Vidyodaya J. Arts, Sci., Lett., Vol. 4 Nos. 1 & 2 pp 54—60, 1971

Genetical Implications of Pest Control — Uses and Possible Dangers —*

by

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AS the title suggests, the aim of the present paper is to spotlight two aspects of the genetical implications involved in pest control. They are, (1), the practical application of genetics in the actual control of pests, and (2), the problems and dangers of a genetical nature that do and could possibly arise with the widespread use of noxious pesticides. As these two aspects are fundamentally different from one another they will be considered separately.

A. Genetical methods of pest control

The use of genetical methods in the control of pests is very recent. The theoretical possibilities of using such control measures were first discussed in the 1930s, but it was well over two decades later — in the mid-1950s — that they were dramatically demonstrated in the field. Genetical methods of pest control are very sophisticated and demand a considerable level of competence and skill in their use. Some of these techniques will be discussed below.

(i) Sterile — male technique

In essence this technique is to sterilize males of a pest by irradiating or chemically treating their testes and releasing such sterile males in the field on a mass scale at frequent intervals of time. Even under the best conditions where this technique is used, the ratio of sterile males to normal males in the field should be over 5 : 1 to obtain good results.

The treatment induces sterility in the male by breaking the chromosomes in the germ cells and disrupting the meiotic process, so that, during spermatogenesis infertile sperms are produced. However, the treatment should be such that it would neither impair the viability and motility of the sperms, nor affect adversely the mating behaviour of the males.

When the sterile, but fully viable, sperms fertilize ova in normal females in the wild, they produce zygotes which will not complete their development and shall, therefore, not hatch out of their eggs. These lethal mutations which are mostly due to large deletions on the treated chromosomes are referred to as dominant lethal mutations. The extent of induced sterility or dominant lethality is measured quantitatively by counting the number of eggs which fail to hatch after successful fertilization by the treated sperms. Dominant lethal mutations, by definition, are not inherited, and, therefore, will have to be induced for each generation.

* This paper has been prepared from a talk given at a Panel Discussion on "CROP PROTECTION—current trends in Insect Pest Control" held on 15.2.71. during the 27th CAAS Annual Sessions (1971).

The sterile—male technique was first suggested on purely theoretical grounds by Knipling in 1937 and was also the first genetic method of control to be demonstrated in the field with spectacular success in the 1950s, also by the same author. He was able to eradicate completely the screw-worm fly pest of cattle (*Cochliomyia horminivora*) in the U.S.A., a pest which was very difficult to control using conventional methods. Since then this technique has been widely used to combat the increase and spread of pests of various sorts, such as : caterpillar pests of paddy and corn, fly pests of fruits, mosquito vectors of disease, hymenopteran and dipteran pests of livestock, etc.

Various methods are used to induce sterility in the males. They are of two main types, physical and chemical. Physical methods depend upon the use of irradiations like gamma-rays and x-rays, while chemical methods depend upon the use of radiomimetic alkylating agents like the mustards, apholate, thiotepa, triethylene melamine etc. When the chemosterilants are used they may be added to a bait and placed in the field so that the pests are drawn to it and get auto-sterilized. In this way, not only the males but females would also get sterilized, thus enhancing the control and eradication of the pest.

Other genetical methods of pest control also ultimately depend upon the sterility principle for eventual control of the pest. In the technique described above sterility is achieved directly by an outside agent. Hence, this technique is more strictly referred to as the *induced-sterility technique* of pest control. The successful use of the induced-sterility method calls for a thorough understanding of the biology of the pest, particularly with reference to population density, distribution, flight range and mating behaviour. This knowledge is essential because :

(*a*) if the density of the pest population is very high, very large numbers of sterile males will have to be released at repeated intervals of time ;

(*b*) if the distribution of the pest is very wide, then sterile males will have to be released over the entire area where the pest is found for otherwise re-infestation from uncontrolled areas would definitely occur ;

(*c*) if the flight range is limited, sterile males will have to be released over the pest infested areas at short spacings ;

(*d*) if the mating behaviour is such that a female can be repeatedly fertilized by different males, then larger number of sterile males will have to be released to overcome the chances of the females being fertilized by the normal males in the wild. Even then the chances of wild males mating with the females at least once is extremely great and will negate the efforts for control. Furthermore, the treatment should in no way affect adversely the mating behaviour of the males in competing with the normal males for females, nor affect the treated sperms when competing with untreated sperms in fertilizing the eggs in the females, if more than one mating is possible.

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Thus, it is seen that the most successful control by this method is possible only in those pests which are of low population density, are localized in distribution, have a wide flight range and are monogamous. Luckily most of these conditions were true for the screw-worm fly pest which accounted for the dramatic vindication of this method in its control.

The major limitations, apart from those listed above, are (a) the long time taken in studying the biology of the pest before control measures are even initiated, during which time a lot of damage could be done by the pest, particularly if it is virulent and spreading fast, and (b) the costs involved in rearing, treating and releasing large numbers of the pests in the field.

Certain naturally occuring substances like juvenile hormones or their synthetic analogues, are capable of inducing sterility in adult females. For example, dihydrochloride methyl farnesoate (DMF) at a concentration of less than 1μ*g*. is able to permanently sterilize an adult female of the plant bug *Pyrrhocorris apterus*. Males could carry over 1000μ*g*. of the substance on them without ill effects, but on coming into contact with females during mating, transfer enough of the chemical to sterilize the female for life. It is seen that this method of sterilizing pests are much more efficient than those discussed above. However, this method is not strictly a genetic method, although the mechanism by which sterility is achieved may have a genetic basis.

(ii) Reciprocal translocation technique

Reciprocal translocations are chromosomal aberrations where an exchange of parts, either a small piece or a whole arm, of heterologous or non-homologous chromosomes in the same cell, have taken place. When the translocated chromosomes are present with their normal untranslocated homologues in the cells of a diploid adult, which is called a 'translocation heterozygote', then at meiosis the segregation of these chromosomes is such that about 50% of the gametes formed become either deficient or duplicated for that translocated region, and are, therefore, sterile. The parent translocation heterozygote is, thus, semi-sterile.

The important fact about this semi-sterility is that it is heritable, for half of the viable progeny are themselves translocation heterozygotes and will reduce the progeny in the next generation again by 50%, while propagating the translocation in increased numbers to yet another generation. Thus, the frequency of the translocation increases from generation to generation producing a greater and greater reduction in the pest population. It has been reckoned that in about 12 generations a species could be completely controlled. If two or more reciprocal translocations are present in the same organism, which is possible only in those species with more than three chromosome pairs in them, then sterility would increase to more than 75% at each generation. One serious limitation to this technique is that after a few generations the translocated chromosomes could supplant the normal chromosomes in the population and fresh translocations will have to be obtained for further use in control.

This was one of the methods of genetic control of pests which was mooted on purely theoretical grounds long before such methods were actually used in the field., Serebrovsky, who published his paper in Russian in 1940, enunciated fully the theoretical aspects of this technique, and it was put into practise about two and a half decades later by Laven for mosquitoes and Curtis for the tsetse fly.

Translocations, like dominant lethals, are due to chromosome breakage and rearrangement, and are produced eithei by irradiations or by chemical treatment. Unlike dominant lethals, however, they are induced at a very much lower frequency and have to be detected first and then multiplied in the laboratory before subsequent release in the field. A few releases are sufficient, most often, as the translocation is self-propagating. Detecting reciprocal translocations is, however, very difficult. In well studied organisms like Drosophila this is comparatively easy because different marker genes on different chromosomes, which are readily available for this organism, show spurious linkage if a translocation has occurred between them. But in organisms where mutant genes are not readily available they are extremely difficult to detect. Testing for semi-sterility is the only method possible, but this is further complicated by the fact that semi-sterility may be due to other genetic causes as well, like for instance, replicating instabilities. In trying to use reciprocal translocations for the control of pests, therefore, it is imperative that the formal genetics of the pest be well studied first.

(iii) **Conditional lethal technique**

Conditional lethals are spontaneously occurring or induced lethal mutations, which express themselves as lethals only under certain conditions, say at temperatures prevailing under field conditions or in the female sex, but are quite harmless under other conditions, like lowered temperatures or in the male sex. Where sex is employed as a condition, the lethals are known as sex-limited lethals. Such conditional mutants are well known in the microorganisms and in experimental eukaryotes like Drosophila, but is only of theoretical interest at present in the control of pests. A diligent search fof such lethals in pests could very well be rewarding. Here again it is seen that a knowledge of the formal genetics of the pest organism is a sine qua non.

(iv) **Hybrid sterility technique**

It is a well known fact that when two different but closely related species interbreed, if this is possible, then the progeny which result from such a mating are infertile or sterile. This is due to the incompatibility of the different chromosome complements of the two parents which when they come together in the hybrid do not segregate normally at meiosis at the time gametes are formed. The gametes which are formed are invariably aneuploid rendering them sterile. The best known case is that of the cross between a horse and a donkey which produces a sterile mule.

In populations of pests showing complex speciation, like in mosquitoes, crosses between species within the complex can be used for producing sterile hybrids. WHO has undertaken a project to test such a technique under field conditions for the Anopheles complex.

(v) Cytoplasmic incompatibility technique

Sometimes when individuals of a population of a species mate with individuals of another population of the *same* species, then egg sterility results. Laven who discovered this phenomenon in mosquitoes considers it likely that certain cytoplasmic factors are transmitted through the eggs which kill the sperms at fertilization, hence, the name cytoplasmic incompatibility for this technique. Other workers have presented different explanations for this phenomenon. Goldschmidt was the first to describe a similar phenomenon for the gypsy-moth, *Lymantra dispar*, with regard to sex-determination.

This is a very practicable technique, where males of one type are reared and mass released into areas populated by the incompatible crossing types. Laven successfully demonstrated this technique in 1969 in a field experiment in Okpo, an isolated village in Rangoon, Burma, when several thousand male *Culex pipiens fatigans*, the vector of filariasis, were released daily over a period of three months. Within a very short time the population of *Culex fatigans* was completely suppressed.

(vi) Plant breeding technique

In the control of pests of plants genetic methods are employed to breed strains and varieties of the crop plants for resistance to their pests. Varieties of bean, maize, paddy, cabbage, cotton, onion, potato, and barley. etc., have been produced, either by selection methods or by induced mutation methods, which show resistance to some of their respective insect and fungal pests. Resistance to insect pests may be due to some character which prevents oviposition or feeding or else due to some biophysical character or even due to the presence in them of physiological inhibitors.

(vii) Other Techniques

There are a number of other phenomena of a genetic nature which could one day be used in the control of pests. They are: inversions, aneuploidy, polyploidy, meiotic drive, distorted sexratios, etc. Theoretically these phenomena appear feasible in being applied for pest control, although no start has been yet given to any one of them by way of even preliminary experimentation.

Conclusions

From the foregoing it becomes abundantly clear that there are a number of genetic methods of pest control of which only a few have been exploited. Active research along these lines should enable us before long to have with us the most formidable weapons system in our fight against pests.

The second fact which emerges from our discussion is that before positive control methods are devised against them we have to study in great detail much of their basic biology. In fact, with a greater knowledge about these pests we may well be able to attack them even at a molecular level.

Although it has not been discussed above it becomes clear that genetic methods of control have two great benefits over other biological methods of control and chemical methods of control. Namely, that most of the genetic methods are density-independent methods, like the chemical methods, offering complete eradication of a pest, as opposed to the other biological methods which are density-dependent, and are, therefore, not able to eliminate a pest but only to control them. For instance, a parasite or a predator population would also drop with that of the pest population, which would then tend to increase and cause temporary damage until the parasite population increases again. Therefore, genetic methods of control are powerful and similar to chemical methods of control in this respect, but they have the added advantage of not polluting the evironment, not allowing the pests to build resistance to them. The development of these methods of control would be anathema not only to the pests, unfortunately, but also to the pesticide industry !

B/. GENETICS AND PESTICIDES

Pesticides are chemicals, naturally occurring or synthesized, which have toxic lethal effects on pests and are used to control them. Although they are considered to be selective in action by the names given to them like insecticides, fungicides, weedicides, acaricides, rodenticides, molluscicides, ovicides, etc., the synthetic pesticides in particular are known to have sub-lethal physiological effects on organisms other than those they are intended for. The possible dangers and drawbacks of pesticide control measures of a genetic nature will be discussed below.

(i) **Possible dangers : mutagenicity ?**

While it is known that certain pesticides have sub-lethal physiological effects, it is not known of a certainty whether they have any harmful effects on the germ cells. With the vast quantities of pesticides dumped into the environment, and with the long lasting action of some of them, every single living creature on the earth must be concentrating in itself dosages which could induce mutations in its hereditary material, the DNA.

Not enough work has been done on pesticides to test for possible mutagenic effects. The few tests which have been conducted seem to give negative results and would, therefore, lull us into a sense of security. Would this turn out to be a false one ? More and more pesticides are being churned out with more and more power to kill the pests, and unless constant research is done to test them for all possible side effects, it would prove too late to avert a catastrophe-as happened with the thalidomide drug !

The possible mutagenic effects which a pesticide could have range from gross chromosonal aberrations to point mutations and crossing over. Any induced dominant mutation, either for a visible character like Huntingtons chorea in man or for a lethal, do not pose a serious threat as they are either detected as soon as they are formed or, like dominant lethal mutations, are not inherited. However, recessive mutations, either visible of lethal, will be carried in a population for generations before they surface into the phenotype and cause untold misery to many.

(ii) Genetic drawbacks of pesticide control: Resistant strains

Apart from the toxic hazards of pesticide use, namely, sub-lethal physiological and possible genetic effects, there is another serious drawback in their use. This is the development of strains of pests resistant to the various chemicals used in their control. With the widespread use of DDT after the war it soon became evident that it required larger and larger doses of DDT to control the house-fly. Very soon there were strains which completely resisted the action of DDT. On testing them it was found that these strains had simple mendelian genes for resistance to the insecticide. This was found to be so for various pests for many pesticides, so that in order to control them various combinations of pesticides at higher concentrations had to be used.

The way resistance to pesticides are built up is purely by a process of selection of pre-existing mutants. At the high rate of reproduction of insects and micro-organisms, within a few years they could evolve resistant stocks. For man to be one jump ahead of the pests he has to keep on synthesizing newer and newer pesticides, and use them in various combinations to effectively check the growth of pest populations. As one could well imagine, the costs of research into and the mass production of chemicals, is enormous.

Conclusions

The use of chemicals in pest control is fraught with danger to ourselves and the possible suffering to future generations. It is the indescriminate use of these pesticides however, which is perilous. If judiciously used, however, they are essential for our suvival. For this, a thoroughly integrated programme of pest control will have to be drawn up-not by vested interests but by those really concerned with the problem in its entirety,—So that chemical and biological methods could be used in conjunction with one another to get the optimum results with the least tampering of our precious, but surely overtaxed, environment.

References

BENES, V. & R. SRAM (1969), Industrial Medicine (Czechoslovakia) **38**, (12) 442.

CURTIS, C. F. (1968), Bull. ent. Res., **57**, 509.

KNIPLING, E. F. (1959), Science, **130**, 902

KNIPLING, E. F., H. LAVEN, G. B. CRAIG, R. PAL, J. B. KITZMILLER, C. N. SMITH AND A. W. A. BROWN, (1968), Bull, Wld Hlth Org. **38**, 421.

LAVEN, H., (1967), Nature, **21ā**, 382.

LAVEN, H. (1969), Nature, **221**, 958.

MORIARTY, F. (1969), Bio. Rev. **44**, (3), 312.

PATHAK, M. D. (1970), Concepts of pest management, Ed. Rabb R.L. & F.E. GUTHRIE, North Carolina State University, p. 138.

SEREBROVSKY, A. S. (1950), Zool. Zh., **19**, 618.

WHITTEN, M. J. (1970), Concepts of pest management, Ed. Rabb, R. L. & F. E. GUTHRIE, North Carolina State University, p. 119.