# Current Status of Insecticide Resistance in the Horn Fly, *Haematobia irritans* (L.)*

**Ronnie L. Byford,** *Ph.D.*
**Buff L. Crosby,** *B.S.*
*Department of Entomology*
*Plant Pathology and Weed Science*
*New Mexico State University*
*Las Cruces, New Mexico 88003*



Resistance to insecticides is a critical problem which threatens our ability to control agricultural pests.[1,2] For example, there are at least eight cases of resistance to synthetic pyrethroids, a class of insecticides that has only been available in the United States since 1977.[3] One of the most recent cases involves a major ectoparasite of cattle, the horn fly, *Haematobia irritans* (L.).

### History of Horn Fly Resistance

Over the past century, horn fly control has depended primarily on the use of insecticides. During the early 1900's toxicants such as fish oil, tar, kerosene, or tobacco emulsions were recommended in the United States.[4,5] Control measures changed very little until after World War II when DDT and other chlorinated hydrocarbon insecticides were introduced. DDT, as a whole body dip or spray, effectively controlled horn flies through the mid 1950's.[6–8] Although horn fly resistance was suspected in the late 1950's,[9–11] it was not confirmed until 1961.[11,13]

During the early 1960's new insecticides like toxaphene, methoxychlor (chlorinated hydrocarbons); fenchlorphos, crufonate, malathion (organophosphates); and carbaryl (carbamate) were developed and recommended for horn fly control. Unfortunately, resistance to many of these materials soon developed (Table 1). For instance, horn fly resistance to fenchlorphos occurred after intensive use of this compound in backrubbers over a 3-year period.[14] During this same period, horn flies developed widespread resistance to a 0.5% toxaphene spray.[10,14]

Table 1. History of insecticide resistance in Haematobia irritans.

| Insecticide Class | Insecticide | Year | State | Reference |
|---|---|---|---|---|
| Chlorinated hydrocarbons | toxaphene | 1960 | TX | 10 |
| | | 1961 | TX | 13 |
| | DDT | 1961 | TX | 13 |
| | | 1984 | LA | 26 |
| | methoxychlor | 1965 | LA | 53 |
| Organophosphates | fenchlorphos | 1962 | LA | 12 |
| | stirofos | 1978 | GA | 17 |
| Pyrethroids | permethrin | 1983 | LA | 23 |
| | | 1983 | FL | 24 |
| | fenvalerate | 1982 | GA | 22 |
| | | 1983 | LA | 23 |
| | | 1983 | FL | 24 |
| | flucythrinate | 1983 | GA | 22 |
| | | 1984 | LA | 26 |
| | cypermethrin | 1984 | LA | 26 |
| | deltamethrin | 1984 | LA | 26 |
| | cyhalothrin | 1988 | LA | 51 |

One of the most significant advancements for horn fly control has been the development of insecticide-impregnated cattle ear tags. Initially, these devices provided cost-effective, season-long control (<50 horn flies/animal for up to 14 weeks) of horn flies.[15,16] However, within 1 to 2 years resistance to stirofos, the insecticide used in the first ear tags, was demonstrated in horn flies in Georgia. This was apparently due to pre-exposure of stirofos as a feed additive over a 1 1/2 year period.[17]

Since the development of stirofos ear tags, increased technology has led to the development of longer-lasting, more effective pyrethroid ear tags.[18–21] The first commercially available pyrethroid ear tags appeared in the early 1980's and contained either fenvalerate or permethrin. Since then, a wide variety of pyrethroid tags have made their way into the market (i.e., flucythrinate, cypermethrin, cyhalothrin).

During the past eight years pyrethroid ear tags have become the predominate method for controlling horn flies on cattle throughout the United States. This novel approach, once thought to be panacea, is threatened by the development of pyrethroid resistance horn fly populations over vast geographical areas of the country (Fig. 1). Resistance to permethrin, fenvalerate, and flucythrinate were first reported in the southeastern United States (Georgia, Louisiana, and Florida).[22–24] Recent surveys indicate that pyrethroid resistance in the horn fly extends from the southeastern and south central regions to the midwest, California and Hawaii,[25,26] and the use of permethrin and fenvalerate appears to have conferred cross-resistance to all other pyrethroids and DDT.[26]

### Mechanisms of Resistance

The mechanisms of pyrethroid resistance in *H. irritans*

* *Journal Article #1481, Agricultural Experiment Station, New Mexico State University, Las Crucas, NM 88003*

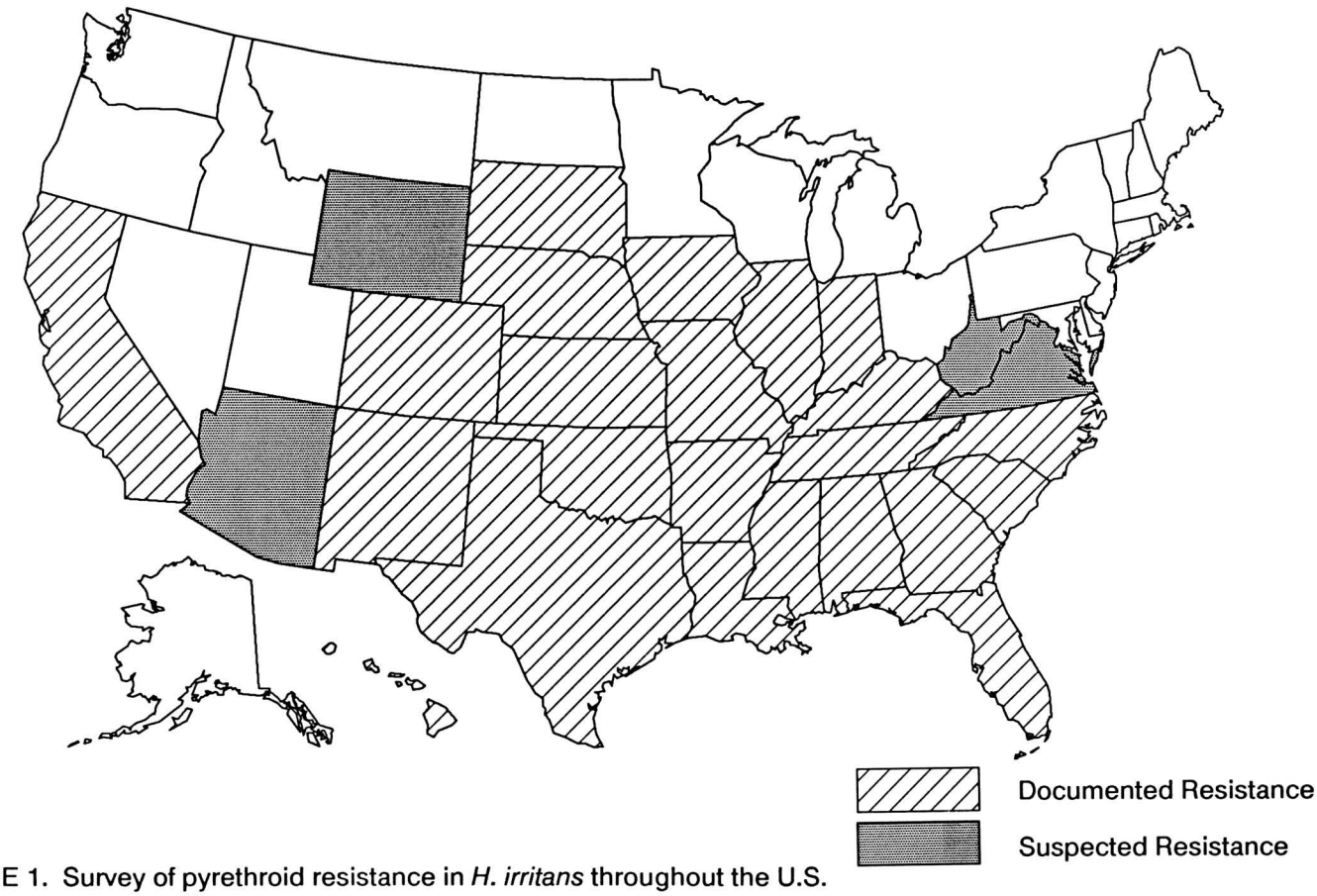



FIGURE 1. Survey of pyrethroid resistance in *H. irritans* throughout the U.S.

have only recently been investigated.[23,24,27,28] These studies suggest that horn fly resistance is a multifactorial phenomenon involving a combination of biochemical, physiological, and behavioral adaptations (Table 2).

TABLE 2. Factors involved in pyrethroid resistance.

| |
|---|
| Physiological/Biochemical |
| ▪ Decreased penetration through insect cuticle. |
| ▪ Increased excretion |
| ▪ Increased metabolism |
| ▪ *kdr* gene active site insensitivity |
| Behavorial |
| ▪ Insecticide irritancy/repellancy |
| ▪ Areas left untreated |

*Physiological and Biochemical Factors*

Any adaptation by the insect that interferes with the mode of action of the insecticide can produce a form of resistance. There are several mechanisms that may be involved in insect resistance to pyrethroids. Some insects have a cuticle that restricts the penetration of the insecticide. Others may rapidly excrete or metabolize an insecticide before it has a chance to act. Where metabolism is involved, insecticides enter the insect's body and are quickly broken down to relatively non-toxic products through oxidative or hydrolytic reactions. Another mechanism, active site insensitivity (*kdr*), is independent of metabolism or detoxification. The nervous system essentially shows reduced sensitivity to the toxicant. Apparently active site insensitivity is the dominant resistance mechanism to pyrethroids and DDT[29–31] but not to organophosphorus, carbamate, formamidine, or cyclodiene insecticides.[32,33]

The resistance pattern observed for the horn fly (i.e., cross-resistance to all pyrethroids and DDT, with little cross-resistance to organophosphates and carbamates; Figs. 2 and 3) is consistent with the presence of active site insensitivity.[26] Studies using selected synergists in combination with pyrethroids suggested that metabolism also affects pyrethroid resistance in horn flies.[26] However, differences in absorption, metabolism, and excretion between susceptible and resistant horn flies did not indicate these to be major mechanisms in pyrethroid resistance.

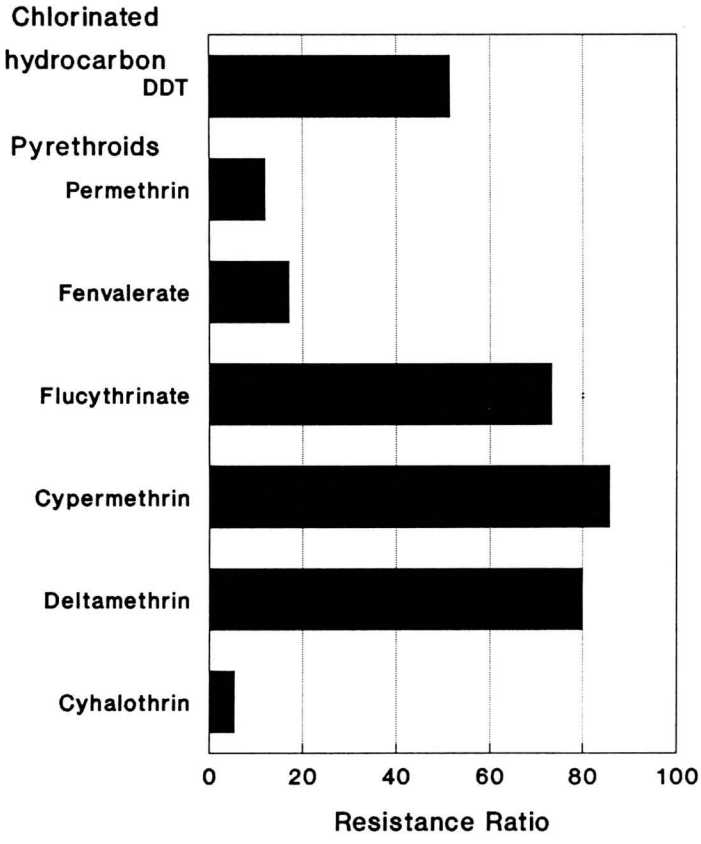



FIGURE 2. Resistance ratios for selected chlorinated hydrocarbon and pyrethroid insecticides. Resistance ratio = $LD_{50}$ resistant population / $LD_{50}$ susceptible population. Data adapted from Byford et al. (1985) and Byford and Sparks (1988).

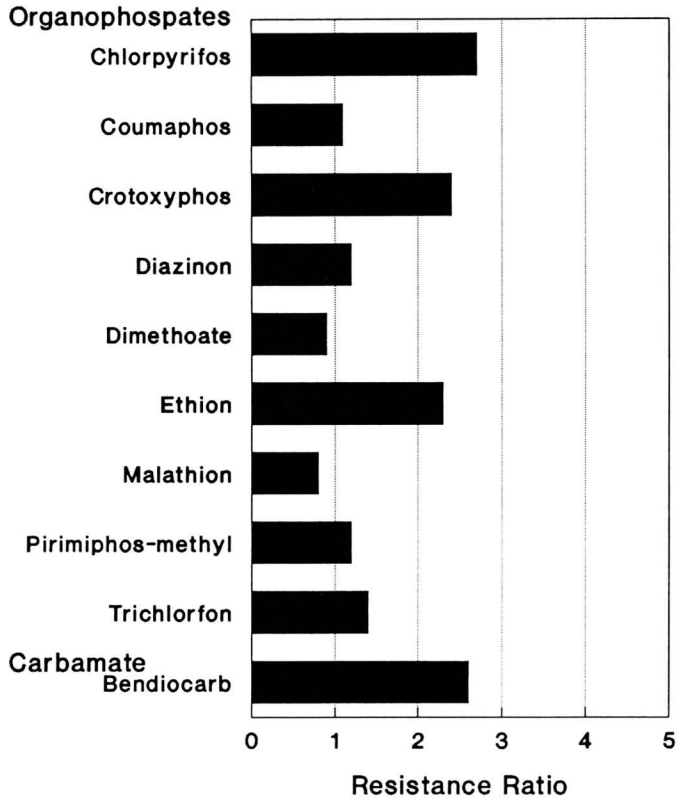



FIGURE 3. Resistance ratios for selected organophosphate and carbamate insecticides. Resistance ratio = $LD_{50}$ resistant population / $LD_{50}$ susceptible population. Data adapted from Byford et al. (1985, 1988).

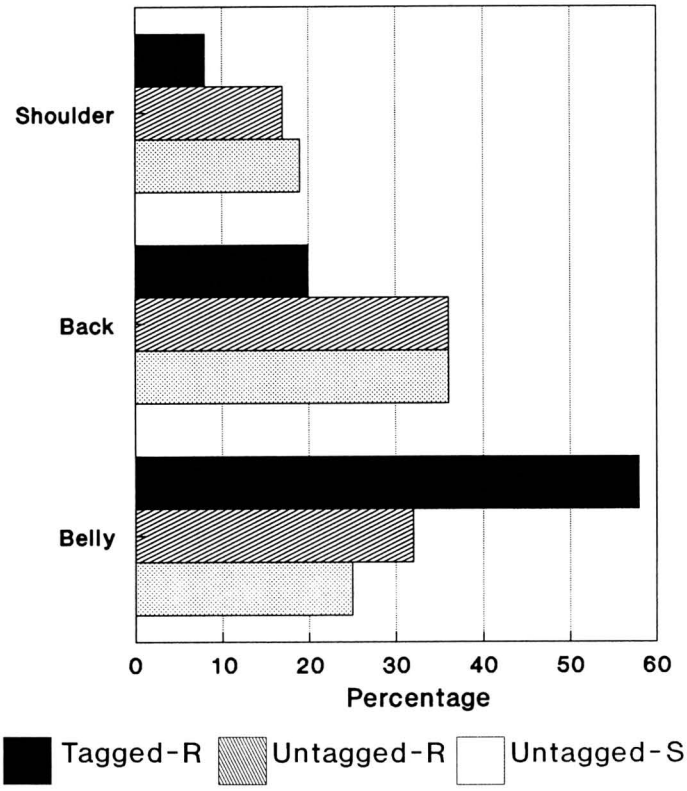
*Behavioral Factors*

In 1984, researchers in Louisiana observed that the irritating properties of permethrin and fenvalerate were altering horn fly distributions on cattle treated with pyrethroid ear tags. Laboratory and field studies demonstrated that resistant horn flies exhibited a hypersensitivity to the pyrethroids. These horn flies preferentially occupied the untreated ventral or posterior regions of pyrethroid tagged cattle and avoided the treated dorsal or anterior regions (Fig. 4). This behavior prevents horn flies from acquiring a lethal dose of the insecticide and produces a "behavioral resistance" mechanism. Should the chronic redistribution of horn flies continue to evolve, ear tags will become increasingly less effective, regardless of the insecticide used.

## Problem

Whenever an entire pest population is intensively pressured with an insecticide for several generations, resistance is expected to develop quickly. For example, resistance to stirofos appeared after 1 to 2 years of use,[17] and resistance to permethrin and fenvalerate after 2 to 3 years.[22,23] The rate at which resistance develops is contingent upon a variety of factors.[34–39] In the case of *H. irritans*, the factors that make ear tags so effective and acceptable for controlling horn flies are the same factors that have contributed to the rapid development of pyrethroid resistance (Table 3). For instance, ear tags are applied to cattle at the beginning of the horn fly season and remain on for 6 to 12 months, releasing the insecticide slowly and providing every generation of the horn fly with continuous exposure to a single insecticide.

Several aspects of horn fly biology also influence the development of resistance. The high host specificity, short generation time and the fact that horn flies remain on the host virtually all of their adult life, ensures continuous selection pressure. Since all cattle within the herd are tagged, all horn flies experience this pressure. The interaction of ear tag characteristics with horn fly biology enhances the rapid development of resistance and complicates resistance management.




Data adapted from Byford et.al. (1987).

FIGURE 4. Distribution (percentage) of resistant (R) and susceptible (S) *H. irritans* on pyrethroid tagged and untagged cattle.

### Management of Resistance

A number of approaches are available for managing pyrethroid horn flies. The most effective approach consists of good pest management practices, involving the integration of biological, cultural, mechanical, and chemical control strategies. However, implementation of many of the non-chemical practices is either too expensive or impossible due to gaps in knowledge of horn fly biology at this time. Chemical approaches include the use of alternative insecticides singly, or in mixtures or rotations with other insecticides, and the use of alternative delivery systems[40–44] (Table 4). Another common practice is to increase the dosage of insecticide.[38] Although this may overwhelm resistant horn flies and provide effective short term control, such techniques exert a greater selection pressure on the population and ultimately increase the level of resistance.

Historically, the approach most often used is to switch to alternative insecticides which have different modes of action. For example, organophosphorus insecticides block the transmission of nerve impulses rather than binding to active sites on the nerve cell, like pyrethroids. Several organophosphorus insecticides have been screened in the laboratory for efficacy against horn flies. Crotoxyphos, diazinon, dimethoate, malathion, pirimiphos-methyl, and trichlorfon were nearly as toxic as the pyrethroid permethrin to both susceptible and resistant flies.[44] In addition, diazinon is more toxic to pyrethroid resistant horn flies than susceptible horn flies.[45] Field studies have shown that diazinon and pirimiphos-methyl ear tags provide acceptable control (90 to 100%) of pyrethroid resistant horn flies for up to 19 weeks.[44,45] Although horn fly resistance to diazinon and pirimiphos-methyl has not been demonstrated, it is expected to occur in the near future if

TABLE 3. Contribution of the treatment strategy and the insect pest to insecticide resistance.

| |
|---|
| Ear Tag |
| ▪ Prolonged exposure to a single insectide |
| ▪ High insecticide selection pressure |
| ▪ Every insect generation is selected |
| ▪ Selection occurs prior to mating |
| ▪ No treatment threshold |
| ▪ Area wide coverage |
| Horn Fly |
| ▪ Highly host specific |
| ▪ Short generation time |
| ▪ High reproductive potential |
| ▪ Highly mobile pest |

TABLE 4. Chemical approaches to resistance management.

| |
|---|
| Management by Saturation |
| ▪ Use of higher odsages |
| ▪ Use of synergists |
| Management by Multiple Attack |
| ▪ Use of insecticide mixtures |
| ▪ Alternations of insecticides |
| Managment by Moderation |
| ▪ Less frequent applications |
| ▪ Use of non-persistent compounds |
| ▪ Localized applications |
| ▪ Leaving generations/populations untreated |
| ▪ Preservation of susceptible individuals |

these ear tags are used in the same manner as pyrethroid tags.

Considering the time (8 to 10 years) and expense ($20 to 25 million) required to develop new insecticides,[2,46,47] simply replacing one class with another is no longer practical. Therefore, it is imperative that measures be taken to prevent or at least slow the development of resistance to current and future insecticides. One approach is to use insecticide mixtures such as an insecticide and synergist, or two (or more) insecticides. In theory, individuals not killed by one insecticide in a mixture will be killed by the other. For mixtures to work, it is important that the pest not be resistant to any of the components in the mixture and that the components have similar decay rates to avoid selection by a single toxicant. Also, modes of action should be different so that resistance to one component does not confer resistance to the entire mixture.[38]

The use of selected synergists may also serve to delay resistance. Synergists inhibit specific metabolic mechanisms and thereby eliminate the selective advantage of those individuals possessing such mechanisms. Since increased metabolism is only a minor factor in pyrethroid resistance, synergists such as piperonyl butoxide (PBO), an oxidase inhibitor, and DEF, an esterase inhibitor, provide very little synergism when combined with permethrin or fenvalerate.[26,48] However, in studies using the $\alpha$S,IR3R stereoisomer of cyhalothrin (possibly the most biologically active pyrethroid known[49,50]), in combination with PBO and DEF nearly doubled efficacy against resistant horn flies as compared to susceptible horn flies, resulting in a resistance ratio to levels below that of the pyrethroids alone.[51]

Although this demonstrates that certain pyrethroid/synergist mixtures can effectively control pyrethroid resistant horn flies, at least in the short term, precautions should be considered with this strategy. Pyrethroids like permethrin, fenvalerate, cypermethrin, flucythrinate, and cyhalothrin are not ideal for use in the mixture because of the high degree of resistance to these insecticides in the fly population. Merely increasing the toxicity of the pyrethroid is insufficient and more importantly, the use of a mixture after resistance has developed to one of the insecticides negates the primary advantage of a mixture—theoretical long-term control of the pest.

Another approach is to rotate or alternate insecticides. This concept assumes that resistant individuals will revert back to susceptibility in the absence of an insecticide. Though little has been done to define the requirements for rotations, certain criteria must be met for this strategy to succeed. First, the insecticides should possess different modes of action.[38,52] Secondly, there must be a low frequency of resistant genes for each insecticide in the rotation to avoid multiple resistance in any single individual in the pest population. Thirdly, rotations must be long enough to allow horn flies to revert back to susceptibility. However, if rotations are too infrequent, coadaptation through genetic recombination may eliminate the disadvantages associated with the resistant genotype and resistance will increase.[41,48,53]

Alternative methods of insecticide application; e.g. sprays, backrubbers, dust bags or boluses, may delay the development of resistance. These delivery systems apply a discrete, less persistent dose of the insecticide than ear tags. Spray treatments every 4 to 6 weeks should be sufficient for adequate horn fly control. In addition, if effective residues from backrubbers and dust bags only last 5 to 6 days, this would provide an opportunity for susceptible horn flies to immigrate into a herd of cattle and dilute the buildup of resistance.

The use of larvicides in the form of sustained-release boluses presents an additional opportunity for survival of susceptible horn flies. By only treating part of a cattle herd with these boluses, a portion of the manure pats are left untreated. Thus, susceptible horn flies will be allowed to survive. Although boluses effectively inhibit the development of horn fly larvae, they have no effect on adults.

## Conclusions

Insecticide resistance is a complex subject with a diversity of opinions relative to its prevention and management. Generally, insecticide resistance occurs through mechanisms having a broad spectrum of effects, notably active site insensitivity or enhanced metabolism.

The evolution of resistant pest populations is a predictable response to insecticide use. The probability of resistance developing is determined by the impact that a particular treatment strategy has on a pest population. The nature of this impact depends on both the biological properties of the pest population and the characteristics of the treatment strategy.

To effectively control *H. irritans* without the fear of rapid development of insecticide resistance, additional information on the psychology, biochemistry and behavior of insecticide resistance is needed. Without this information, many of the previously mentioned approaches will likely result in only a slight delay in the widespread development of insecticide resistance in *H. irritans*.

## References

1. Georghiou, G.P. and R.B. Mellon. 1983. Pesticide resistance in time and space, pp. 1–46. IN: G.P. Georghiou and T. Saito (eds.), Natural Products for Innovative Pest Management. Pergamon Press, New York. 2. Dover, M. and B. Croft. 1984. Getting tough: Public policy and the management of pesticide resistance. World Resources Institute, Wash., DC. 80 pp. 3.Roush, R.T. 1985. Status of pyrethroid resistance in U.S. Proc. 1985 Beltwide Cotton Prod. Res. Conf. pp. 126–127. 4. Riley, C.V. 1889. The horn fly, Insect Life 2:93. 5. Osborn, H. 1896. Insects affecting domestic animals: an account of the species of importance in North America, with mention of related forms occurring in other animals. U.S. Dept. Agric. Entomol. Bull., 5. 6. Laake, E.W. 1946. DDT for the control

of horn fly in Kansas. J. Econ. Entomol. 39:65–68. 7. Matthysse, J.G. 1946. DDT to control horn fly and gulf coast ticks on range cattle in Florida. J. Econ. Entomol. 39:62–65. 8. Knipling, E.F. 1954. On the insecticide resistance problem. Agric. Chem. 9:46–47. 9. Burns, E.C., S.E. McCraine and D.W. Moody. 1959. Ronnel and Co-Ral for horn fly control on cable type backrubbers. J. Econ. Entomol. 52:648–650. 10. McDuffie, W.C. 1960. Current status of insecticide resistance in livestock pests. Misc. Pub. Entomol. Soc. Amer. 2:49–54. 11. Lewis, L.F. and G.W. Eddy. 1961 Laboratory evaluation of insecticides against the adult horn fly. J. Econ. Entomol. 54:392–393. 12. Burns, E.C. and B.H. Wilson. 1963. Field resistance of horn flies to the organic phosphate insecticide ronnel. J. Econ. Entomol. 56:718. 13. Harris, R.L. 1964. Laboratory tests to determine susceptibility of adult horn fly and stable fly to insecticides. J. Econ. Entomol. 57:492–494. 14. Harris, R.L., E.D. Frazar and O.H. Graham. 1966. Resistance to ronnel in a strain of horn flies. J. Econ. Entomol. 59:387–390. 15. Harvey, T.L. and J.R. Brethour. 1970. Horn fly control with dichlorvos-impregnated strips. J. Econ. Entomol. 63:1688–1689. 16. Ahrens, E.H. 1977. Horn fly control with an insecticide impregnated ear tag. Southwest. Entomol. 2:8–10. 17. Sheppard, C. 1983. Stirofos resistance in a population of horn flies. J. Ga. Entomol. Soc. 18:370–376. 18. Ahrens, E.H. and J. Cocke. 1979. Season long horn fly control with an insecticide impregnated ear tag. J. Econ.Entomol. 72:215. 19. Schmidt, C.D. and S.D. Kunz. 1980. Fenvalerate and stirofos ear tags for control of horn flies on range cattle. Southwest. Entomol. 5:202–206. 20. Knapp, F.W. and F. Herald. 1981. Face fly and horn fly reduction on cattle with fenvalerate ear tags. J. Econ. Entomol. 74:295–296. 21. Williams, R.E. and E.J. Westby. 1980. Evaluation of pyrethroids impregnated in cattle ear tags for the control of face flies and horn flies. J. Econ. Entomol. 73:791–792. 22. Sheppard, C. 1984. Fenvalerate and flucythrinate resistance in a horn fly population. J. Agric. Entomol. 1:305–310. 23. Quisenberry, S.S., J.A. Lockwood, R.L. Byford, H.K. Wilson and T.C. Sparks. 1984. Pyrethroid resistance in the horn fly, *Haematobia irritans* (L.) (Diptera:Muscidae). J. Econ. Entomol. 77:1095–1098. 24. Schmidt, C.D., S.E. Kunz, H.D. Peterson and J.L. Robertson. 1985. Resistance of horn flies (Diptera:Muscidae) to permethrin and fenvalerate. J. Econ. Entomol. 78:402–406. 25. Kunz, S.E. and C.D. Schmidt. 1985. The pyrethroid resistance problem in the horn fly. J. Agric. Entomol. 2(4):358–363. 26. Byford, R.L., S.S Quisenberry, T.C. Sparks and J.A. Lockwood. 1985. Spectrum of insecticide resistance in pyrethroid resistant populations of *Haematobia irritans* (L.). J. Econ. Entomol. 78:768–773. 27. Lockwood, J.A., R.N. Story, R.L. Byford, T.C. Sparks and S.S. Quisenberry. 1985. Behavioral resistance to the pyrethroids in the horn fly *Haematobia irritans* (L.) (Diptera:Muscidae). Environ. Entomol. 14:873–880. 28. Bull, D.L., R.L. Harris and N.W. Pryor. 1988. The contribution of metabolism to pyrethroid and DDT resistance in the horn fly (Diptera:Muscidae). J. Econ. Entomol. 81:449–458. 29. Farnham, A.W. 1971. Changes in cross-resistance patterns of houseflies selected with natural pyrethrins or resmethrin (5-benzyl-3- furyl-methyl (+) cis-trans-chrysanthemate). Pestic. Sci. 2:138–143. 30. Farnham, A.W. 1973. Genetics of resistance of pyrethroid selected houseflies, *Musca domestica* L. Pestic. Sci. 4:513–520. 31. Farnham, A.W. 1977. Genetics of resistance of houseflies, (*Musca domestica*) to pyrethroids 1. Knock-down resistance. Pestic. Sci. 8:631–636. 32. Miller, T.A.. and M.E. Adams. 1982. Mode of action of pyrethroids, pp. 3–27, In. J.R. Coats (ed.), Insecticide Mode of Action. Academic Press, New York. 33. Miller, T.A., V.L. Salgado and S.N. Irving. 1983. The *kdr* factor in pyrethroid resistance, pp. 353–366. IN: G.P. Georghiou and T. Saito (eds.), Pest Resistance to Pesticides. Plenum Press, New York. 34. Georghiou, G.P. and C.E. Taylor. 1976. Pesticide resistance as an evolutionary phenomenon. Proc. XV Int. Cong. Entomol., Wash, D.C., August 19–27, 1976, Entomol. Soc. Amer. pp. 759–785. 35. Georghiou, G.P. and C.E. Taylor. 1977a. Genetic and biological influences in the evolution of insecticide resistance. J. Econ. Entomol. 70:319–323. 36. Georghiou, G.P. and C.E. Taylor. 1977b. Operational influences in the evolution of insecticide resistance. J. Econ. Entomol. 70:653–658. 37. Wood, R.J. and J.A. Bishop. 1981. Insecticide resistance: Populations and Evolution, pp. 97–127. IN: J.A. Bishop and L.M. Cook (eds.), Genetic Consequences of Man Made Change. Academic Press, New York. 38. Georghiou, G.P. 1983. Management of resistance in Arthropods, pp. 769–792. IN: G.P. Georghiou and T. Saito (eds.), Pest Resistance to Pesticides. Plenum Press, New York. 39. Forgash, A.J.. 1984. History, evolution, and consequences of insecticide resistance. Pestic. Biochem. Physiol. 22:178–186. 40. Sheppard and Hinkle. 1985. Pyrethroid resistance in horn flies: the problem, causes and possible solutions. J. Agric. Entomol. 2:317–324. 41. Sparks, T.C., S.S. Quisenberry, J.A. Lockwood, R.L. Byford and R.T. Roush. 1985. Insecticide resistance in the horn fly, *Haematobia irritans*. J. Agric. Entomol. 2(3):217–233. 42. Byford, R.L., J.A. Lockwood, S.M. Smith and D.E. Franke. 1987. Redistribution of behaviorally resistant horn flies (Diptera: Muscidae) on cattle treated with pyrethroid-impregnated ear tags. Environ. Entomol. 16:967–970. 43. Byford, R.L., J.A. Lockwood and T.C Sparks. 1987. A novel resistance management strategy for horn flies (Diptera:Muscidae). J. Econ. Entomol. 80:291–296. 44. Byford, R.L., T.C. Sparks, B. Green, J. Knox and W. Wyatt. 1988. Organophosphorus insecticides for the control of pyrethroid-resistant horn flies (Diptera:Muscidae). J. Econ. Entomol. 81:1562–1566. 45. Sheppard, D.C. and A.A. Marchiondo. 1989. Toxicity of diazinon to pyrethroid resistant and susceptible horn flies, *Haematobia irritans* (L.): Laboratory studies and field trials. J. Agric. Entomol. In press. 46. Gubler, K. 1983. Innovation in pesticide (insecticide) chemistry, pp. 33–44. IN: D.L. Whitehead and W.S. Bowers (eds.), Natural Products for Innovative Pest Management. Pergamon Press, New York. 47. Menn, J.J. 1983. Present insecticides and approaches to discovery of environmentally acceptable chemicals for pest management, pp. 5–25. IN: D.L. Whitehead and W.S. Bowers (eds.), Natural Products for Innovative Pest Management. Pergamon Press, New York. 48. Byford, R.L., J.A. Lockwood, S.M. Smith, T.C. Sparks and D.G. Luther. 1987. Insecticide mixtures as an approach to the management of pyrethroid-resistant horn flies (Diptera:Muscidae). J. Econ. Entomol. 80:111–116. 49. Bentley, P.D., R. Cheetman, R.K. Huff, R. Pascoe and J.D. Sayle. 1980. Fluorinated analogues of chrysanthemic acid. Pestic. Sci. 11:156–164. 50. Ruigt, G.S.F. 1985. Pyrethroids, pp. 183–262. In. G.A. Kerkut and L.I. Gilbert (eds.), Comprehensive insect physiology biochemistry and pharmacology. Pergamon Press, New York. 51. Sparks T.C. and R.L. Byford. 1988. Pyrethroid-synergist mixtures: toxicity, resistance, and field efficacy toward pyrethroid-resistant horn flies (Diptera:Muscidae). J. Econ. Entomol. 81:1567–1574. 52. Georghiou, G.P. 1980. Insecticide resistance and prospects for its management. Res. Rev. 76:131–145. 53. Georghiou, G.P. 1981. The occurrence of resistance to pesticides in arthropods: an index of cases reported through 1980. FAO Plant Production and Protection Series, FAO, Rome. 172 pp.