

## **Pesticide Resistance in Insect-Pests Indian Scenario**

**K.N. MEHROTRA**

Division of Entomology, Indian Agricultural Research Institute, New Delhi 110 012

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 menace 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.<sup>1,2</sup> 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,<sup>3</sup> followed by HCH in 1949<sup>4</sup>, organophosphates in 1953 and carbamates a little later.<sup>5</sup> Despite the fact that these pesticides have brought immense benefits to the country, they also had environmental consequences<sup>6,7</sup>. It is interesting that DDT and HCH, which have been withdrawn from use in most of the advanced countries of the world, are still being used freely in India.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<sup>8</sup>. 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<sup>3</sup>, 5,75,000 tonnes of HCH<sup>4</sup>, 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.<sup>9</sup> 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.<sup>10</sup> 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<sup>11</sup>. Since then this mosquito has been reported to be resistant to both DDT and HCH in various parts of the country.<sup>12</sup> The resistance in urban malaria transmitter, *Anopheles stephensi*, to DDT was reported first from Erode, Tamil Nadu in 1956<sup>13</sup>. A year later *An. culicifacies*, a major vector of malaria in rural area, was reported to be resistant to DDT in Gujarat in 1957<sup>14</sup>. Both these malaria vectors are now widely resistant to DDT and HCH in various parts of the country<sup>15-19</sup>. 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<sup>20</sup>. Another malaria vector, *An. annularis*, was reported to be resistant to DDT since 1962 from Meerut (U.P.), Balaghat (M.P.) and Dhanbad (Bihar)<sup>12</sup>. Similarly, *An. fluviatilis* has been reported to have developed resistance to DDT in Maharashtra and Mysore since 1964<sup>12,21</sup>. Among three transmitters of viral diseases and dengue, *Aedes aegypti*, *Ae. vittatus* and *Ae. albopictus*, the first report of resistance to DDT was reported in *Ae. aegypti* from Calcutta in 1963, *Ae. vittatus* from Baroda in 1964 and *Ae. albopictus* from Lucknow in 1965<sup>12,22</sup>. All these three vectors are now known to be resistant to DDT and HCH in various parts of the country<sup>12</sup>.

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
<i>Culex fatigans</i>	1952
<i>Cimex lectularis</i>	1955
<i>Anopheles stephensi</i>	1956
<i>Anopheles culicifacies</i>	1957
<i>Pediculus humanus corporis</i>	1959
<i>Xenopsylla cheopsis</i>	1961
<i>Anopheles annularis</i>	1962
<i>Aedes aegypti</i>	1963
<i>Boophilus microplus</i>	1963
<i>Aedes vittatus</i>	1964
<i>Anopheles fluviatilis</i>	1964
<i>Musca domestica nebulosa</i>	1964
<i>Musca domestica vicina</i>	1964
<i>Aedes albopictus</i>	1965

See references 10-35.

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

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<sup>35</sup>. 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-*

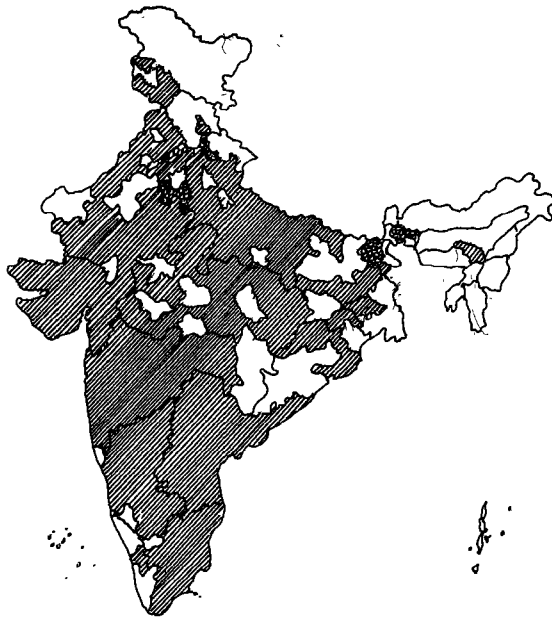


Figure 1 Distribution of DDT resistance in *Anopheles culicifacies* in India (Sharma<sup>20</sup>)

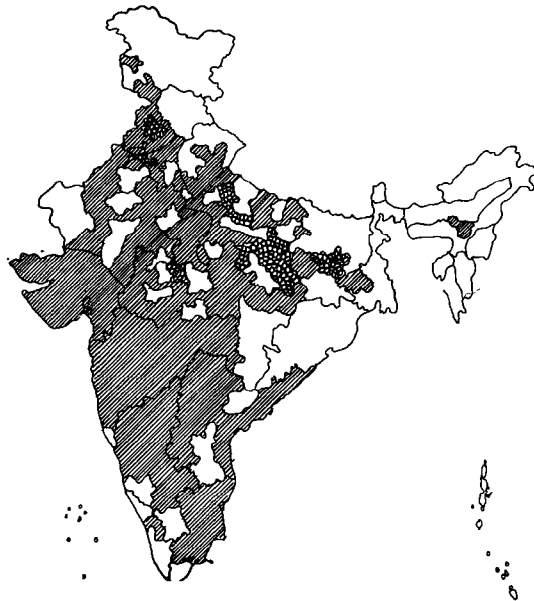


Figure 2 Distribution of HCH resistance in *Anopheles culicifacies* in India. (Sharma<sup>20</sup>)

*ucella birmanica*, from Delhi was reported to be resistant to DDT and HCH<sup>36,37</sup>. Next insect pest of agricultural importance to have become resistant to pesticides was the tobacco caterpillar, *Spodoptera litura*, from Rajasthan to HCH in 1965<sup>38</sup>. 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<sup>39,40</sup>. 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,<sup>41,42</sup> to endrin in Hisar in 1972<sup>43</sup>, and parathion and fenitrothion in Punjab in 1976.<sup>44</sup> Biochemical parameters indicated that jassid, *Empoasca kerri*<sup>45</sup>, and aphids, *Lipaphis erysimi*<sup>46</sup> and *Aphis craccivora*<sup>46</sup>, 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<sup>47</sup>.

Table 3 Pesticide resistance in insect pests of agricultural crops.

Common Name	Scientific Name	Year
Singhara beetle	<i>Galerucella birmanica</i>	1963
Tobacco caterpillar	<i>Spodoptera litura</i>	1965
Diamond backmoth	<i>Plutella xylostella</i>	1968
Gram pod borer	<i>Heliothis armigera</i>	1986
Aphids and jassids	<i>Empoasca kerri</i>	1986
	<i>Lipaphis erysimi</i>	1986
	<i>Aphis craccivora</i>	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 country showed a differential response to pesticides<sup>48</sup>. 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<sup>49</sup>. 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.<sup>50-51</sup> 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 chlorpyrifos used for the control of this pest<sup>52</sup>. A recent report, however, suggests that the *Heliothis armigera* populations 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<sup>53</sup>. 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<sup>54,55</sup>. Since then *T. castaneum* has developed resistance to lindane and phosphine also in various parts of the country.<sup>56,57</sup> Initial reports of rice weevil, *Sitophilus oryzae*, another serious pest of stored grain, becoming resistant to malathion originated from Kanpur in 1973<sup>55</sup>. 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<sup>57</sup>. *Rhizopertha dominica*, lesser grain borer, is

resistant to malathion, lindane and phosphine in and around Bombay, Karnal, Kota and Meerut since 1976<sup>57</sup>. Similarly, the grain beetle *Ryzaephilus surinamensis* resistant to malathion and lindane has been encountered in Maharashtra since 1976<sup>57</sup>. Resistance to phosphine in Khapra beetle, *Dermestes granarium*, has been reported from Punjab in 1979<sup>58</sup>. Leather beetle, *Dermestes maculatus* originating from India are known to be resistant to lindane since 1978<sup>59</sup>. 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
<i>Tribolium castaneum</i>	1971
<i>Strophilus oryzae</i>	1973
<i>Rhyzopertha dominica</i>	1976
<i>Oryzaephilus surinamensis</i>	1976
<i>Trogoderma granarium</i>	1979
<i>Dermestes maculatus</i>	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 fertilizer - increased irrigation - pesticides, has led to precipitation of resistance in insect vectors of public health importance<sup>60-64</sup>. Although these views have been refuted,<sup>65-69</sup> 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<sup>70</sup>. 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,<sup>3,4</sup> 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 classified 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 precautions 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<sup>71</sup>. 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<sup>72</sup>. 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<sup>73</sup>. Till today, 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.<sup>74</sup> 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 understanding 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 programme is also effectively pursued and the *Homo sapiens* numbers are kept within reasonable limits.

## REFERENCES

1. Brattsten, L.B., Hollyoke, C.W., Jr. Lecerper, I.R. and Raffa,

- K.F. 1986, Insecticide resistance: challenge to pest management and basic research. *Science* 231: 1255-1260.
2. Brown, T.M. Brogdon, W.G. 1987, Improved detection of insecticide resistance through conventional and molecular techniques. *Annual Review Entomology* 32: 145-162.
  3. Mehrotra, K.N. 1985, Use of DDT and its environmental effects in India. *Proceeding Indian National Science Academy* B51: 169-184.
  4. Mehrotra, K.N. 1985, Use of HCH (BHC) and its environmental effects in India. *Proceedings Indian National Science Academy* B51: 581-595.
  5. Banerjee, S.N. 1979, Agricultural production through increased pesticide usage. *Pesticide Information* 4: (4) 17-19.
  6. Mehrotra, K.N. 1983, Benefits and hazards of pesticides to society. *Pesticide Information* 9: (3) 38-42.
  7. Mehrotra, K.N. 1989, *Pesticide Residues in Food, Consumer Education and Research Centre, Ahmedabad*, 42-58.
  8. Mehrotra, K.N. 1987, Pesticide vs Human Welfare. *Economic & Political Weekly* 22: 1045.
  9. Rangaswamy, G. 1983, Biodegradation of pesticides. *Pesticide Information* 9: (3) 55-63.
  10. *Indian Journal Malariology* 1958, 12: (4) 261.
  11. Pal, R., Sharma, M.I.D. Krishnamurthy, B.S. 1952, Studies on development of resistant strains of houseflies and mosquitoes. *Indian Journal of Malariology* 6: 303-316.
  12. Raghavan, N.G.S. Watal, B.I., Bhatnagar, V.N., Choudhury, D.S., Joshi, G.C. and Krishnan, K.S. 1967, Present status of susceptibility of arthropoda of public health importance to insecticides in India. *Bulletin Indian Society of Communicable Diseases* 13: 209-245.
  13. Rajagopalan, N., Vedamanikkam, J.C. and Ramoo, H.C. 1956, A preliminary note on the development of resistance to DDT by larvae of *Anopheles stephensi* in Erode South India. *Bulletin National Society India Malariology and Mosquito Diseases* 4: 126-128.
  14. Rahman, J., Roy, M.L. and Singh, K. 1959, Development of increased tolerance to DDT in *A. culicifacies* Giles in the Panch Mahal district of Bombay State (India). *Indian Journal Malariology* 13: 125-130.
  15. Das, P.K. and Rajgopalan, P.K. 1980, Insecticide susceptibility status of colonized strains of *Anopheles culicifacies* Giles. *Indian Journal Medical Research* 72: 218-221.
  16. Roy, R.G., Sitaraman, D.C., Raghuvir Rao, L., Patil, K.S.B., Shivaswami, K.C. and Vijayan, C.P. 1979, Susceptibility status of *A. culicifacies* in Karnataka State (1973-1978). *Indian Journal Medical Research* 70: 209-215.
  17. Rajagopal, R. 1977, Malathion resistance in *Anopheles culicifacies* in Gujarat. *Indian Journal Medical Research* 66: 27-28.
  18. Roy, R.G. Sitaraman, N.L., Vijayan, C.P., Ramakrishnan, T.N., Nair, T.R. and Bhojan, T. 1978, Susceptibility status of adult of *Anopheles stephensi* to propoxure in Tamil Nadu. *Indian Journal Medical Research* 68:

- 744-746.
19. Roy, R.G., Sitaraman, N.L., Ghosh, R.B., Samson, F., Balakrishnan, R., Chandrahasan, A., Augustine, Y., Pandey, A. and Ponnappan, C.V. 1978, Susceptibility of *Anopheles stephensi* from some urban areas in Tamil Nadu and Karnataka to some commonly used insecticides. *Indian Journal Medical Research* 67: 947-952.
  20. Sharma, G.K. 1984, Review of malaria and its control in India. In *Indo-U.K. Workshop on Malaria* p 13-40 (Ed. V.P. Sharma) Malaria Research Centre, Delhi.
  21. Roy, R.G., Vijayan, C.P. and Pattanayak, S.C. 1980, Susceptibility status of *Anopheles fluviatilis* in some areas of Karnataka, Kerala and Goa. *Indian Journal Medical Research*. 72: 654-658.
  22. Wal, Y.C., Perti, S.L. and Damodar, P. 1982, Susceptibility of some insect vectors of diseases to synthetic contact insecticides. *Indian Journal Malariology* 16: 129-136.
  23. Rao, T.R. and Halgeri, A.V. 1956, A note on resistance of bed bugs to DDT in some part of Bombay State. *Indian Journal Malariology* 10: 149-154.
  24. Kalra R.L. and Krishnamurthy, B.S. 1965, Studies on the insecticide susceptibility and control of bed bugs. *Bulletin Indian Society Malariology and Communicable Diseases* 2: 223-229.
  25. Menon, P.B., Karani, N.D.P., Narasimhan, D. 1958, Control of bed bugs and the problem of resistance. *Indian Journal Public Health* 3: 265-271.
  26. Sinha, V.P. 1967, Bedbug resistance in Bihar, India (Research Notes). *Bulletin Indian Society Malariology and Communicable Diseases* 4: 63-64.
  27. Shetty, K.M., Subbiah, V.K. and Panickar, K.K. 1975, A comparative evaluation fenitrothion, Dursban and malathion for the control of bedbugs. *Indian Journal Public Health* 19: 79-83.
  28. Mohan, B.N. 1960, A note on high DDT tolerance in rat fleas collected from Gundlupet town of Mysore State. *Indian Journal Malariology* 14: 19-21.
  29. Sharma, M.I.D. and Joshi, G.C. 1961, A note on the susceptibility of rat fleas of Delhi to DDT, dieldrin and gamma BHC. *Indian Journal Malariology* 15: 123-127.
  30. Sharma, M.I.D. and Joshi, G.C. 1961, A preliminary note on DDT-resistance in rat fleas, *Xenopsylla cheopsis* and *Openopsylla astia* in a sprayed area of Delhi. *Bulletin World Health Organisation* 25: 270.
  31. Brown, A.W.A. 1958, *Insecticide resistance in Arthropods*. pp 240, World Health Organisation, Geneva.
  32. Karani, N.D.P. and Menon, P.B. 1959, DDT resistance in house flies in Cantonments. *Proceeding 46th Indian Science Congress* 4: 25.
  33. Sharma, M.I.D., Krishnamurthy, B.S. and Singh, N.N. 1957, Note on the susceptibility to DDT of houseflies of Delhi and Rajasthan. *Indian Journal Malariology* 12: 203-207.
  34. Rahaman, S.J. and Khan, N.H. 1968, Inheritance of DDT resistance in *Musca domestica nebulosa* Fabr. *Indian Journal of Entomology* 30: 69-76.
  35. Chaudhuri, R.P. and Naithani, R.C. 1964, Resistance to BHC in cattle tick *Boophilus microplus* in India. *Bulletin Entomological Research* 55: 405-410.
  36. Pradhan, S., Jotwani, M.G. and Sarup, P. 1963, Failure of BHC and DDT to control Singhara beetle, *Galerucella birmanica* Jacoby. *Indian Journal Entomology* 34: 176-179.
  37. Pradhan, S., Jotwani, M.G., Sarup, P. and Rai, B.K. 1964, Relative efficacy of different insecticides to the grubs of Singhara beetle, *Galerucella birmanica* Jacoby (Chrysomelidae : Coleoptera) *Indian Journal of Entomology* 26: 91-96.
  38. Srivastava, B.K. and Joshi, H C. 1965, Occurrence of resistance to BHC in *Prodenia litura* Fabr. (Lepidoptera: Noctuidae). *Indian Journal Entomology* 27: 102-104.
  39. Verma, A.N. Verma, N.D. and Singh, R. 1971, Chemical control of *Prodenia litura* Fab. (Lepidoptera : Noctuidae) on cauliflower. *Indian Journal Horticulture* 28: 240-243.
  40. Ramakrishnan, N., Saxena, V.S. and Dhingra, S. 1984, Insecticide resistance in the population of *Spodoptera litura* (F) in Andhra Pradesh. *Pesticides* 18. (9): 23-27.
  41. Verma, A.N. and Sandhu, G.S. 1968, Chemical control of diamondback moth, *Plutella maculipennis* (Curt). *Journal Research*. Punjab Agricultural University, Ludhiana. 5: 420-423.
  42. Deshmukh, S.N. and Saramma, P.U. 1973, Comparative susceptibility of *Plutella maculipennis* (Curtis) collected from Ludhiana and Jullundur districts to some insecticides. *Pesticides* 7(1): 21.
  43. Verma, A.N., Verma, N.D. and Khurana, A.D. 1972, Chemical control of *Plutella xylostella* infesting cauliflower in Haryana. *Indian Journal of Entomology* 34: 206-212.
  44. Chawla, R.P. and Kalra, R.L. 1976, Studies on insecticide resistance in *Plutella xylostella* (Diamond back moth) *Indian Journal Plant Protection* 4: 170-180.
  45. Mehrotra, K.N. and Phokela, A. Unpublished data.
  46. Phokela, A. and Mehrotra, K.N. 1987, Inhibition of aphid carboxylesterases (EC 3.1.1.1) by carbamates and organophosphate inhibitors. *Proceeding Indian National Science Academy* B53: 35-38.
  47. Udeaan, A.S. and Narang, D.D. 1986, A survey of mustard aphid, *Lipaphis erysimi* (Kalt.) populations for resistance to insecticides in Punjab. *Proceedings 2nd National Symposium Recent Trends in Aphidological Studies* p. 265.
  48. Reed, W. and Pawar, C.S. 1982, *Heliothis* : a global problem. *Proceedings International Workshop Heliothis Management* ICRISAT, Patancheru India. p. 9.
  49. Mehrotra, K.N. and Phokela, A. 1986, Variations in carboxylic ester hydrolase (EC 3.1.1.1) activity in *Heliothis armigera* Hubner larvae. *Current Science* 55: 508-509.
  50. Dhingra, S. Phokela, A. and Mehrotra, K.N. 1988, Cypermethrin resistance in the populations of *Heliothis armigera* Hubner. *National Academy Sciences Letters* 11: 123-125.
  51. McCaffery, A.R., Maruf, G.M. Walker, A.J. and Styles, K. 1988, Resistance to pyrethroids in *Heliothis* spp. Bloas-



- say methods and incidence in populations from India and Asia. *Brighton Crop Protection Conference 4C-14*: 433-438.
52. Phokela, A., Dhingra, S. and Mehrotra, K.N. 1989, Pyrethroid resistance in *Heliothis armigera* Hubner I. Response to cypermethrin. *Proceedings National Academy of Sciences, India B55* (In press).
  53. McCaffery, A.R., King A.B.S., Walker, A.J. and El-Nayir, H. 1989, Resistance to synthetic pyrethroids in the bollworm, *Heliothis armigera* from Andhra Pradesh, India. *Pesticide Science 27*: 65-76.
  54. Bhatia, S.K. 1971, Focus on the spread of insecticide resistance in stored product pests. *Entomologists' Newsletter 1*: 41-42.
  55. Rajak, R.L., Ghagte, M. and Krishnamurthy, K. 1973, Bioassay technique for resistance to malathion of stored product insects. *International Pest Conference 15*: 11-13.
  56. Kalra, R.L., Udeaan, A.S. and Bindra, O.S. 1975, Status of Insecticide resistance in stored grain insects in the Punjab. *Indian Journal plant Protection 3*: 186-196.
  57. Champ, B.R. and Dyte, C.E. 1976, Report of FAO global survey of pesticide susceptibility of stored grain pests. *FAO Plant Production and Protection Series No. 5*, FAO Rome pp 1-297.
  58. Borah, B. and Chahal, B.S. 1979, Development of resistance to *Trogoderma granarium* Everts to phosphine in the Punjab. *FAO Plant Protection Bulletin 29*: 28-42.
  59. Binns, T.J. and Tyler, P.S. 1978., Lindane resistance in *Dermestes maculatus* DEG (Coleoptera: Dermestidae). *Journal Stored Products Research 14*: 19-23.
  60. Rajagopalan, P.K., Chandrasah, R.K. and Panniker, K.N. 1979, Mosquito collections in Pattukottai and adjacent localities in Thanjavur district (Tamil Nadu) with particular reference to *Anopheles culicifacies* Giles, *Indian Journal Medical Research 69*: 589-597.
  61. Wattal, B.L., Joshi, G.C. and Das, M. 1981, Role of agricultural insecticides in precipitating vector resistance. *Journal Communicable Diseases 13*: 71-74.
  62. Chapin, G. and Wasserstrom, R. 1981, Agricultural production and malaria resurgence in Central America and India. *Nature 293*: 181-185.
  63. Chapin, G. and Wasserstrom, R. 1983, Pesticide use and malaria resurgence in Central America and India. *Social Science & Medicine 17*: 273-290.
  64. *Indian Journal of Public Health 1972*, 16: 105.
  65. Bruce-Chawatt, L.J. 1981, Malaria debated. *Nature 294*: 302-303.
  66. Sharma, V.P. and Mehrotra, K.N. 1982, Return of malaria. *Nature 298*: 210.
  67. Sharma, V.P. and Mehrotra, K.N. 1982, Malaria resurgence. *Nature 300*: 212.
  68. Curtis, C.F. 1981, Malaria debated. *Nature 294*: 303.
  69. Sharma, V.P. and Mehrotra, K.N. 1986, Malaria resurgence in India: a critical study. *Social Science & Medicine 22*: 835-845.
  70. Singh P.P., Battu, R.S. Joia, B.S., Chawla, R.P. and Kalra, R.L. 1986, Contributions of DDT and HCH used in malaria control programme towards the contamination of bovine milk. *Proceedings Symposium on Pesticide Residues and Environmental Pollution 86-92*.
  71. Metcalf, R.L. 1980, Changing role of insecticides in crop protection. *Annual Review Entomology 25*: 219-256.
  72. Phokela, A. and Mehrotra, K.N. 1989, Pyrethroid resistance in *Heliothis armigera* Hubner II. Permeability and metabolism of cypermethrin. *Proceedings Indian National Science Academy B55*: 235-238.
  73. Bhatia, S.K. 1986, Pesticide resistance in agricultural pests in India. *Proceedings Indian National Science Academy B52*: 148-164.
  74. Annual Report. Indian Agricultural Research Institute, New Delhi. p 94-95.