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CHALLENGES IN PRODUCING RESISTANCE MANAGEMENT STRATEGIES FOR *MYZUS PERSICAE*

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ABSTRACT

Insecticide resistance is widespread in *Myzus persicae,* causing control problems in annual crops and its primary host, peach. Several aspects of the biology and nature of resistance in this species have combined to make the production of resistance management guidelines a challenge. These include a single predominant resistance mechanism conferring cross-resistance to all major classes of insecticide, application of insecticides to both summer and winter hosts, and crop protection measures frequently dictated by other pests occurring simultaneously with *M. persicae*.

INTRODUCTION

The IRAC (Insecticides Resistance Action Committee) Fruit Crops Working Group produced guidelines for the resistance management of spider mites in top fruit and citrus (Leonard & Wege, 1994). The guidelines are purposely simple and pragmatic to facilitate their adaptation to specific situations. Their successful integration into a Belgian IPM system (Sterk & Highwood, 1992) demonstrates the validity of this approach. The present paper discusses the problems encountered in attempting to devise a similar set of guidelines for managing insecticide resistance in *Myzus persicae*, and aims to initiate dialogue on this challenging problem.

INSECT CONTROL ON PEACH

Where the holocyclic life cycle predominates, *M. persicae* is a principal pest of the primary host, peach and nectarine (*Prunus persica*) in all major growing areas. Fundatrices emerge from eggs in the spring and give rise to apterous parthenogenetic females, of which there may be several generations. These can cause serious damage by feeding on newly opened leaves, or distortion or premature fall of fruit by feeding on fruits and flowers. In mid summer, alates are produced and migration to secondary host plants occurs. Alates return to the primary host in the late summer where they give rise to sexual forms which, following sexual reproduction, lay eggs in crevices in the bark. A proportion of the population may overwinter on peach as parthenogenetic females (Cravedi & Cervato, 1991).

As a consequence of the pest status of *M. persicae* in most major peach growing areas, a large proportion of regional populations may be treated with 1-5 foliar applications of insecticide and are thus subject to intense selection pressure. The first application is made pre-flowering or immediately post-flowering, although the exact timing varies regionally and may be made according to calendar (e.g. Japan), crop growth stage (e.g. Spain), the appearance of other, locally more significant pests (e.g. plum cuculio in USA), the first sign of aphids or on carefully determined thresholds (e.g. Italy and France).

Spray thresholds are typically set at low population levels, for example, the pre-flowering threshold for nectarines in the Emelia Romagna region of Italy is 1% of shoots infested. Foliage is minimal at this time, and effective spray coverage can be achieved. At this point in the life cycle of holocyclic *M. persicae*, there is maximum diversity in levels of resistance within the population. Treatment at this time and under these conditions contributes to effective control and helps prevent the build up of large populations of (resistant) individuals.

Choice of insecticides used for aphid control is often influenced by the local significance of other early season pests, including thrips (*Frankliniella occidentalis, Thrips meridionalis*) scale (*Quadraspidiotus perniciosus*), pentatomid and mirid bugs (e.g. *Lygus lineolaris, Acrosternum hilare*), Coleoptera (*Conotrachelus nemuphar*), and Lepidoptera (*Grapholitha molesta, Adoxophyes orana, Synanthedon hector*). The necessity for broad spectrum control limits the choice of products available to the grower and restricts the options available for resistance management, especially where product alternation or rotation strategies are favoured. Alternatively, additional treatments are necessary to control these or other later occurring pests, further exposing the residual aphid population to insecticides.

MYZUS RESISTANCE IN PEACH

One resistance mechanism, that of elevated levels of carboxylesterase (E4) enzymes which can neutralise insecticides through hydrolysis or sequestration, appears to predominate in *M. persicae* (Devonshire & Moores, 1982). The mechanism confers cross-resistance to carbamates, organophosphates (OP's) and pyrethroids (Sawicki & Rice, 1978). Individual aphids may be broadly classified as susceptible, moderately resistant (R1), very resistant (R2) or extremely resistant (R3) according to the quantity of E4 present.

Resistance to one or more classes of insecticide has been reported for *M. persicae* in most of the major peach growing areas (Voss, 1987). Samples of *M. persicae* from Australian peach have been shown to consist predominantly of R2 individuals (Herron *et al.*, 1993) whereas samples taken in Greece, Spain, Portugal, France and Italy have been found to consist predominantly of R3 aphids (Table 1). Against such populations, little, if any control is obtained with many OP insecticides and the efficacy of carbamate insecticides is often reduced. Pyrethroids surprisingly remain effective in many areas, even against populations consisting of predominantly R3 strains, which show strong pyrethroid resistance in bioassays. This might be explained by the initial, transient effects of the compounds (hyperactivity and ataxia) causing aphids to fall from the foliage.

Specific resistance mechanisms

Specific resistance mechanisms have been identified in other species of aphid, for example pirimicarb- and OP-insensitive acetylcholinesterases have been identified in *Aphis gossypii* (Silver, 1984; Sun *et al.*, 1987). In certain peach growing localities where the extensive and sole use of pirimicarb has occurred over many years, *M. persicae* with acetylcholinesterase specifically insensitive to pirimicarb and triazamate have been discovered.

This mechanism was found to occur both in conjunction with, and separately from elevated levels of esterase (Moores *et al.*, 1994). As an example of a specific, altered site resistance mechanism in *M. persicae*, this emphasises the consequences of heavy use of a single product, which may initially be highly effective against current resistant strains. The lesson is particularly relevant to recently launched novel aphicides, which are largely unaffected by the E4 resistance mechanism.

TABLE 1. Percentages of resistant and susceptible *Myzus persicae* sampled from primary and secondary host plants.

Country	Year	Crop	S	R1	R2	R3	n*
Germany	1992	potato	2	48	49	1	400
Germany	1990	sugar beet	18	59	23	0	42
Denmark	1991	beet clamps	1	96	3	0	937
France	1991	potato	6	35	51	8	168
Spain	1991	nectarine	0	4	28	68	84
Portugal	1991	peach	1	6	22	71	365
Italy	1991	peach	0	0	8	92	168
Greece	1990	tobacco	0	0	1	99	168
Greece	1990	peach	0	0	47	53	84
Argentina	1993	peach	0	42	54	4	79

* n=number of aphids in sample.
Samples provided by Zeneca. Esterase levels determined by A.L. Devonshire at Rothamsted.

INSECT CONTROL ON SECONDARY HOSTS

Crops which serve as secondary host plants for *M. persicae* are frequently found in close proximity to peach or nectarine orchards, often cultivated by the same grower. These are typically vegetables (e.g. France, Italy, Spain, South Africa, Turkey), potatoes (e.g. Argentina, South Africa) and tobacco (e.g. Greece and Turkey). Other secondary host plants of which *M. persicae* is an important pest include sugar beet and oilseed rape. Occasionally populations may build up sufficiently to cause physical damage, however, the species has a tendency to disperse, and economic damage most frequently results from the transmission of plant viruses. In many regions of Northern Europe, the primary host is uncommon and holocyclic forms appear rare (Broadbent & Heathcote, 1955). Aphids overwinter parthenogenetically on secondary host plants such as autumn sown brassicas, oilseed rape, beet clamps, and weeds.

Where virus control is the primary objective, sprays of pyrethroids or pyrethroid mixtures are often favoured over other chemical classes for their effects on virus transmission (Gibson, 1983). Spraying to carefully determined thresholds is common for virus control in potato and sugar beet (e.g. Dunning, 1986; Bacon *et al.*, 1978), however, there is a tendency amongst growers to make insurance sprays which increases selection pressure.

Soil and seed treatments for the control of *M. persicae* or other aphids are becoming increasingly popular in a number of annual crops. The consequences of this in terms of resistance are not yet fully understood. Situations will increasingly arise where aphids move from one treated crop to another without exposure to different chemistry. Where resistance exists, soil applied treatments have been shown to contribute to its development in aphids (Hardee & Ainsworth, 1993), however, they may generate fewer problems than the alternative of foliar insecticide applications principally due to preservation of beneficials.

Insecticide applications are frequently required to control other insect pests which occur simultaneously with aphids, for example *Leptinotarsa decemlineata* and *Pththorimaea operculella* in potatoes, *Ostrinia nubilalis* and other Lepidoptera in pepper, and *Heliothis sp.* in tobacco. The necessity to control these insects leads to increased selection pressure for *M. persicae* resulting from additional chemical applications or the use of compounds which may be less favourable in terms of selecting for resistance.

Rapid parthenogenetic multiplication on secondary hosts greatly multiplies the genotype of resistant individuals. Applications to the secondary host may therefore strongly influence the genotype entering the sexual phase and therefore the resistance status of the fundatrices of the following season. Resistance management practices implemented on peach may be compromised if complementary efforts are not made on the secondary hosts in the vicinity. Treatment of summer and winter hosts also occurs in areas where *M. persicae* overwinters parthenogenetically; for example winter oil seed rape, a preferred winter host of *M. persicae*, is increasingly treated in the late autumn with pyrethroids in the UK for the control of aphid transmitted virus, cabbage stem flea beetle and flea beetles.

MYZUS RESISTANCE IN SECONDARY HOSTS

Control problems can occur in populations that consist of a large proportion of R2 or R3 aphids. The distribution of these strains has been extensively studied in the UK (Furk *et al.*, 1990; Smith & Furk, 1989; ffrench-Constant & Devonshire, 1988; Sawicki *et al.*, 1978). Over the last 20 years, the proportion of susceptible aphids has remained low in the UK and the proportion of the very resistant R2 types has gradually increased, with a corresponding increase in control failures in sugar beet and potatoes. Similar trends have been observed in other European countries such as Northern France, Belgium and Denmark. The appearance of significant proportions of R3 strains in these areas has generally been slow, possibly due to the inferior overwintering capability of these strains (Hockland *et al.*, 1992). Although insecticide resistance in *M. persicae* in secondary crops is widely documented, few workers have fully characterised aphid populations in terms of esterase levels. High proportions of R2 aphids have been reported in populations from New Zealand potatoes (Cameron & Walker, 1989) and very high levels of R3's occur in Greek tobacco (Table 2).

PRESENT RESISTANCE MANAGEMENT

A variety of measures is used to manage the effects of resistance in *M. persicae* in peaches. These include increasing rates, tank mixtures and alternation of chemical types. The prime motive behind these measures is maintaining control in the short term rather than extending the useful life of the currently available compounds by preventing the build up of resistant strains. There is little evidence of rationally based resistance management in secondary hosts based on alternation or mixing of different products. Exceptions may be found in the UK, where recommendations have been made to reduce the selection of resistant strains in sugar beet by limiting pyrethroid-OP mixtures to the first application (Dewar *et al.*, 1992), and by the use of carbamate compounds such as pirimicarb and aldicarb, which select less strongly for resistant strains. The lack of technically based resistance management guidelines for product use is probably a reflection of the difficulty in formulating meaningful guidelines.

POSSIBLE TOOLS FOR RESISTANCE MANAGEMENT

There are considerable differences in the degree to which OP's, carbamates, pyrethroids and newer compounds of different chemistry (and individual compounds within those classes) are affected by E4 in *M. persicae* (Devonshire & Moores, 1982). The recently released novel compounds (imidacloprid, diafenthiuron and pymetrozine) are largely unaffected. Resistance management guidelines could be based around resistance factors (RF) which are a measure of inactivation by E4. RF values are calculated from the ratio of LC_{50} values between resistant and susceptible strains. Resistance factors between R2 and R1 *M. persicae* in contact bioassays for a range of insecticides are presented in table 2. These data, generated by Zeneca, are broadly consistent with those of Sawicki & Rice (1978) and Sawicki *et al.* (1978).

TABLE 2. Average resistance factors (RF) at LD_{50} for R2 vs. R1 *Myzus persicae.*

Compound	Chemical class	RF (LC_{50} R2/LC_{50} R1)	n
imidacloprid	chloronicotinyl	1	1
propoxur	methylcarbamate	1	2
triazamate	carbamyl triazole	3	2
acephate	methylphosphate	4	1
pirimicarb	dimethylcarbamate	8	5
diazinon	diethylphosphate	14	1
tefluthrin	ester pyrethroid	15	5
endosulfan	cyclodiene	20	1
heptenophos	dimethylphosphate	21	1
flufenprox	ether pyrethroid	22	5
fenvalerate	ester pyrethroid	33	5
permethrin	ester pyrethroid	40	5
cypermethrin	ester pyrethroid	59	5

*n= number of tests.

The use of this index as a tool for resistance management guidelines is supported by field data generated in the UK by Dewar *et al* (1992), Smith & Devonshire (1990) and ffrench-Constant *et al.* (1987): These data demonstrate (albeit for a limited range of products) that compounds with higher RF values, such as pyrethroids and some OP's, select for resistant strains more rapidly than those less affected by E4 esterases such as carbamates. No such work has yet been completed for *M. persicae* on the primary host.

RF values derived from a single set of clones characterised for varying levels of esterase could provide a reliable basis for resistance management guidelines. Amongst numerous field samples bioassayed using a variety of techniques (Choi & Kim, 1986; Attia & Hamilton, 1978; Cameron & Walker, 1989; Cloquemin *et al.*, 1990 and Herron *et al.*, 1993) there was no strong evidence of significant departure from the trends in RF values suggested by Sawicki & Rice (1978) and rationalised biochemically by Devonshire & Moores (1982). Absolute values do differ and are dependent on bioassay technique (Sawicki & Rice, 1978). This is particularly relevant for pyrethroids, the repellant properties of which can lead to avoidance of treated surfaces, resulting in artificially high RF values. The presence of specific resistance mechanisms in *M. persicae,* arguably compromises the use of RF's based on single strains of aphids. However, these strains appear strictly localised and the E4 mechanism can, at present, be considered valid for the majority of situations.

Further work to establish the relationship between laboratory generated RF values and field efficacy for a wider range of compounds and crops is required in order to determine the practical significance of this approach. These studies should also incorporate factors such as the persistence of foliar applied insecticides, selectivity to beneficials, and possible physiological effects such as the stimulated nymph production which can be associated with some compounds, all of which can affect the rate at which resistant *M. persicae* are selected or the rate at which resistant populations become established (ffrench-Constant *et al.*, 1987)

IRAC GUIDELINES FOR RESISTANCE MANAGEMENT.

At present, the IRAC Fruit Crops and Field Crops Working Groups are unable to define a general set of practical guidelines for the resistance management of *M. persicae* in the manner proposed for spider mites (Leonard & Wege, 1994). However, a number of basic instructions can be proposed:

1. Use compounds at the manufacturers' recommended rates and timings. Under no circumstances should application rates be increased over and above label recommendations.

2. Ensure effective coverage of the infested part of the crop.

3. Tank mixtures should employ the full label rates of both compounds.

4. Compounds should be used in such a way that impact on beneficial populations is minimised.

5. Monitoring should be used to detect the early signs of resistance*.

6. Where specific resistance mechanisms are identified, further exposure of the population to that active ingredient should be avoided.

*Resistance monitoring methods for *M. persicae* are described by IRAC (1990) and, in addition, biochemical and ELISA assays for E4 activity or quantity have been developed (e.g. Devonshire & Moores, 1984; Devonshire, 1975).

IRAC welcomes further dialogue and ideas from research workers, advisors, and growers on resistance management guidelines and their implementation.

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INSECTICIDE RESISTANCE ACTION COMMITTEE (IRAC) FRUIT CROPS SPIDER MITE RESISTANCE MANAGEMENT GUIDELINES 1994

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ABSTRACT

A principle objective of the Insecticide Resistance Action Committee (IRAC) is to delay or prevent the onset of insecticide resistance through the development of resistance management guidelines and their subsequent implementation as part of IPM or other production schemes. In line with this objective, IRAC Fruit Crops Working Group (FCWG) produced guidelines for spider mite resistance management in 1988. The present paper represents the second revision of these guidelines incorporating both newly available acaricide compounds and an extension of the crops covered by the guidelines.

INTRODUCTION

IRAC's guidelines for resistance management of spider mites in top fruit first published in 1988 (Lemon, 1988). An IRAC sponsored research programme (Dennehy & Wentworth, 1991) and further experiences within the individual companies represented on the IRAC Fruit Crops Working Group (FCWG) led to a revision of these guidelines (Leonard, 1992).

Five important new acaricides have subsequently appeared on the market, namely diafenthiuron, fenazaquin, pyridaben, tebufenpyrad and fenpyroximate. There is strong evidence to suggest that the latter four of these share a common mode of action acting on the rotenone site in the mitochondrial respiration electron transport chain (Hollingworth *et al.*, 1992, 1993; Motoba *et al.*, 1992; Anon, 1993a). Bioassays undertaken in Japan on *Panonychus citri* have indicated the presence of strains with reduced susceptibility to respiration inhibitor acaricides in certain locations (Anon, 1993b; Anon, 1994). Further tests on one of these strains by a company represented on the FCWG suggested cross-resistance between the four compounds. For this reason, the four compounds have been placed in one group in the compound groupings. There are no data available to suggest that strains of mite resistant to diafenthiuron have yet developed.

In accordance with developments in mite control practices in top fruit, the guidelines now recognise that reduced rates of application can be adopted, but only as part of established Integrated Pest Management (IPM) schemes in which the effects of acaricide treatments are augmented with the use of beneficial organisms. This can only be undertaken under the guidance of, and at the responsibility of, the local advisory services.