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# Pesticide Resistance in Insect-Pests Indian Scenario

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Large scale chemical control of insect pests using synthetic pesticides started in India 40 years ago with the introduction of DDT and HCH. Since then nearly 350 thousand tonnes of DDT, 575 thousand tonnes of HCH and 150 thousand tonnes of organophosphates have been used in the country to control insect vectors of parasitic diseases and pests of agriculture. The current annual consumption of pesticides in the country is nearly 80 thousand tonnes, of which 18 thousand tonnes is DDT, 36 thousand tonnes HCH and 18 thousand tonnes of organophosphates. This use of pesticides has led to appearance of pesticide resistance in 27 insect pests; 14 of public health importance, 7 of agricultural crops and 6 of stored grains and commodities. Chronologically, in India, the pesticide resistance appeared first in insect vectors of parasitic diseases in 1952, in agricultural pests in 1963 and in insect pests of stored grains and commodities in 1971. Methods to combat and avoid menance of pesticide resistance have been enumerated.

One of the consequence of the large scale use of pesticides to control insect pests is the development of resistance in the target species. At global level, insect pests have developed resistance to all major classes of pesticides and will develop resistance to future pesticides as well.[1,2] The resistance to synthetic pesticides had developed mainly because these have been used intensively in situations that otherwise favour rapid pest build up. The present review attempts to give briefly the present status of pesticide resistance in insect pests in India and some suggestions to combat it.

Among the third world countries, India was one of the first country to start a large scale use of synthetic pesticides for the control of insect pests of public health and agricultural importance. The modern era of vector control and plant protection in India started with the introduction of DDT in 1947,[3] followed by HCH in 1949[4], organophosphates in 1953 and carbamates a little later.[5] Despite the fact that these pesticides have brought immense benefits to the country, they also had environmental consequences[6,7]. It is interesting that DDT and HCH, which have been withdrawn from use in most of the advanced countries of the world, are still being used freely in India. In fact, India is the biggest consumer and manufacturer of DDT and HCH in the world[8]. It was, therefore, of interest to assess the extent of pesticide resistance in insect pests in India, after nearly four decades of the use of pesticides in agriculture and public health. The major use of DDT in India has been and is in public health, whereas that of HCH has been mainly in agriculture. Since their introduction nearly 3,50,000 tonnes of DDT[3], 5,75,000 tonnes of HCH[4], and nearly 1,50,000 tonnes of organophosphates have been used in the country till todate. When compared to other countries, the consumption of pesticides per unit area in India has been very small (Table 1); at present, compared to Japan's 12,000 g Europe's 3000 g and USA's 2500 g, India is using only nearly 450 g of pesticide per hectare per year.[9] The current annual consumption of pesticides in India is, DDT 18,000 tonnes, HCH 36,000 tonnes and organophosphates 18,000 tonnes. Even such a small usage of pesticides has led to the appearance of pesticide resistance in a number of insect pests of public health, veterinary, household, agricultural crops, stored grain, and commodities.

The pesticide resistance in India was first noticed in insect pests of public health importance (Table 2) and the concern about it led to an International Conference organised jointly by the World Health Organisation and the Government of India in 1958 at New Delhi.[10] Mosquitoes transmitting malaria and other vector diseases were the first to become resistant to pesticides. This was because of the large scale use of DDT in the National Malaria Control Programme / National Malaria Eradication Programme. The first report of DDT resistance in mosquitoes came in

1952 from U.P. and Bombay in *Culex fatigans* a transmitter of filaria [11]. Since then this mosquito has been reported to be resistant to both DDT and HCH in various parts of the country.[12] The resistance in urban malaria transmitter, *Anopheles stephensi*, to DDT was reported first from Erode, Tamil Nadu in 1956 [13]. A year later *An. culicifacies*, a major vector of malaria in rural area, was reported to be resistant to DDT in Gujarat in 1957 [14]. Both these malaria vectors are now widely resistant to DDT and HCH in various parts of the country [15-19]. In fact *An. culicifacies* which accounts for more than 70% of the rural malaria is resistant throughout the country to one or the other pesticide used in Malaria Control Programme (Figure 1 and 2).The pesticide resistance problem in malaria vectors is acute in Western India, specially Gujarat and Maharashtra, where *An. culicifacies* has developed resistance to DDT, HCH and malathion [20]. Another malaria vector, *An. annularis*, was reported to be resistant to DDT since 1962 from Meerut (U.P.), Balaghat (M.P.) and Dhanbad (Bihar) [12]. Similarly, *An. fluviatilis* has been reported to have developed resistance to DDT in Maharashtra and Mysore since 1964 [12,21]. Among three transmitters of viral diseases and dengue, *Aedes aegypti, Ae. vittatus and Ae. albopictus*, the first report of resistnace to DDT was reported in *Ae. aegypti* from Calcutta in 1963, *Ae. vittatus* from Baroda in 1964 and *Ae. albopictus* from Lucknow in 1965 [12,22]. All these three vectors are now known to be resistant to DDT and HCH in various parts of the country [12].

**Table 1 Consumption of pesticides in different countries (1980)**

| Country | g a.i. / ha |
|---|---|
| Japan | 10,790 |
| U.S.A | 1,490 |
| Europe | 1,870 |
| India | 450 |
| Africa | 127 |

See reference (9)

**Table 2 Pesticide resistance in the pests of public health Importance**

| Name | Year first reported |
|---|---|
| *Culex fatigans* | 1952 |
| *Cimex lectularis* | 1955 |
| *Anopheles stephensi* | 1956 |
| *Anopheles culicifacies* | 1957 |
| *Pediculus humanus corporis* | 1959 |
| *Xenopsylla cheopsis* | 1961 |
| *Anopheles annularis* | 1962 |
| *Aedes aegypti* | 1963 |
| *Boophilus microplus* | 1963 |
| *Aedes vittatus* | 1964 |
| *Anopheles fluviatilis* | 1964 |
| *Musca domestica nebulo* | 1964 |
| *Musca domestica vicina* | 1964 |
| *Aedes albopictus* | 1965 |

See references 10-35.

Among the household pests, the bed bug, *Cimex lectularius*, was reported to be resistant to DDT from Pune in 1953 [23]. Since then it has become resistant to both DDT and HCH in different parts of the country[24-27]. Human body louse, *Pediculus humanus corporis* has developed resistance against HCH in hilly tracts of the country since 1952 [12]. Rat flea, *Xenopsylla cheopsis* was reported to be resistant to DDT in Maharashtra and Mysore in 1961 [28-30]. Common housefly *Musca domestica* nebulo, was susceptible to DDT upto 1951 but developed resistance to it by 1957 at Bombay and Assam [31]. Now the houseflies are known to be resistant to DDT and HCH throughout the country [32-34].

Of the various insect pests of veterinary importance only *Boophilus microplus* infesting cattle has been shown to have developed a high degree of tolerance to lindane at the Indian Veterinary Research Institute, Mukteshwar in 1963 [35]. The degree of tolerance observed was 30-fold. No other pest of veterinary importance has been reported to be resistant to pesticides so far. It appears that no efforts have been directed to find out either the baseline of susceptibility / resistant status of various veterinary pests in India.

Pesticide resistance in an agricultural pest was first noticed in 1963, when Singhara beetle, *Galer-*

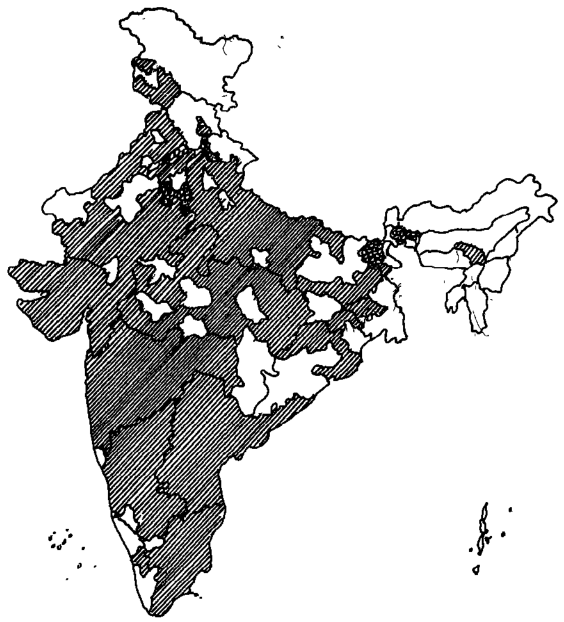

Figure 1 Distribution of DDT resistance in *Anopnetes culicifacies* in India (Sharma[20])

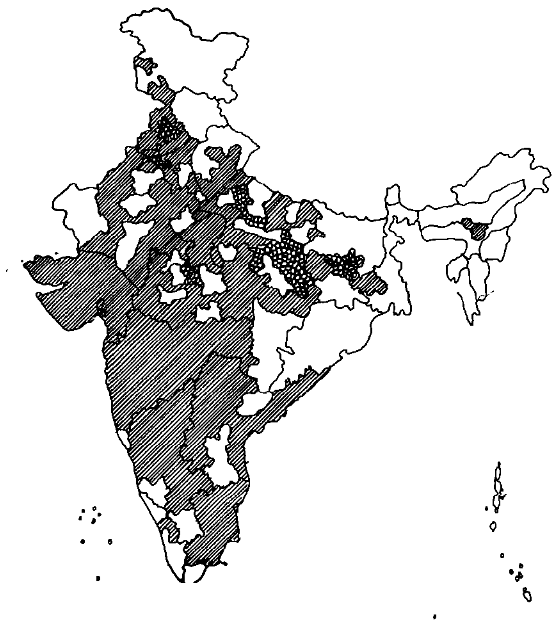

Figure 2 Distribution of HCH resistance in *Anophetes culicifácies* in India. (Sharma[20])

*ucella birmanica*, from Delhi was reported to be resistant to DDT and HCH [36,37]. Next insect pest of agricultural importance to have become resistnat to pesticides was the tobacco caterpillar, *Spodoptera litura*, from Rajasthan to HCH in 1965 [38]. Since then this pest is reported to have become resistant not only to HCH but also to malathion, endosulfan and carbaryl in Haryana and Andhra Pradesh [39,40]. It is likely that *S. litura* is resistant to other pesticides as well in other parts of the country. Diamond back moth, *Plutella xylostella*, has been reported to be resistant to DDT in Punjab in 1968,[41,42] to endrin in Hisar in 1972 [43]. and parathion and fenitrothion in Punjab in 1976.[44] Biochemical parameters indicated that jassid, *Empoasca kerri*[45], and aphids, *Lipaphis erysimi*[46] and *Aphis craccivora*[46], have most probably, developed resistance to organophosphates and other pesticides. Indeed, resistance to endosulfan and tolerance to malathion and dimethoate has developed in *Lipaphis erysimi* in some areas in Punjab [47].

**Table 3 Pesticide resistance in insect pests of agricultural crops.**

| Common Name | Scientific Name | Year |
|---|---|---|
| Singhara beetle | *Galerucella birmanica* | 1963 |
| Tobacco caterpillar | *Spodoptera litura* | 1965 |
| Diamond backmoth | *Plutella xylostella* | 1968 |
| Gram pod borer | *Heliothis armigera* | 1986 |
| Aphids and jassids | *Empoasca kerri* | 1986 |
| | *Lipaphis erysimi* | 1986 |
| | *Aphis craccivora* | 1986 |

See references 36-53.

Appearance of pesticide resistance in *Heliothis* to pyrethroids in India is most interesting. An earlier report had suggested that *Heliothis* obtained from various regions of the coutnry showed a differential response to pesticides [48]. Biochemical parameters also suggested that *Heliothis* populations in various parts of the country differ significantly and that resistance to pesticides may be round the corner [49]. Finally, failure to control *Heliothis* in Andhra Pradesh during cotton season 1987-88 was traced to the development of a high degree of resistance to synthetic pyrethroids in this pest.[50-51]. Further, it appears that the resistance to synthetic pyrethroids is restricted to the populations of *Heliothis armigera* occurring on cotton only and in an area nearly 75 kms wide and 200 kms long comprising of districts of Guntur, Prakasham and parts of Krishna. The populations of *Heliothis* occurring in other crops are, perhaps, still susceptible to synthetic pyrethroids. The pesticide resistance in *Heliothis* in India still appears to be restricted to pyrethroids and does not extend to other conventional insecticides, endosulfan, monocrotophos and chlorpyriphos used for the control of this pest [52]. A recent report, however, suggests that the *Heliothis armigera* popualtions occurring in the International Crops Research Institute for the Semi Arid Tropics at Patancheru, Hyderabad are not only resistant to pyrethroids, cypermethrin and fenvalerate but also to DDT. These populations were collected from chickpea and pigeonpea [53]. It is strange that resistance has not been reported so far from other cotton pests, *Pectinophora gossypiella, Earias insulana and Earias fabia*, although large amounts of pesticides have been used and are still being used against these pests. It may be mentioned that no serious exercise has been undertaken to generate the baseline susceptibility / resistance data on agricultural pests in general and cotton pests in particular. There is an urgent need to initiate work in this area because cotton occupies nearly 5 per cent of the total cropped area and uses nearly 55 per cent of the total pesticides consumed in the country.

Unlike insect vectors of medical importance, where the pesticide resistance was first reported in 1952 and pests of agricultural crops in 1963, pesticide resistance in stored grain pests appeared comparatively later. It was first reported in flour beetle, *Tribolium castaneum*, in 1971 against DDT and malathion from Delhi [54,55]. Since then *T.castaneum* has developed resistance to lindane and phosphine also in various parts of the country.[56,57] Initial reports of rice weevil, *Sitophilus oryzae*, another serious pest of stored grain, becoming resistant to malathion originated from Kanpur in 1973 [55]. Now the rice weevil is known to be resistant not only to malathion but also to lindane and phosphine in various regions of the country [57]. *Rhizopertha dominica*, lesser grain borer, is resistant to malathion, lindane and phosphine in and around Bombay, Karnal, Kota and Meerut since 1976 [57]. Similarly, the grain beetle *Ryzaephilus surinamensis* resistant to malathion and lindane has been encountered in Maharashtra since 1976 [57]. Resistance to phosphine in Khapra beetle, *Dermestes granarium*, has been reported from Punjab in 1979 [58]. Leather beetle, *Dermestes maculatus* originating from India are known to be resistant to lindane since 1978 [59]. Thus the pesticide resistance in stored grain pests although appeared late, has assumed serious proportions in the country now. It is fortunate that *Callosobruchus chinensis* a serious pest of pulses, has not developed resistance to pesticides so far and is still susceptible.

**Table 4 Pesticide resistance in insect pests of stored grains**

| Name | Year first reported |
|---|---|
| *Tribolium castaneum* | 1971 |
| *Sitophilus oryzae* | 1973 |
| *Rhyzopertha dominica* | 1976 |
| *Oryzaephilus surinamensis* | 1976 |
| *Trogoderma granarium* | 1979 |
| *Dermestes maculatus* | 1978 |

See references 54-59

The reason why insecticide resistance appeared first in insect pests of public health importance, then in agriculture and last in storage pests can now be given. High amounts of pesticides were used throughout the country under the National Malaria Control Programme / National Malaria Eradication Programme from 1948 to 1960 which precipitated the pesticide resistance in insect vectors of human diseases. The slow pace of appearance of resistance in agricultural pests was mainly because the agricultural revolution in true sense started only in 1966, when emphasis was given to High Yielding Variety, increased use of irrigation. fertilizer and pesticides. An appreciable increased use of pesticides in agriculture was seen only from 1970 onwards. It is, therefore, understandable that pesticide resistance in agricultural pests would appear late. It is only in recent years that pesticide resistance is becoming a problem in agricultural sector. The last appearance of pesticide resistance in storage pests can be ascribed to the fact that India was net grain importing nation till early 1970s and did not have significant quantities of grains in storage. The food self-sufficiency and increasing amounts of grains in storage and consequent use of pesticides to control them brought the resistance in the pests of storage.

Primarily, the resistance to pesticides in insect pests develop a result of the direct use of these chemicals to control them. In Indian context, however, a controversy has been created by suggesting that the currently used agricultural technology, high yielding variety(HYV) - higher doses of fertilize - increased irrigation - pesticides, has led to precipitation of resistance in insect vectors of public health importance [60-64]. Although these views have been refuted,[65-69] it is likely that under certain situation the agricultural use of pesticide may precipitate pesticide resistance in insect vectors of public health importance. Views have also been expressed to suggest that the public health use of pesticides has led to considerable degradation of environment and appearance of pesticide residues in bovine milk [70]. Whatever be, the pesticides are being used, and will continue to be used, to contain losses in agricultural production and protecting society from afflictions perpetuated by insect vectors. Although, high amounts of DDT and HCH are seen in our environment.[3,4] the situation is not too bad and can certainly be retrieved if research priorities are fixed, administrative decision taken and strategies formulated. To contain pesticide resistance as well as to protect the environment from the adverse effects of pesticides a number of strategies have been used. They can properly be classifieds as follows:

(1) Judicious use of pesticides: Pesticides should be used only if their use is essential and their use should be based on monitoring the pest population in field.
(2) Use of synergist which will enhance the toxicity of a given pesticide by inhibiting the detoxification mechanism.
(3) Alternation of chemicals with unrelated mode of action.

One or the other combination of the above three methods can effectively be utilised in combating the pesticide resistance if once reported. India is in a somewhat fortunate situation. Unlike insect vectors of public health and pests of stored food-grains, the pesticide resistance is not a serious problem in agricultural sector as yet. However, if appropriate action is not taken, it will become a problem in near future. It is, therefore, better if the plant protection techniques which are not conducive to build up of pesticide resistance are used, and the wrong / over use of pesticides is not resorted to. In this regard new and ecologically safe innovative methods of pest control will have to be devised and used. The methods which have been utilised can be divided into three broad categories.

(a) *Physiological, Biochemical and Genetical:* The approach requires a knowledge of the rate of penetration of pesticide through cuticle, the rate of detoxification of pesticides in target species, the sensitivity of target and the rate of appearance of pesticide resistance genome. An evaluation of these parameters by a Systems Analysis Approach gives sufficient information to predict the rate of appearance of resistance in a population. Since pesticide resistance is either pre-adaptive or through gene amplification, it is essential to avoid the use of persistent pesticides and residual treatment of insect population to reduce the selection pressure.

(b) *Biological:* In this approach it is essential to determine the levels of insect populations which remain unaffected after the use of pesticides. It is better to use pesticide only at one stage of their life cycle and not subject the insect populations at every stage of development and growth to pesticide selection. It is better to use ovicides wherever possible. The use of ovicide is encouraged because the eggs have either no or very poorly developed detoxification mechanism. These percautions reduce the rate of development of pesticide resistance in the population. It is also essential to frequently monitor for pesticide resistance in field populations. It is better to change the pesticide before the resistance actually appears.

(c) *The chemical nature of pesticides:* The pesticides chosen should be such that when used they should leave the least amount of residues. The residues should be photo-degradable and also preferably bio-degradable. The chemical nature of the pesticides should be such that pests are unable to develop resistance easily. Although this is an Utopian concept yet human ingenuity should be able to create such chemical structures. The pesticides chosen should be such that they have unrelated mode of action and different routes of metabolism. It is possible that the field application of pesticides, unrelated in their mode of action to adjacent fields could theoretically minimize resistance to each pesticide. In this regard it is advisable first to use pesticides that impart resistance by a single one-factor mechanism and show limited cross resistance, for example, malathion. Secondly, it is better to avoid chemicals which complicate the resistance. Diazinon, for example, which imparts resistance by enhanced detoxification through phosphatases and mixed function oxidases, and also the insensitivity to the target, should be used with caution. Thirdly, it is better not to use pesticides which enhance the resistance to quite unrelated group of pesticides, for example, insects exposed to some organophosphorus insecticides are known to develop resistance faster against pyrethroids [71]. A knowledge of previous history of exposure of the insect populations to pesticides, is, therefore, important and can provide useful clues. In short, pesticide management should become an integral part of the Integrated Pest Management (IPM) system.

Although, pesticide resistance has been reported from India in a number of insect pest-species, the mechanism by which this resistance is imparted is not known. In majority of these cases the resistance has been reported because of the failure of pesticide in controlling pests under field conditions. The failure of pesticide in field could be due to various reasons other than resistance. The exact mechanism of resistance in Indian pest species has not been worked out except in case of *Heliothis*. It has been shown that the pyrethroid resistance in *Heliothis* in Andhra Pradesh is due to increased detoxification in resistant populations [72]. In most of these cases it has been presumed that it is due to enhanced detoxification of the pesticide. Genetics of resistance has been worked out only in few cases [73]. Till todate, no authentic example of target insensitivity has been reported from this region, except, perhaps, in *Anopheles stephensi* resistant to malathion where the frequency of acetylcholinesterase insensitive to sumioxon is higher in resistant insects than in susceptible insects.[74] This would suggest that the strategy to control *A. stephensi* should be such that it would not precipitate resistance due to insensitivity of the target. Target insensitivity is an extreme case of resistance which is not easily amenable to reversion and would have cross resistance to other organophosphates as well. Studies may be undertaken in this direction using different pest species so that it monitors not only for appearance of resistance but also predicts if and when such a phenomenon is likely to occur. This would greatly help in the management of the pesticide resistance once reported. In short, IPM or any other innovative strategy formulated for the control of pests and diseases, both in agriculture and public health should have a sound biological base. These strategies will differ from region to region and pest to pest. Whatever is true for public health may not be true for agriculture and vice versa. The technology for this will have to be generated in India and cannot be imported. The successful IPM requires fundamental knowledge of not only a pest but also of the cropping system. Information on this aspect is scanty and must be generated on a priority basis. There are no short cuts for devising strategies to minimize losses due to insect pests and also preserve the quality of environment.

In conclusion, Indian sub-continent at the present juncture provides excellent opportunities, on one hand in the area of multidisciplinary basic research and, on the other for research of applied value useful for management of insect pests affecting agricultural production and public health. A better understnading of pesticide resistance and its effective management will go a long way in providing "food for all" and "health for all" by 2000 AD, provided the family planning pogramme is also effectively persued and the *Homo sapiens* numbers are kept within reasonable limits.

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