resistant local ones. Being confined to a more or less limited space, their chance of migrating away from the release site (without transmitting their genes to the next generation) is low.

A possibly useful approach may be to release the susceptible males in large numbers in the warehouse or when the grain is removed to the market. Just before a new shipment of grain is stored there, the insecticide should be applied. The interval between the two dates should be sufficient for the released insects to mate with the resistant females, so that a large proportion of those surviving the pesticide would be carrying sperm with susceptible genes.

If resistance is recessive or semidominant to susceptibility, the level of resistance should fall already in the next generation. If resistance is dominant, the effect will be delayed one generation, but susceptibility genes may have a better chance of securing a hold in the population (in *Tribolium*). I have shown that hybrid males between two strains were more successful in mating than either of the two pure strains, [29].

Finding a susceptible strain requires no irradiation. Furthermore, susceptible strains (for any pesticide) existed and were very successful before the application of the pesticide - this was the reason for the use of the chemical in the first place and if males of the same genotypes are reared in the laboratory and released, they should still be able to function in the local conditions, at least long enough to mate. If the pure laboratory males are too sensitive to pesticide remains in the field and unable to survive long enough to mate, crosses with resistant females may be produced in the laboratory and hybrid males released which will be able to function and transmit the susceptibility genes. Rearing large numbers of stored products insects, especially Coleoptera, should require smaller facilities and lower expenses than other pests. Timing of releases to periods of low pest population sizes could of course help reduce the cost of this operation.

PRELIMINARY RESULTS WITH <u>TRIBOLIUM</u>: I have tried to use the flour beetle, *Tribolium castaneum*, to test whether migration of susceptible males, into a resistant population exposed periodically to selection in DDT may reduce the level of resistance despite treatment. The earliest attempts were very encouraging. Replicate populations of a resistant strain in jars, were exposed at the adult stage to DDT-impregnated filter paper for 24 hours every two weeks. Following exposure, the live beetles were counted, and susceptible males were introduced - 40%, 20%, 10% and 0% of the live population size. After two such treatments (1 month, or approximately one generation), resistance was reduced (measured as % mortality on the same dose used for selection) in proportion to the migration rate, i.e., mortality was in the order control (0% migration) 10% 20% 40%. However, this effect was not that clear in subsequent counts, and by a combination of sporozoan infection and bad luck, the experiment was destroyed. A graduate student of mine, Mr. Michael Paz, has been trying to continue this investigation, and encountered unforeseen difficulties some of them related apparently to the mating system in his populations. When controlled, crosses were made between resistant and susceptible beetles, resistance was reduced in the offspring, but the effect did not continue when susceptible males were added to these offspring. Clearly this work is far from complete. There was one interesting result, however; Mr. Paz succeeded in selecting from his resistant strain, within 4 generations of family selection, a susceptible population. Mortality of the source strain for the selective dose was only 4% but that of the back-selected strain was 82%.

CONCLUDING REMARKS: The point I would like to make here is that the genetic approach to the solution of the problem of insecticide resistance in stored products insects is worth investigating. I wish I had more impressive results to show; I am hoping to get them in the future.

There are no control measures applicable to all pests. I shall welcome cooperation with anyone here, and any attempts to try this method on another insect. It may not be easy, but in the long run it seems to be worth trying.

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