DAN52C Executive Summary

An insecticide resistance management (IRM) strategy was introduced into the summer rainfall cropping areas of eastern Australia in the 1983/84 season. The aims of this IRM strategy were to manage pyrethroid and endosulfan resistance problems in *Helicoverpa armigera* (Hübner), formerly *Heliothis armigera* (Hübner), and to avoid any possible future problems with organophosphate or carbamate resistance. An alternation strategy was adopted which was based on the rotation of unrelated chemical groups on a per generation basis, along with a strong recommendation for the use of ovicidal mixtures. These chemical countermeasures were then incorporated into an acceptable integrated pest management (IPM) programme. The voluntary restrictions were applied to all crops susceptible to *H. armigera*. They were even applied to other co-incident pest species on these hosts, such as sorghum midge *Contarinia sorghicola* (Coquillet) (Diptera: Cecidomyiidae), as it was shown that pyrethroids applied to flowering sorghum for midge control caused selective mortality of co-incident *H. armigera* larvae and resulted in differential selection for resistance. The demonstration of the independence of the endosulfan and pyrethroid resistance mechanisms vindicated the sequential use of these two groups in Stages I and II of the IRM strategy, respectively.

The impact of the IRM strategy on pyrethroid and endosulfan resistance was followed using a monitoring technique based on discriminating dose testing of larvae reared from field collected eggs. This proved to be a very sensitive technique which facilitated fine tuning of the strategy's guidelines as and when necessary, e.g. the reduction of the pyrethroid window from 42 to 35 days from the 1989/90 season onwards. Pyrethroids selected for resistance in both moths and larvae and this was manifested within the Stage II window and in the early Stage III period, respectively. The two main factors influencing the frequency of pyrethroid resistance were dilution by susceptibles immigrating from the refugia and pyrethroid selection pressure. However, as the refugia became increasingly contaminated, their effectiveness as a dilution source declined, resulting in gradually increasing pyrethroid resistance levels in all areas over time. This highlights the importance of maintaining an effectively large susceptible gene pool for sustained dilution of resistance as was shown in the case of self regulated resistance management in the polyphagous, highly mobile sibling species *Helicoverpa punctigera* (Wallengren). Inadequate cultivation of post-harvest fields harbouring overwintering pupae resulted in the carry over of large numbers of resistant pupae. The strategy was shown to be a successful delaying tactic for pyrethroid resistance. The possible reasons for the much more successful management of endosulfan resistance are discussed.

The Via tolerance curve analysis of F_1 data indicated an abrupt change in the relative importance of field pyrethroid resistance mechanisms following the introduction of the IRM strategy. The strategy favoured the selection of the more amenable oxidative resistance mechanism over the intractable nerve insensitivity resistance mechanism which was also clearly demonstrated by the dual insecticide ± synergist discriminating dose technique. Two possibly complementary explanations are put forward for this; differential genetic dominance, and/or selection in more than one life stage. The Beeman-Nanis analysis was unsuccessful in identifying the relative importance of the field resistance genes due to lack of full genetic dominance.

Moths expressed pyrethroid resistance to both direct (eye test) and indirect (tarsal plate test) exposure without hypo-irritability. Selection of adults in the field resulted in dispersal of resis-

tant moths from sprayed to nearby unsprayed cotton. The phenotypic expression of pyrethroid resistance in moths declined with age. This resulted in poor correlation of adult resistance (determined from pheromone trapped males) and resistance in field collected eggs. Oxidative metabolic detoxification was shown to be the major pyrethroid resistance mechanism in moths as well as larvae.

Both pyrethroid and endosulfan resistant *H. armigera* larvae were shown to have marginally longer development times. However, these were not manifested as significant biological deficits in laboratory and field competition studies on pyrethroid resistant larvae and prepupae (endosulfan not studied). The absence of back selection against pyrethroid resistant *H. armigera* in the unsprayed refugia, due to the lack of any selective disadvantage in the immature stages (adults not studied), helps explain the gradually deteriorating pyrethroid resistance situation.There was no evidence of selection of fitness modifiers to overcome the slower development of either pyrethroid or endosulfan resistant larvae.

The demonstration that the strategy has favoured selection of the more amenable oxidative resistance mechanism, led to the study of possible chemical countermeasures, such as synergists and resistance breaking pyrethroids. The methylenedioxyphenyl and acetylenic compounds were the most effective synergists with moderate activity from some organophosphate compounds. All the other compounds tested were either ineffective or only marginally effective, including most organophosphates tested, pyrethroid analogues, N-alkyls, esterase and glutathione transferase inhibitors, various nitrogen heterocycles, juvenile hormone and analogues, formamidines, organochlorines, anti-oxidants, and kojic acid. The most promising synergists indicated for further evaluation were synthetic analogues of piperonyl butoxide (Pbo), phosmet, propargite and possibly also fenthion, phosalone, azinphos-ethyl, pyrazophos and kinoprene. Studies with various solvents indicated that the mode of action of Pbo and the other synergists in this study, is principally true biochemical inhibition and not quasi-synergism (improved penetration). Studies on Pbo indicated that a set rate of Pbo should be used, irrespective of the activity of the accompanying pyrethroid, residual activity of Pbo is poor but that this could be partially overcome by increasing the rate, straight Pbo applied onto a weathered pyrethroid deposit could restore control but only temporarily and would probably be of little practical field use and that, no difference in residual activity could be found between the four Pbo formulations tested. In order to preserve the long-term effectiveness of Pbo as a pyrethroid synergist within the Australian IRM strategy, an optimal use strategy (based on synergist rotation within the present insecticide rotation scheme) is discussed.

The structural requirements for designing a resistance breaking pyrethroid to overcome oxidative metabolic pyrethroid resistance in *H. armigera* were studied. Changes from the conventional phenoxybenzyl alcohol moiety could overcome most, if not all, resistance. Simple benzyl alcohols were the most effective followed by cyclopentenolones and a methylated biphenyl alcohol. Incorporation of synergophore groupings (methylenedioxyphenyl and acetylenic) were fully effective in breaking resistance. Changes from the conventional central ester bond to an ether and reversion to an unsubstituted alpha carbon analogue, both lowered resistance. Some evidence was found to indicate that Pbo could be acting both as a classical monooxygenase inhibitor and a preferential penetration synergist in resistant larvae. Fully or partially resolved isomers were clearly much more toxic on resistant strains, indicating a possible blocking effect of the inactive isomers. A simple benzyl resistance breaking pyrethroid (Series Two) was shown to be equally effective on both adult and larval *H. armigera*, giving similar results to a pyrethroid/Pbo mix. The ideal requirements for a resistance breaking pyrethroid are discussed as well as factors acting against their possible commercialization.