Horticulture Research International, Stockbridge House, Cawood, Selby, N.Yorks.

PROJECT REPORT

To:
Horticultural Development Council
18 Lavant Street
Petersfield
Hants, GU32 3EW

The future role of fenbutatin oxide (Torque)
in the integrated control of spider mites
in protected edible and ornamental crops

April 1996

The results and conclusions in this report are based on one series of experiments. The conditions under which the experiments were carried out and the results have been reported with detail and accuracy. However, due to the biological nature of the work it is possible that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

FINAL REPORT

Project Number:	PC93
Project Title:	The future role of fenbutatin oxide (Torque) in the integrated control of spider mites in protected edible and ornamental crops
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Key Words:	Spider mites, fenbutatin oxide, protected crops.

Authentication

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

Signature ....

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RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

General Background

Reliable control of spider mites within IPM programmes in protected edible crops depends on the combined use of the predatory mite, *Phytoseiulus persimilis*, and the selective acaricide, fenbutatin oxide (Torque). *P. persimilis* suppresses the pest population throughout the season while fenbutatin oxide is required to redress the pest/predator equilibrium during difficult periods. Neither product provides cost-effective control when used alone.

The continued availability of fenbutatin oxide is not only vital to IPM in these crops, but also to the development of new IPM programmes in ornamental crops. However, in recent seasons there has been concern that the chemical has not been performing well against all populations of spider mites in the UK. Resistance has already been reported in colonies of *Tetranychus urticae* (two-spotted spider mites) on pears in California and it was feared that similar problems may be developing here.

Objective

The overall objective of the project was to generate knowledge which would aid the development of a strategy to prolong the useful life of Torque in IPM programmes.

Summary of results

There were significant differences in the response to Torque of *T. urticae* populations from different sources in the UK. One population was resistant, another partially resistant and two susceptible to the acaricide; in all cases reflecting the degree of difficulty encountered in controlling the pests on the nurseries of origin. These results demonstrated that resistance to the chemical did exist in the UK.

Survival of mites treated with Torque increased significantly in three of four *T. urticae* populations cultured from survivors of a single exposure to the chemical and in one population of *Tetranychus cinnabarinus* (carmine mite) after two exposures. The rapid change in the resistance status indicated that tolerant individuals were already present in these populations and they were selected for by using the chemical.

The *T. urticae* populations reverted to being more susceptible when the chemical selection pressure was relaxed. It is therefore possible that resistance levels in some spider mite populations on commercial nurseries could fluctuate considerably during a single season depending on recent exposure to the acaricide. This could explain why many growers have experienced intermittent difficulties with Torque without the development of complete and widespread resistance.

Nine of the eleven spider mite populations tested showed no additional response to Torque when the application rate was increased from half to double the recommended rate. Problems are therefore unlikely to be resolved by increasing the application rate within sensible limits.

Survival of *P. persimilis* exposed to Torque at the recommended application rate ranged from 39% to 93%. The predators may be more susceptible to the chemical when they are under stress and the variation in the results could reflect the quality of the materials delivered. There was no additional detrimental effect on *P. persimilis* when the rate of application of Torque was increased to double that recommended but survival was lower at triple rate.

Premixing Torque with Codacide enhanced the effect of the acaricide on susceptible but not on the most resistant populations of spider mites. This practice had no additional effect on the mortality of *P. persimilis*.

Recommended strategy

A resistance management strategy is recommended in the full report. In summary:

1. Over use of the acaricide must be avoided.

2. In chemical based control programmes, Torque should not be used continuously but in rotation with Approved acaricides with a different mode of action.

3. In IPM systems, the predatory mites, *P. persimilis*, must be used as the principal control measure. Torque should be used only in difficult circumstances to redress the balance between the pest and predator. If possible, treatments should be restricted to localised areas of crop or specific parts of the plants (eg just the tops).

4. Application rates must not exceed 50g product per 100l water. There is no evidence to suggest that higher rates will improve the level of control. It is more important to ensure that very good spray coverage is achieved.

5. If treatments have failed and there are no obvious explanations, the resistance status of the population should be confirmed by laboratory bioassay to establish whether the problem is due to resistance or some other cause, such as incorrect application.

6. Where resistance is confirmed by bioassay, Torque should not be used again until a re-test shows that the population has reverted from being predominantly resistant to susceptible.

7. Premixing Torque with Codacide should enhance the performance of the acaricide against all but the most resistant populations of spider mites but this is done entirely at the "user's risk". Growers should not be tempted to use lower than recommended rates of Torque when applying it with Codacide.

INTRODUCTION

1. General Background

Control of two-spotted spider mites (*Tetranychus urticae*) in cucumber, pepper and tomato crops depends on the combined use of the predatory mite, *Phytoseiulus persimilis*, and the selective organotin acaricide, fenbutatin oxide (Torque). *P. persimilis* suppresses the pest population throughout the season while fenbutatin oxide is required to redress the pest/predator equilibrium during periods when biological control alone is inadequate. Neither product provides complete cost-effective control when used alone.

The continued availability of fenbutatin oxide is not only vital to IPM in cucumber, pepper and tomato crops, but also to the development of new IPM programmes in ornamental crops. However, in recent seasons there has been concern that the chemical is not performing well against all populations of spider mites in the UK. For example, in some grower field tests the pests are claimed to have survived high volume sprays of three times the recommended application rate. Resistance to fenbutatin oxide has been reported in colonies of *T. urticae* on pears in California (Tian et al, 1992) and it was feared that similar problems may be developing in the UK. Furthermore, many growers believe the recommended application rate of fenbutatin oxide (50g product per 100l water) is too low and this could be accelerating the selection of resistant strains of spider mites.

The use of alternative, non-selective acaricides against spider mites is unacceptable because they harm *P. persimilis* and may also kill beneficial organisms used against other pests, thereby disrupting entire IPM programmes. It is therefore important to develop strategies which will prolong the useful life of this chemical which is so important to the UK industry.

The original objective of this project was to establish the optimum application rate of fenbutatin oxide which would provide the maximum kill of spider mites without harming *P. persimilis*. This was to be done by collecting populations of *T. urticae* from nurseries that had varying degrees of success with the acaricide and testing their susceptibility to fenbutatin oxide at concentrations up to twice the recommended application rate. Parallel tests would determine the effect of the same application rates on *P. persimilis*.

2. Preliminary studies

Development of experimental methods

The development of the bioassays which are described in the "Materials and Methods" section of this report, included the following preliminary studies:

1. The Potters Tower precision spray equipment was tuned to provide total coverage of the chemical at the correct application rates by spraying test dyes and weighing spray deposits.

2. Experiments to determine whether untreated controls should be unsprayed or sprayed with distilled water showed the performance of spider mites in the test dishes to be slightly better when sprayed, possibly because the leaves remained in fresher condition.

3. The performance of the mites was found to be similar whether they were placed on the test leaf immediately before or immediately after spraying, indicating that the residual effect of the chemical on the leaf was more important than direct application to the mites.

4. Spider mite development at 21°C was monitored in the test dishes in both untreated controls and following application of various concentrations of fenbutatin oxide. The key times for experimental assessments were found to be:

   i). Adult survival - Days 4 to 6.
   ii). Eggs - Days 5 to 8.
   iii). Progeny - Days 9 to 10.

Variability of Experimental Material

The preliminary studies revealed many variables that could become sources of experimental error. The effects of most were minimised by fine tuning experimental techniques but there were large differences in the fecundity of individual mites which could not be controlled. Experiments were designed with biometricians to minimise the risk of the inherent variability masking differences between treatments.

Selection of "resistant" individuals

Preliminary experiments indicated that a single application of Torque could change significantly the resistance status of a population of *T. urticae*. Adult mortality in the first culture tested showed a progressive response to increased rates of application of Torque up to 1.5 times the recommended rate (Figure 1a).

However, the progeny of the survivors of these applications showed no response to the chemical, even when applied at twice the recommended rate (Figure 1b).

3. Revised Objectives for Stage 1 of the Project

Based on the results of the preliminary experiments, and following consultation with HRI Biometricians and HDC representatives, the original objectives of the project were modified. It was agreed that the experiments should concentrate on a reduced number of spider mite populations and that the effect of Torque on both the populations as collected and on the progeny of survivors of the initial application should be determined. The tests with *P. persimilis* were to progress as planned originally.

4. Stage 2 - Studies with Codacide

A supplementary experiment in stage one of the project demonstrated that pre-mixing Torque with the rapeseed oil adjuvant, Codacide, enhanced the effect of the acaricide. At the request of the HDC the project was extended to investigate further the use of this mixture against spider mites and to determine whether it was detrimental to *P. persimilis*.

Fig.1. Mortality of adult spider mites following exposure to five application rates of Torque

Fig.1a. Original spider mite population.

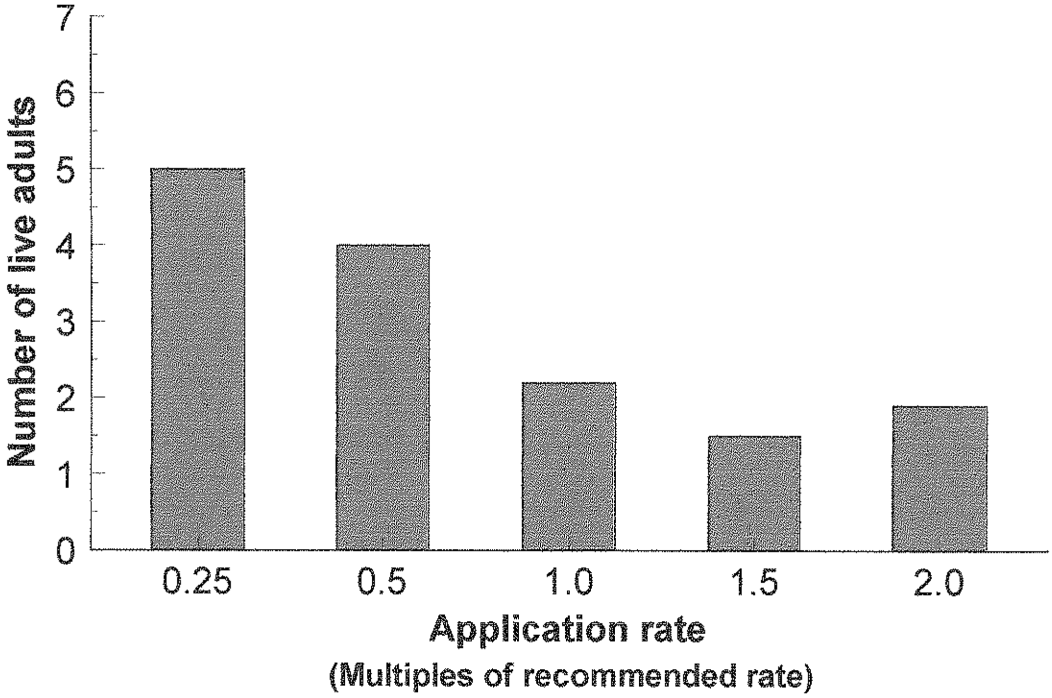
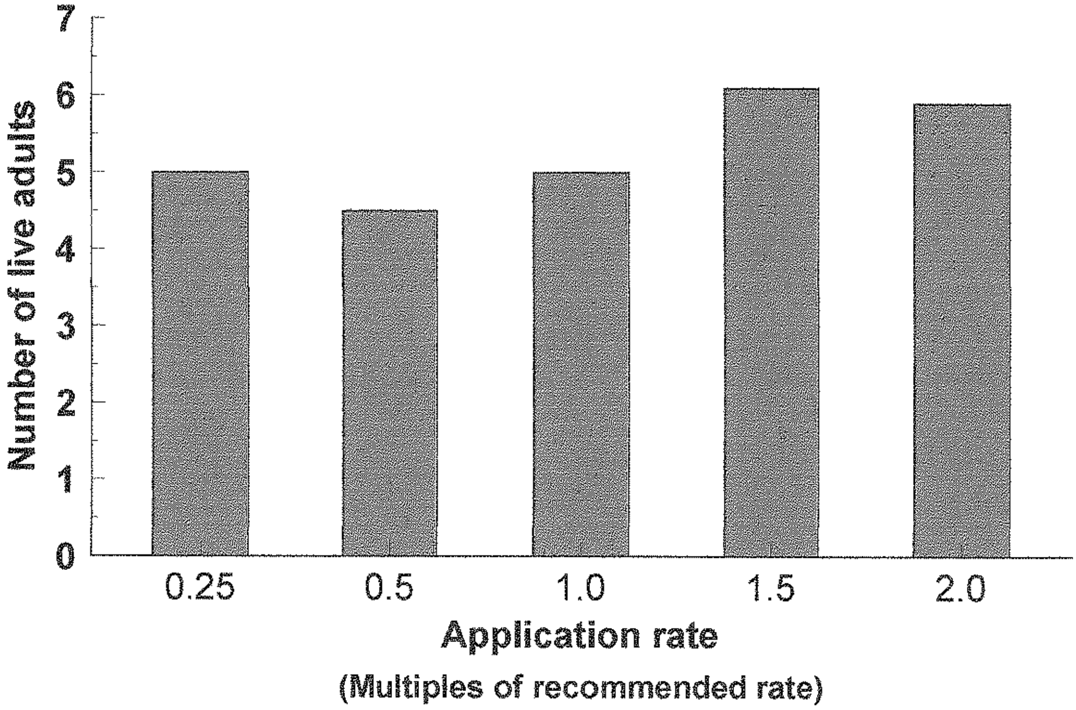


Fig.1b. Culture based on survivors of one exposure to Torque.



OBJECTIVES

The overall objective of the project was to provide knowledge which would aid the development of a strategy to prolong the useful life of Torque in IPM programmes. Specific objectives were:

Stage 1 of the Project

1.1. To investigate differences in the response of five spider mite populations to the recommended application rate of Torque.

1.2. To determine the response to Torque in populations of spider mites cultured from survivors of exposure to an application of the acaricide.

1.3. To determine the effect of Torque application rates on populations of spider mites with differing histories of exposure to the chemical.

1.4. To determine the effect of Torque, applied at up to three times the recommended application rate, on populations of *P. persimilis* from three different suppliers.

1.5. To determine whether pre-mixing Torque with Codacide will enhance the effect of the acaricide on spider mites.

Stage 2 of the Project

To determine whether pre-mixing Torque with Codacide could:

2.1. Enhance the effect of the acaricide on the more resistant populations of *T. urticae*.

2.2. Enable lower than recommended rates of Torque to be used against the more susceptible populations of *T. urticae*.

2.3. Result in more harmful effects to *P. persimilis*.

MATERIALS AND METHODS

1. Source of spider mite populations

Twelve populations of spider mites with different histories of exposure to fenbutatin oxide were obtained from various sources and cultured in isolation. Five of these populations (A, B, C, D and E) were subsequently chosen for inclusion in the detailed experiments (Table 1).

Adult females from the same five populations of spider mites were confined separately for nine days on leaves treated with Torque. Cultures A1, B1, C1, D1 and E1 were established from the surviving progeny (Table 1).

Adult females from culture E1 were confined for nine days on leaves treated with Torque and culture E2 established from the surviving progeny (Table 1).

2. Stock cultures of spider mites

Spider mites were reared in a small experimental greenhouse at a minimum temperature of 20°C with automatic ventilation at 25°C. Day length was maintained at 16 hours minimum using supplementary lighting when necessary. Each culture was based on two dwarf french bean plants grown in a 100mm diameter pot on a raised platform above a tray containing soap-water. The latter prevented movement of mites between cultures. The populations were sub-cultured onto new plants at intervals of approximately two weeks to prevent overcrowding.

TABLE 1: Details of spider mite populations used in the experiments.

Population Reference	Species	Source and Background information
A	*T. urticae*	Commercial cucumber nursery. Poor control with Torque during the last 6 years.
A1	*T. urticae*	Population A. Survivors of exposure to Torque.
B	*T. urticae*	Biocontrol production unit. Not exposed to Torque for over 6 years.
B1	*T. urticae*	Population B. Survivors of exposure to Torque.
C	*T. urticae*	Experimental cucumber crops grown to commercial standards. Acceptable control with Torque.
C1	*T. urticae*	Population C. Survivors of exposure to Torque.
D	*T. urticae*	Experimental tomato crops grown to commercial standards. Intermittent difficulties in control with Torque.
D1	*T. urticae*	Population D. Survivors of one exposure to Torque.
E	*T. cinnabarinus*	Commercial tomato nursery. Intermittent difficulties in control with Torque.
E1	*T. cinnabarinus*	Population E. Survivors of one exposure to Torque.
E2	*T. cinnabarinus*	Culture E1. Survivors of a second exposure to Torque.

3. Preparation of synchronised cultures of spider mites

Synchronised cultures of spider mites for use in bioassays were established from the stock cultures.

Adult female spider mites were transferred from stock cultures to excised bean leaves mounted on tap water agar in Petri-dishes. The dishes were inverted and incubated (20°C, 16:8 L:D) for a 48 hour egg laying period. The mites were then removed. After a further six days the offspring were removed from the incubator and reared to adults on bean plants using the technique described for stock cultures. These adults were collected for use in bioassays.

4. Source of *P. persimilis*

Populations of *P. persimilis* were obtained from three producers of biological pest control agents (X, Y and Z). The products were ordered as normal commercial transactions and delivered to HRI Stockbridge House by post.

5. Bioassay of spider mites with Torque +/- Codacide

Each experimental unit was based on one 90 mm diameter Petri-dish containing an excised bean leaf mounted on tap water agar and covered with a ventilated lid. Ten adult female spider mites of the same age were placed on the leaf immediately before application of treatments.

Torque test solutions were prepared by dissolving the required quantity of product in water. When Codacide was included, the Torque was first mixed to a paste with a small volume of water, then mixed with Codacide to form an emulsion and finally diluted with water. The prepared test solutions were agitated constantly.

One ml of test solution was applied to each dish using a Potters Precision Laboratory Spray Tower fitted with the intermediate atomizer and set to the operating pressure of 0.6 bar.

Following application of test solutions, the dishes were inverted and incubated (21°C, 18:6 L:D) for 9 days. The number of surviving spider mite progeny were then recorded.

6. **Bioassay of *P. persimilis* with Torque +/- Codacide.**

Each experimental unit was based on one 140 mm diameter Petri-dish containing an excised bean leaf mounted on tap water agar and covered with a ventilated lid. Ten adult female spider mites were placed on the leaf, the dish inverted and incubated (21°C, 18:6 L:D) for five days to produce prey for *P. persimilis*.

Immediately before application of treatments, a fresh bean leaf was placed on the agar to provide additional food for the spider mites and five adult female *P. persimilis* were released in each dish.

Test solutions were prepared and applied as described for bioassays of spider mites, except 1.27 ml of solution was sprayed on each of these larger dishes.

Following application of test solutions, the dishes were inverted and incubated (21°C, 18:6 L:D) for seven days. More spider mites were released after three and five days if numbers were depleted to ensure prey were always available. The numbers of surviving *P. persimilis* progeny were recorded at the end of the incubation period.

7. Application rates of Torque +/- Codacide

Application rates of Torque:

Quarter recommended rate
- Equivalent to 12.5 g per 100 l water.

Half recommended rate
- Equivalent to 25 g per 100l water.

Recommended rate
- Equivalent to 50 g per 100 l water.

Double recommended rate
- Equivalent to 100 g per 100 l water.

Treble recommended rate
- Equivalent to 150g per 100l water.

Application rates of Torque pre-mixed with Codacide:

Quarter recommended rate of Torque
- Equivalent to 12.5 g Torque plus 50 ml Codacide per 100 l water.

Half recommended rate of Torque
- Equivalent to 25 g Torque plus 50 ml Codacide per 100 l water.

Recommended rate of Torque
- Equivalent to 50 g Torque plus 50 ml Codacide per 100 l water.

Double recommended rate of Torque
- Equivalent to 100 g Torque plus 50 ml Codacide per 100 l water.

8. Treatments and Replication

The reference numbers of these sections are consistent with those used for the Objectives.

1.1/1.2/1.3. Effect of Torque on populations of spider mites.

The following concentrations of Torque were applied to all eleven spider mite populations.

Treatment 1. Control (distilled water only).

Treatment 2. Half recommended rate.

Treatment 3. Recommended rate.

Treatment 4. Double recommended rate.

Each treatment was replicated five times.

1.4. Effect of Torque on three populations of *P. persimilis*.

The following concentrations of Torque were applied to *P. persimilis* strains X, Y and Z.

Treatment 1. Control (distilled water only).

Treatment 2. Recommended rate.

Treatment 3. Double recommended rate.

Treatment 4. Treble recommended rate.

Each treatment was replicated three times.

1.5. Effect of Torque pre-mixed with Codacide on one population of spider mites.

The following emulsions of Torque/Codacide were applied to spider mite culture C.

Treatment 1.	Control (distilled water only).
Treatment 2.	Half recommended rate of Torque.
Treatment 3.	Recommended rate of Torque.
Treatment 4.	Double recommended rate of Torque.
Treatment 5.	Codacide. Equivalent to 50ml Codacide per 100l water.
Treatment 6.	Half recommended rate of Torque pre-mixed with Codacide.
Treatment 7.	Recommended rate of Torque pre-mixed with Codacide.

Each treatment was replicated five times.

2.1. Effect of Torque pre-mixed with Codacide on one "resistant" population of spider mites.

The following emulsions of Torque/Codacide were applied to spider mite culture A.

Treatment 1.	Control (distilled water only).
Treatment 2.	Half recommended rate of Torque.
Treatment 3.	Recommended rate of Torque.
Treatment 4.	Double recommended rate of Torque.

Treatment 5. Codacide.
Equivalent to 50ml Codacide per 100l water.

Treatment 6. Half recommended rate of Torque pre-mixed with Codacide.

Treatment 7. Recommended rate of Torque pre-mixed with Codacide.

Treatment 8. Double recommended rate of Torque pre-mixed with Codacide.

Each treatment was replicated four times.

2.2. Effect of Torque pre-mixed with Codacide on one "susceptible" population of spider mites.

The following emulsions of Torque/Codacide were applied to spider mite culture C.

Treatment 1. Control (distilled water only).

Treatment 2. Quarter recommended rate of Torque.

Treatment 3. Half recommended rate of Torque.

Treatment 4. Recommended rate of Torque.

Treatment 5. Codacide.
Equivalent to 50ml Codacide per 100l water.

Treatment 6. Quarter recommended rate of Torque re-mixed with Codacide.

Treatment 7. Half recommended rate of Torque pre-mixed with Codacide.

Treatment 8. Recommended rate of Torque pre-mixed with Codacide.

Each treatment was replicated four times.

2.3. Effect of Torque pre-mixed with Codacide on one strain of *P. persimilis*.

The following emulsions of Torque/Codacide were applied to *P. persimilis* strain X.

Treatment 1. Control (distilled water only).

Treatment 2. Recommended rate of Torque.

Treatment 3. Double recommended rate of Torque.

Treatment 4. Treble recommended rate of Torque.

Treatment 5. Codacide.
Equivalent to 50ml Codacide per 100l water.

Treatment 6. Half recommended rate of Torque mixed with Codacide.

Treatment 7. Recommended rate of Torque pre-mixed with Codacide.

Treatment 8. Double recommended of Torque pre-mixed with Codacide.

Each treatment was replicated four times.

9. Analysis of data

The numbers of mites surviving Torque (+/- Codacide) applications were expressed as percentages of the untreated controls. Square-root transformations of the percentages were analyzed using Analysis of Variance (ANOVA) to provide Least Significant Differences (L.S.D.).

The following abbreviations are used in the script:

F	=	A measure of the ratio of variation between treatments to the sample (residual) variation. A non significant effect of treatments produces low F values.
L.S.D.	=	The least (minimum) difference when comparing any two figures within a given column that is required for those figures to be statistically different.
$P < 0.05$	=	The probability of this result occurring by chance is less than 1 in 20. Only *P* values lower than 0.05 indicate a significant result.
sd	=	A measure of the variation around the mean values in a sample.

RESULTS

The reference numbers of these sections are consistent with those used for the Objectives and Treatments.

1.1. Response of various spider mite populations to applications of Torque at the recommended application rate.

The results in Figure 2 show the survival of progeny from four of the original populations of *T. urticae* at the recommended rate of Torque.

ANOVA of the transformed data on the overall effect of Torque indicate significant differences between populations of mites ($F = 49.5$, $P < 0.001$). Comparing the means from the populations shows that; survival of population A was significantly higher than the other three and population D had a significantly higher percentage survival than population B or population C (L.S.D = 24.6, $P < 0.05$).

1.2. Response to Torque of populations of spider mites cultured from survivors of exposure to the acaricide.

Figures 3-7 show the effects of prior exposure to Torque on the survival of progeny of four populations of *T. urticae* and one population *T. cinnbarinus*.

Figure 3 - The overall effect was significant and survival of population A1 was greater than that of population A (L.S.D. = 27.1, $P < 0.05$).

Figure 4 - The overall effect was significant and survival of population B1 was greater than that of population B (L.S.D. = 16.9, $P < 0.05$).

Figure 5 - There was no difference between the survival of populations C and C1 (L.S.D. = 14.5, $P > 0.05$).

Figure 6 - The overall effect was significant and survival of population D1 was greater than that of population D (L.S.D. = 13.7, $P < 0.05$).

Figure 7 - Prior exposure to Torque affected *T. cinnbarinus* survival ($F = 22.0$, $P < 0.001$). This was significantly greater in population E2 than populations E and E1 (L.S.D. = 15.7, $P < 0.05$).

1.3. Effect of rate of application of Torque on various populations of spider mites.

The results in Figure 3 show that increased rates of Torque application did not significantly effect the survival of population A or A1 (L.S.D. = 27.2, $P > 0.05$).

Similarly, there were no significant effects of increased rates of Torque on populations B and B1 (L.S.D. = 29.2, $P > 0.05$) (Figure 4) or populations C and C1 (L.S.D. = 25.1, P > 0.05) (Figure 5).

Increasing the rate of Torque significantly affected the survival of population D mites but not population D1 (Figure 6). Survival of population D was greater at half than double the recommended rate (L.S.D. = 23.7, $P < 0.05$).

The results in Figure 7 show that increased rates of Torque produced a significant decline in survival of population E ($F = 5.41$, $P = 0.009$) but not populations E1 or E2. Survival of population E was greater at half recommended rate than at recommended and double rates (L.S.D. = 27, $P < 0.05$).

1.4. Effect of Torque on *P. persimilis*.

Figure 8 shows the effect of three rates of Torque on survival of three populations of *P. persimilis*.

For each rate, there was no significant difference between the populations (F = 0.30, P = 0.875).

Survival of progeny of all populations declined with increased application rates of Torque (F = 4.1, P = 0.036) but the only significant difference was in the survival of population Y; survival at triple recommended rate was greater than recommended rate (L.S.D. = 40.5, P < 0.05). The large sd values account for the non-significance among the other populations.

1.5./ 2. Effects of pre-mixing Torque with Codacide

1.5. Preliminary experiment in Stage 1 of the project.

The results in Figure 9 show that pre-mixing Torque with Codacide significantly enhanced the effects of the acaricide (F = 28.7, P < 0.001) at both the half and full recommended application rates (L.S.D. = 37.2, P < 0.05).

2.1. Effect of Torque and Codacide on a more resistant population of *T. urticae*.

Figure 10 shows the effects of Torque and Codacide on population A. There were no differences in survival of progeny between the Torque and Torque plus Codacide treatments (F = 0.04, P = 0.959).

2.2. Effect of low rates of Torque on the most susceptible population of *T. urticae.*

The results in figure 11 show the effects of Torque and Codacide on population C. Pre-mixing Torque with Codacide significantly reduced the survival of mites when half and full recommended rates of Torque were used but not at quarter rate (L.S.D. = 37.2, $P < 0.05$).

2.3. Effect on *P. persimilis*

Survival of progeny of *P. persimilis* was not significantly reduced by the addition of Codacide to Torque ($F = 0.10$, $P = 0.909$) (Figure 12).

As seen in Figure 8, increasing rates of Torque produced a non-significant decline in offspring survival; large sd values could again account for the statistical result.

Fig. 2. Mean response (+/-sd) of four populations of *T.urticae* to Torque at the recommended application rate
(values are a mean percentage of untreated controls, n = 5).

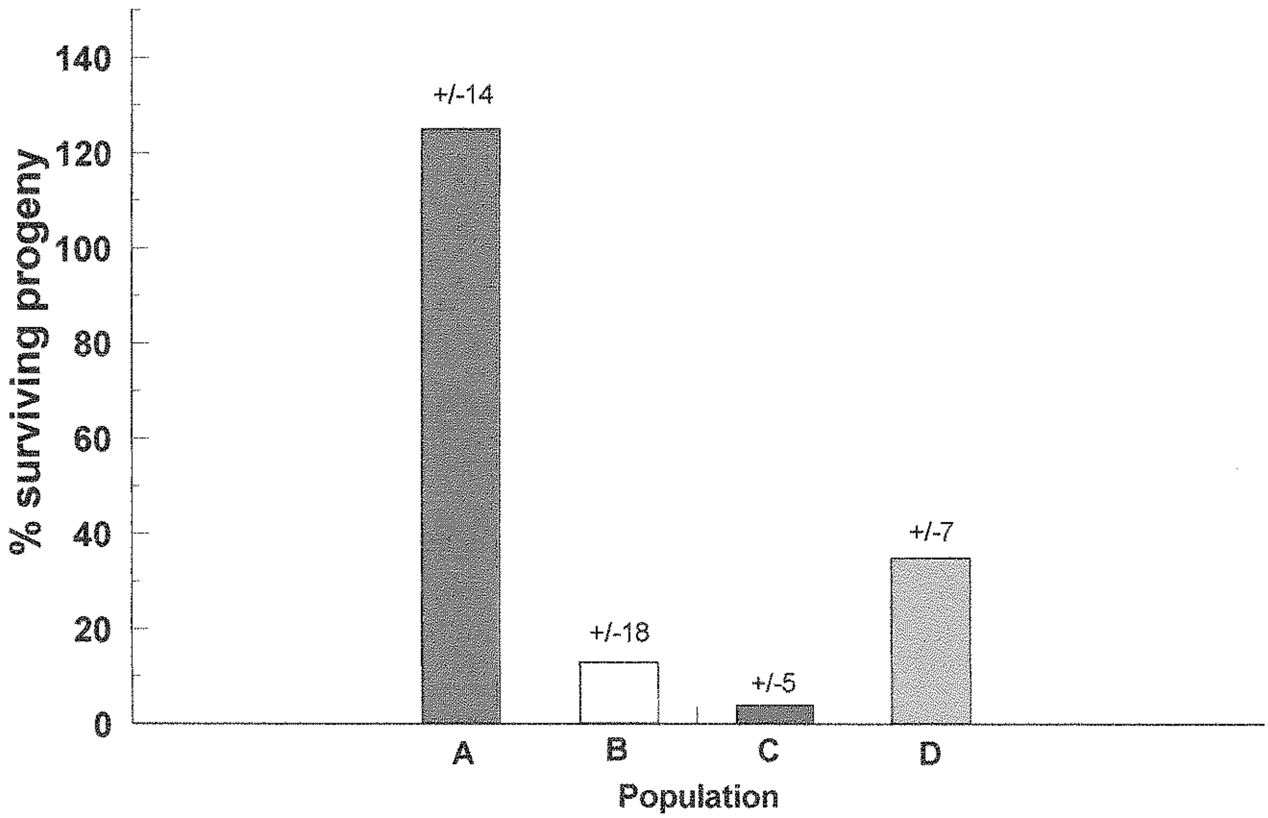


Fig.3. The effects of three rates of Torque on populations A and A1 (values are a mean percentage (+/-sd) of untreated controls,n = 5).

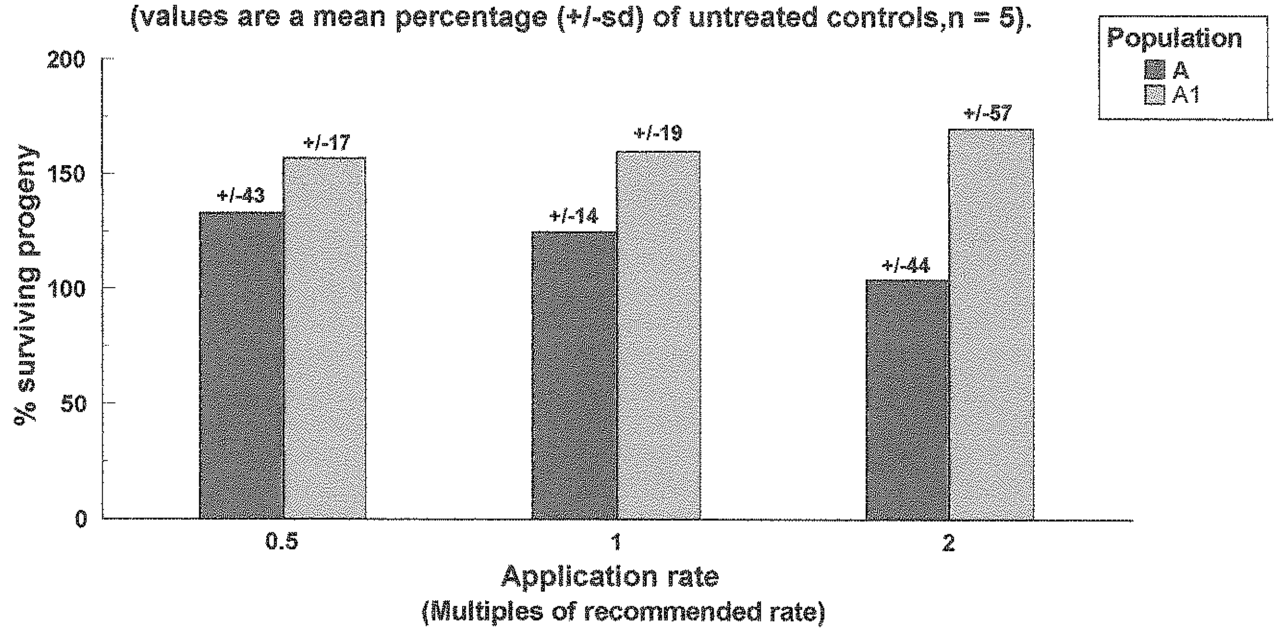


Fig.4. The effects of three rates of Torque on populations B and B1 (values are a mean percentage (+/-sd) of untreated controls, n = 5).

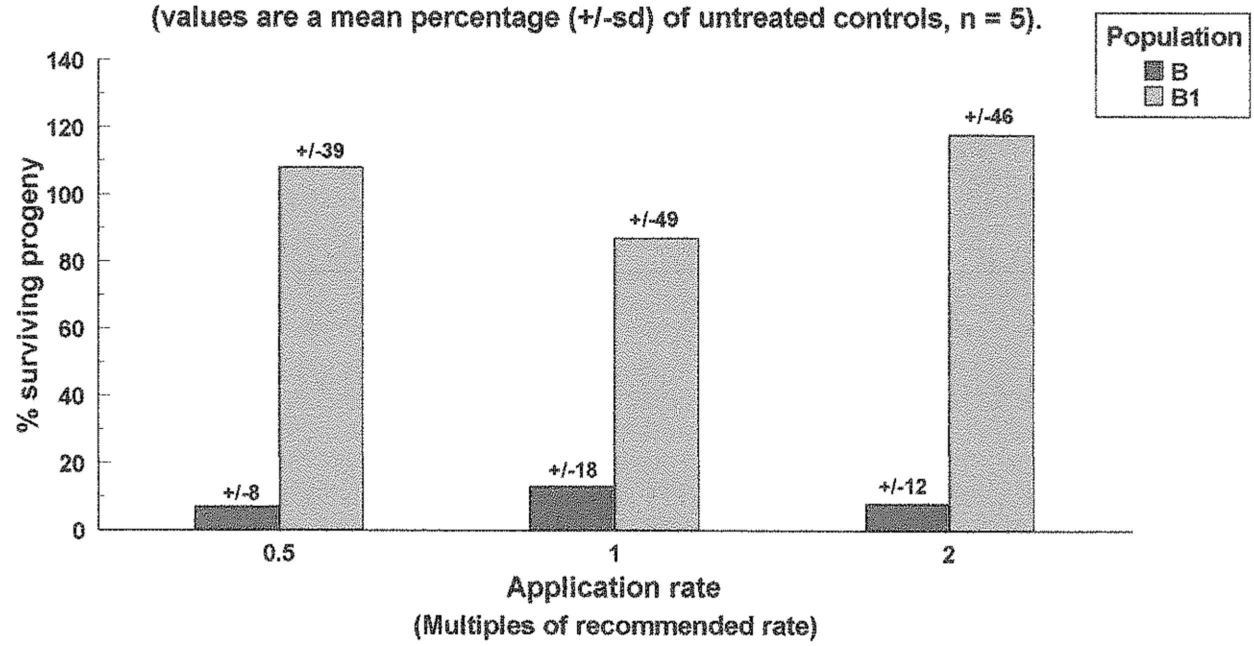


Fig.5. The effects of three rates of Torque on populations C and C1 (values are a mean percentage (+/-sd) of untreated controls, n = 5).

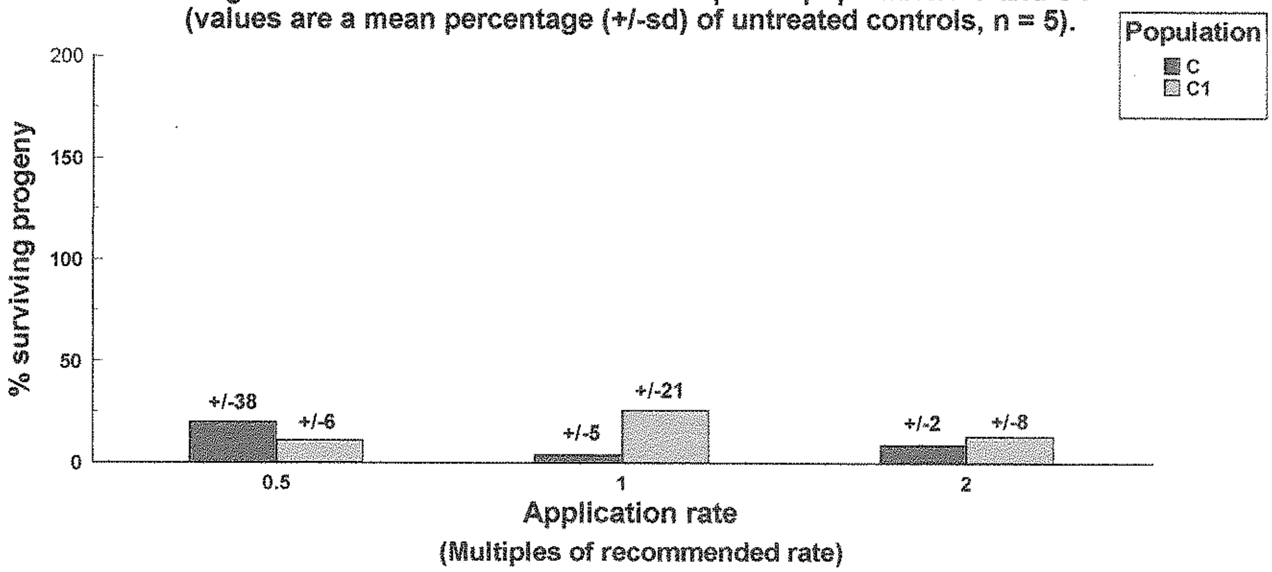


Fig.6. The effects of three rates of Torque on populations D and D1 (values are a mean percentage (+/-sd) of untreated controls, n = 5).

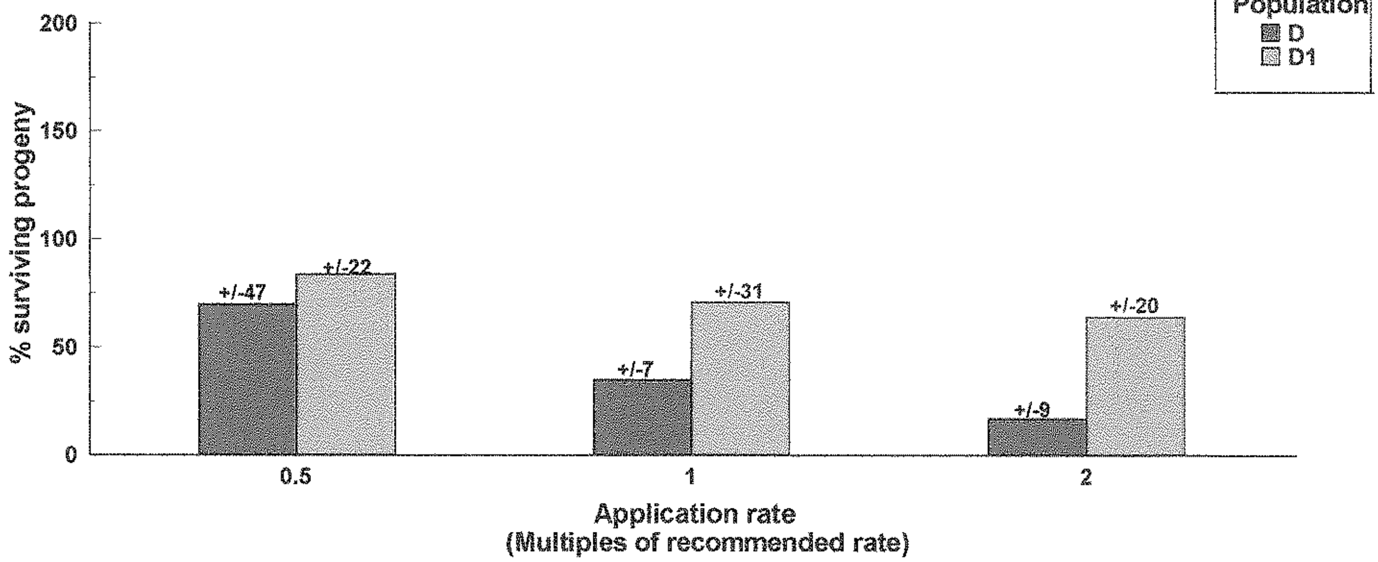


Fig.7. The effects of three rates of Torque on populations E, E1 and E2 (values are a mean percentage (+/-sd) of untreated controls, n = 5).

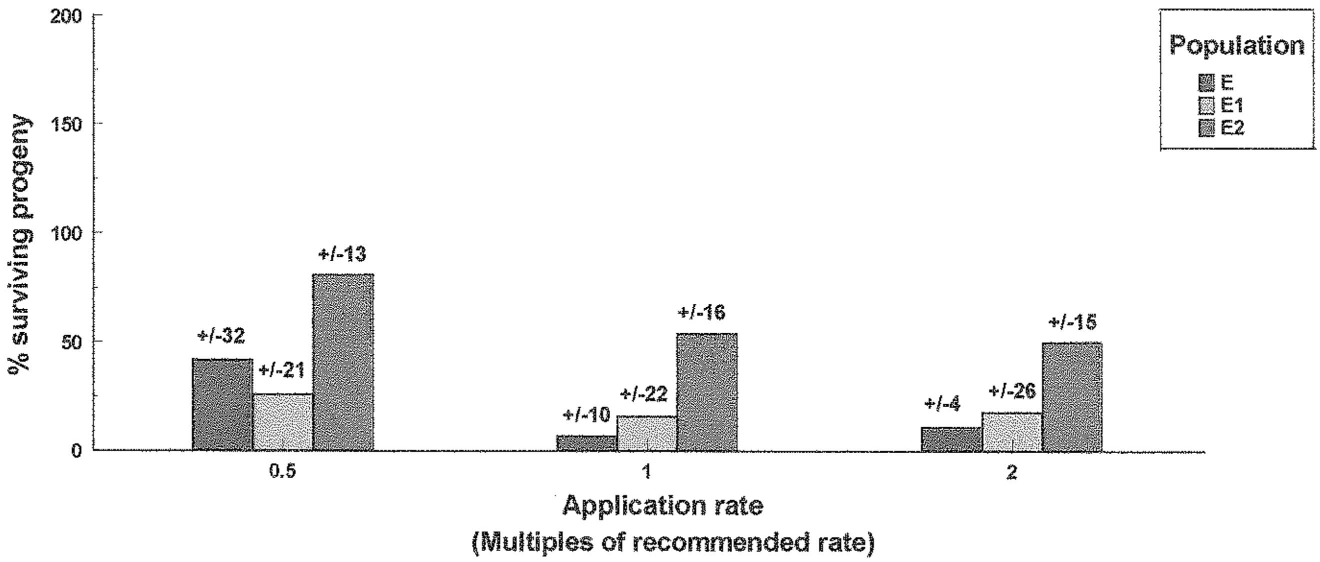


Fig.8. The effects of three rates of Torque on three populations of *P.persimilis* (values are a mean percentage (+/-sd) of untreated controls, n=3).

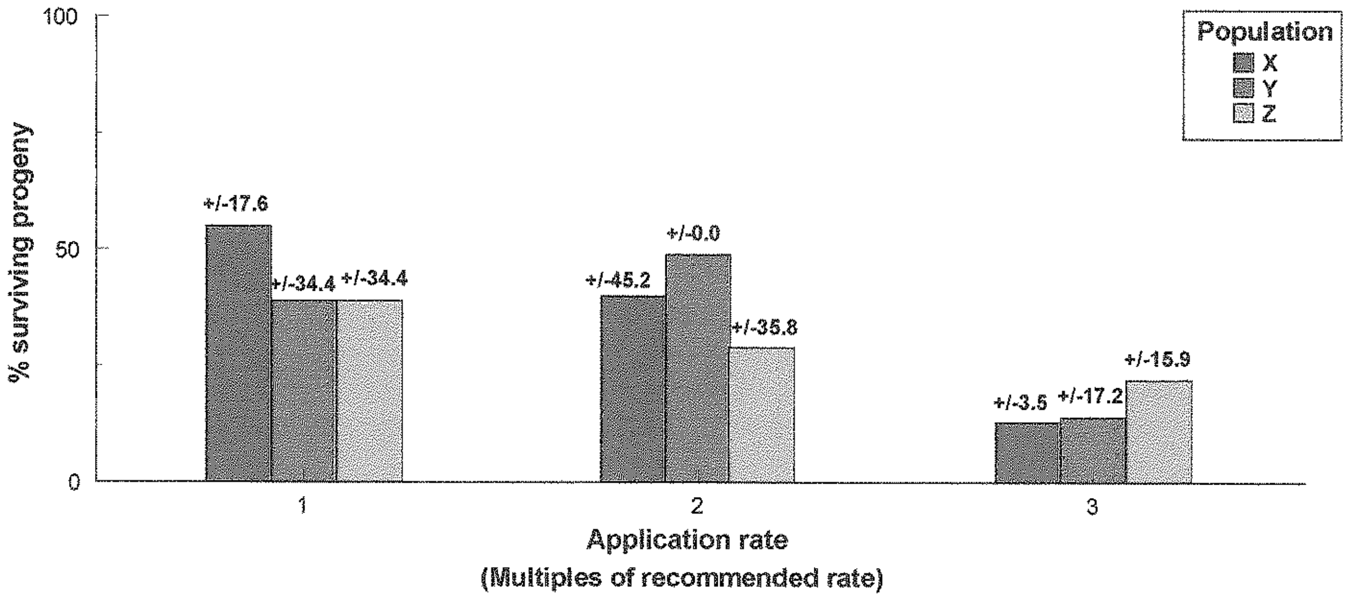


Fig.9. The effects of Torque +/- Codacide on *T.urticae* (Population C)
(values are a mean percentage (+/-sd) of untreated controls, n = 5)

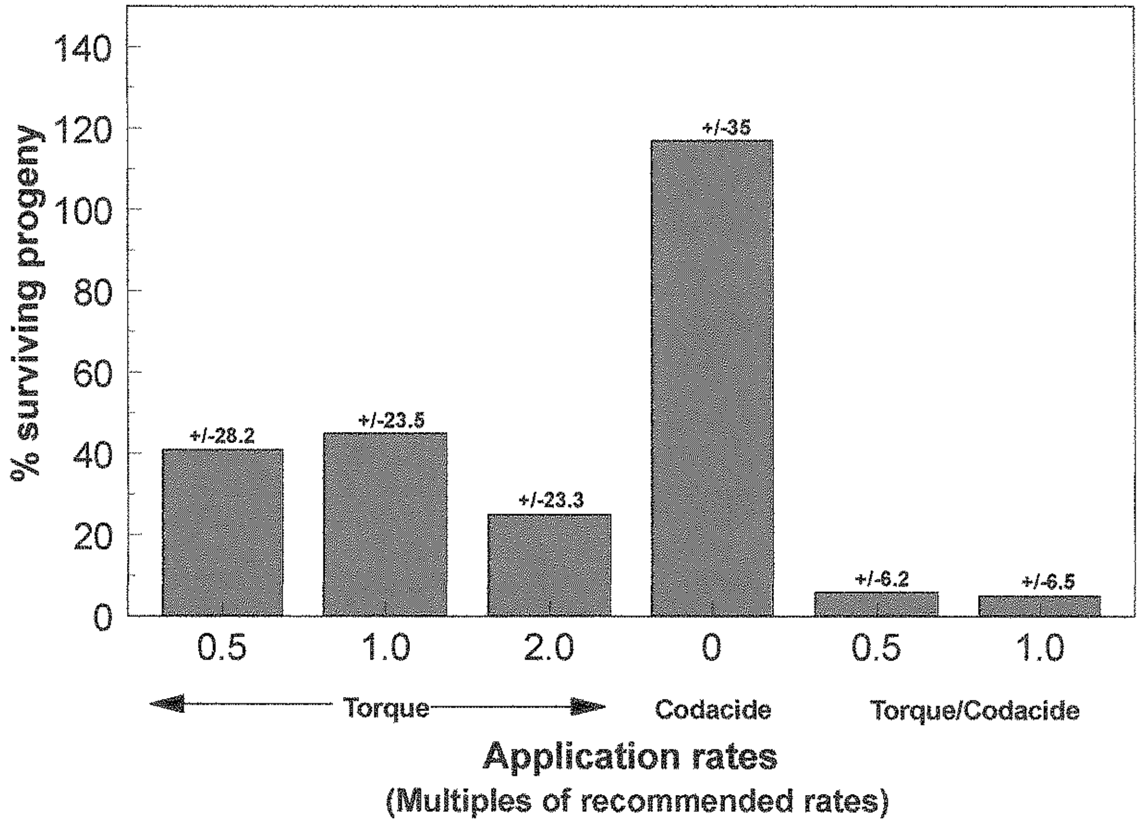


Fig.10. The effects of Torque +/- Codacide on a resistant population of *T.urticae* (Population A)
(values are a mean percentage (+/-sd) of untreated controls, n = 4).

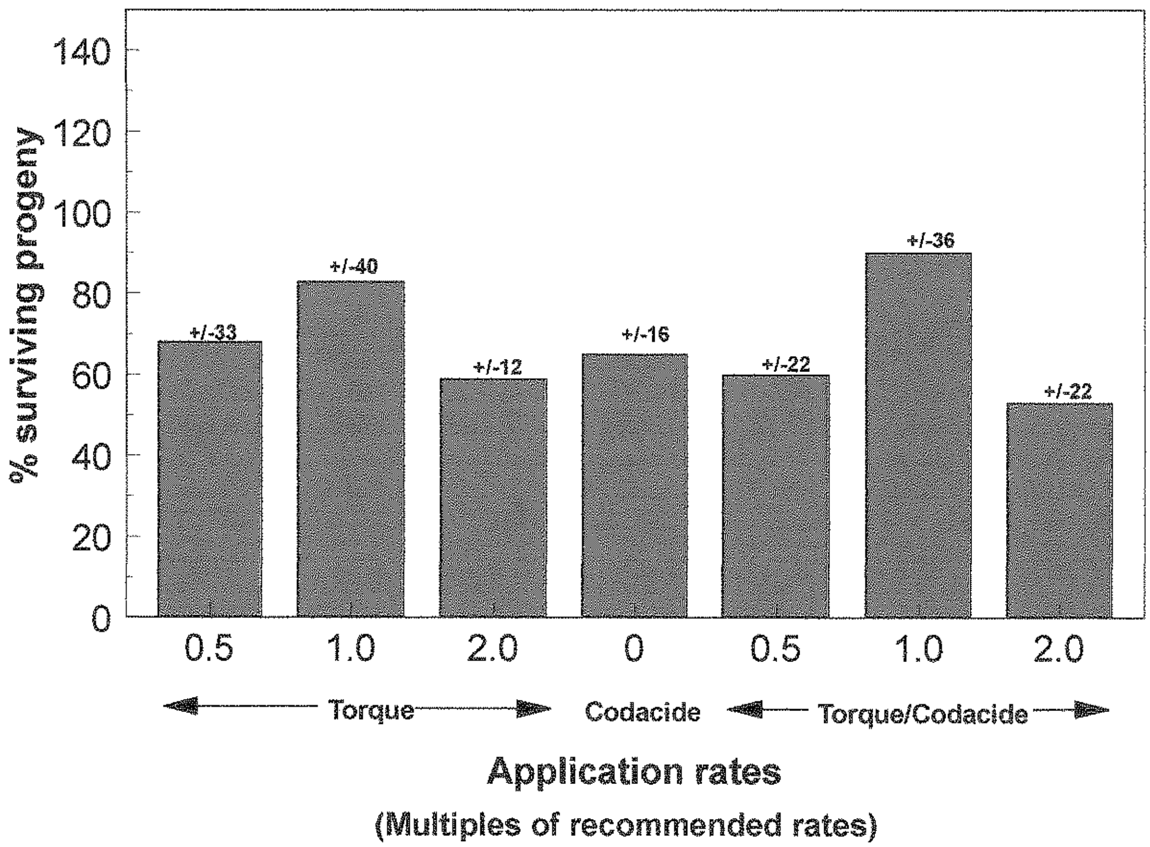


Fig.11. The effects of Torque +/- Codacide on a susceptible population of *T.urticae* (Population C) (values are a mean percentage (+/-sd) of untreated controls, n = 5)

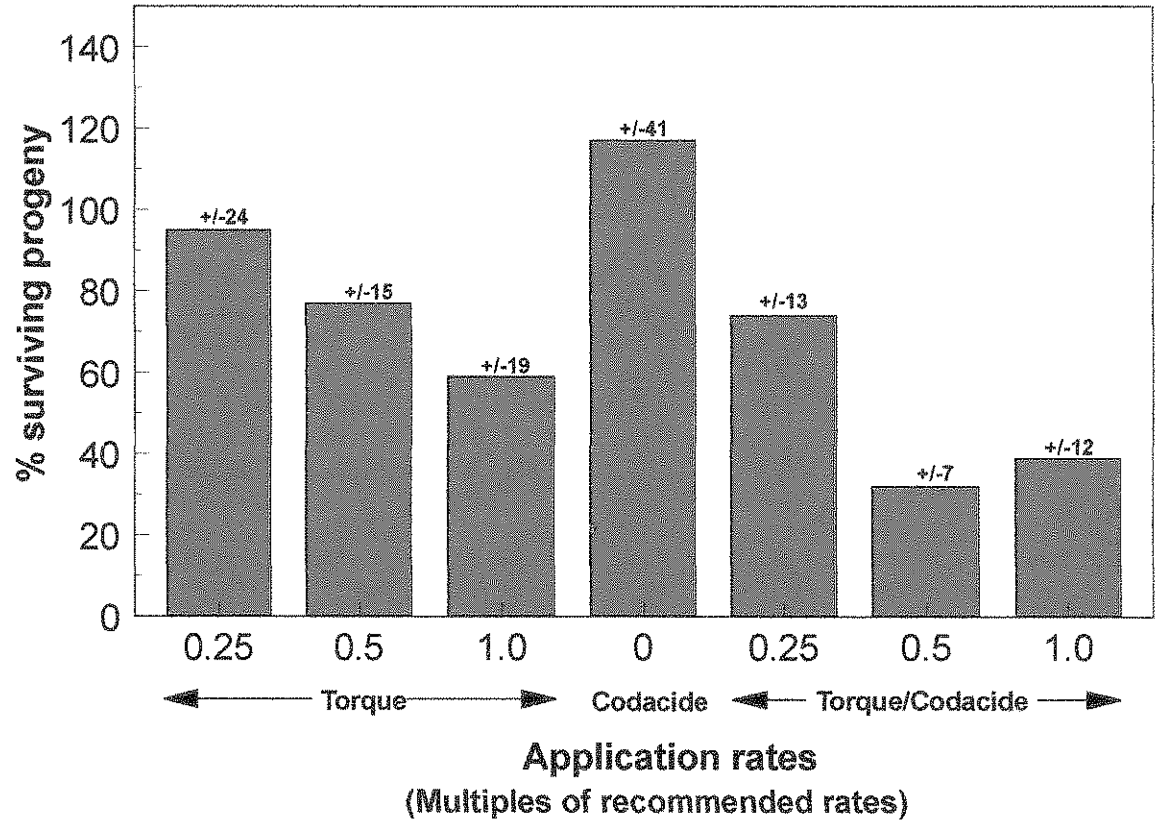
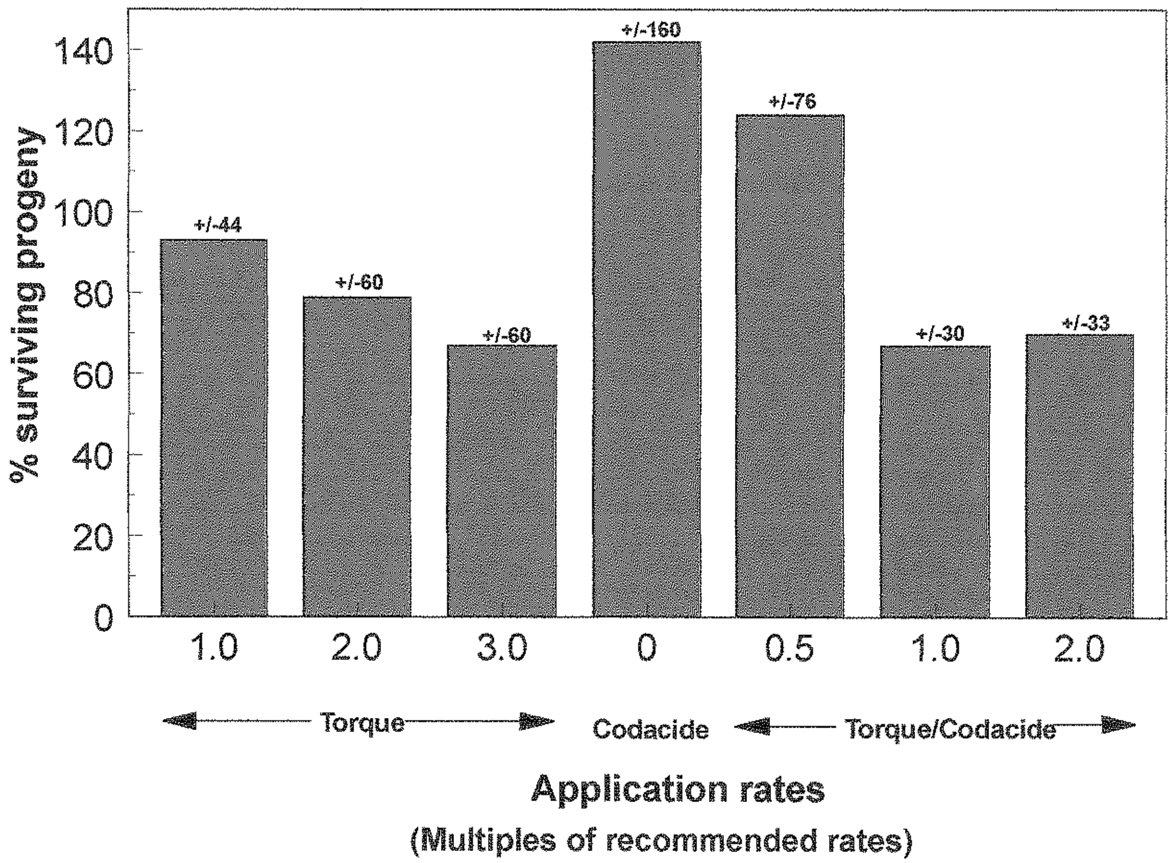


Fig.12. The effects of Torque +/- Codacide on one population of *P.persimilis* (values are a mean percentage (+/-sd) of untreated controls, n = 4).



DISCUSSION

The reference numbers of these sections are consistent with those used for the Objectives, Treatments and Results.

1.1. Response of various spider mite populations to applications of Torque at the recommended application rate.

One of the four original populations of *T. urticae* tested (population A) showed no response to Torque at up to double the recommended application rate and must be considered to be resistant to this acaricide. The population was chosen for inclusion in the project because the mites had been extremely difficult to control on the nursery for at least six years and some level of resistance was anticipated. However, discussions with growers and consultants indicate that persistent control failures on this scale are unusual in the UK and this should be considered an exceptional population.

The numbers of progeny of two of the other collected populations of *T. urticae* (populations B and C) were reduced to 87% and 96% of untreated controls following application of the recommended rate of Torque. This is an acceptable level of control and both populations may be considered susceptible to the chemical. Neither population was known to have survived treatments in crops.

Significantly more progeny of the fourth population (population D) survived application of the recommended rate of Torque than either population B or C, and it may be considered partially resistant to the chemical. This was consistent with the history of this population which had been difficult to control in commercial crops.

Only one population of *T. cinnabarinus* was included in the project (population E). The number of progeny of this population was reduced to 93% of untreated controls following application of the recommended application rate of Torque. This is an acceptable level of control indicating susceptibility to the chemical but not entirely consistent with reports of intermittent difficulties on the nursery of origin.

1.2. Response to Torque of populations of spider mites cultured from survivors of exposure to the acaricide.

Tolerance to Torque increased significantly in two of the *T. urticae* populations following exposure to the chemical. Only 13% of progeny of the collected population B survived an application of the recommended rate of Torque compared to 87% of those cultured from the survivors of a single exposure (population B1). Similarly, 35% of the original population D survived compared to 71% following exposure (population D1). A similar response to exposure to Torque was noted with *T. cinnabarinus* (population E) except two exposures were required before survival was enhanced (population E2). However, such a response was not observed in all cases; no increased tolerance was noted in population C following exposure to Torque.

The rapid change in the resistance status of populations B, D and E indicated that tolerant individuals were already present in these populations and they were selected for by application of the chemical. Such a response may have been anticipated for population D and E because they had been subjected to repeated use of the chemical over recent years. However, the result was more surprising for population B which had not been exposed to Torque for at least six years.

There is a strong indication that resistant populations revert to more susceptible status when the chemical selection pressure is relaxed. For example, one population (population D1) was tested after a recent exposure to Torque, and then kept in culture for 16 weeks before being re-tested. The first test showed 71% survival of progeny at the recommended application rate, indicating a significant level of tolerance to Torque. However, this had declined to 20% after 16 weeks (Figure 13). There were similar results with double rate Torque on the most tolerant population (population A1); the first test showing complete survival, declining to 59% after 16 weeks in culture (Figure 14). These observations are consistent with reports of cyhexatin (another organotin acaricide) resistance reversion in colonies of *T. urticae* on pears in California (Flexner et al., 1988).

Reversion of resistance to cyhexatin has been attributed to differences in the fitness of the resistant and susceptible colonies. The susceptible mites have shorter development times and higher percentage survival and therefore dominate the population in the absence of selection pressure from the chemical. Moderately resistant populations have reverted to susceptibility in three to six generations (Flexner et al., 1989).

It is therefore possible that the resistance status of some spider mite populations on commercial nurseries could fluctuate considerably during a single season depending on recent exposure to the chemical. This could explain why growers have experienced intermittent difficulties with Torque without the development of complete and widespread resistance.

Fig.13. Decline in tolerance of a "susceptible" *T.urticae* population in the absence of Torque for 16 weeks (values are a mean percentage of untreated controls).

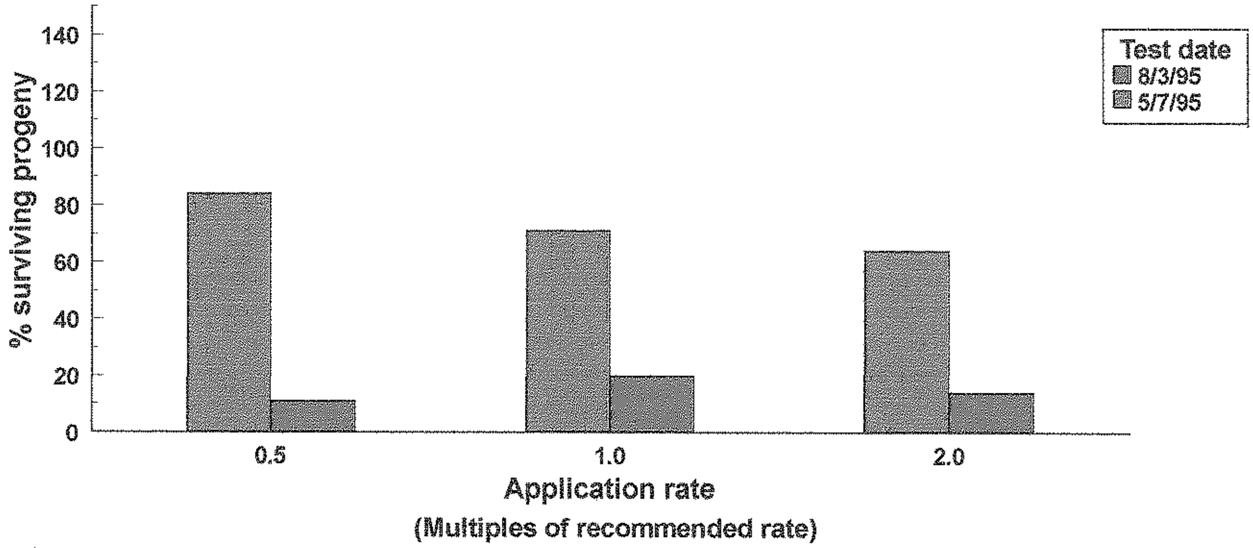
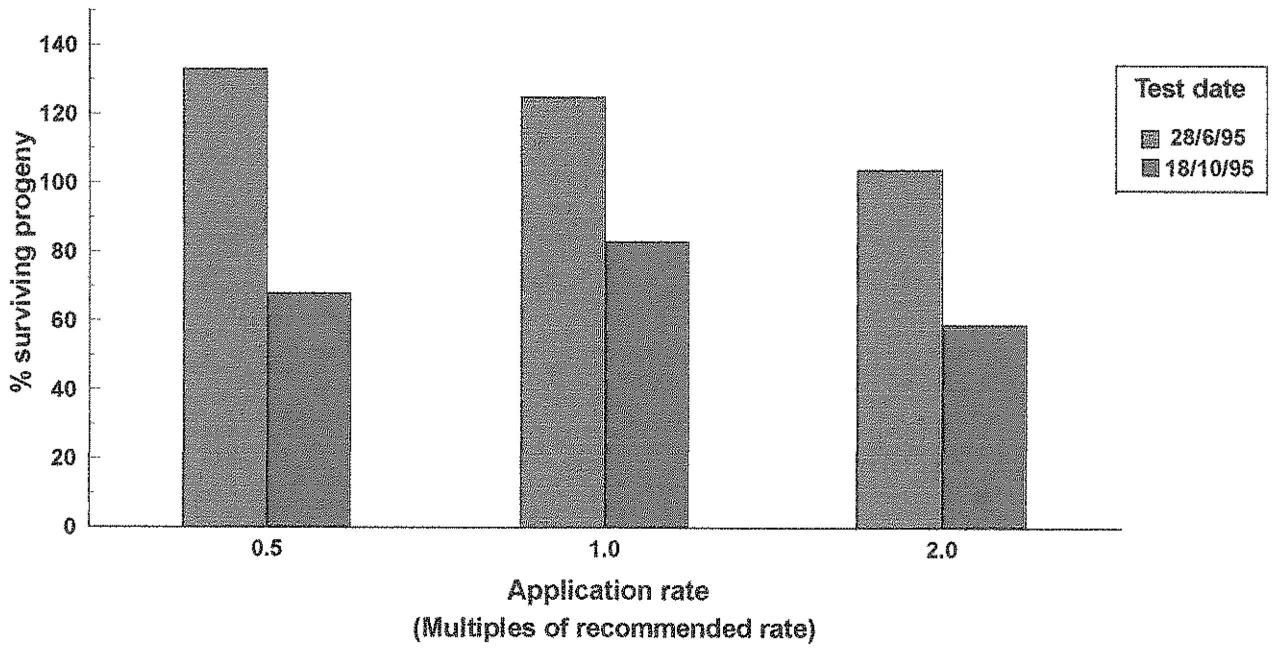


Fig.14. Decline in tolerance of a "resistant" *T.urticae* population in the absesnce of Torque for 16 weeks (values are a mean percentage of untreated controls).



1.3. Effect of rate of application of Torque on various populations of spider mites.

Three of the four original *T. urticae* populations (populations A, B and C) showed no additional response to Torque when the application rate was increased from half to double the recommended rate. The fourth population (population D) showed no additional response at up to the recommended rate but a significant reduction in survival of progeny at double rate.

The original population of *T. cinnabarinus* showed a significant reduction in survival of progeny between half and recommended application rates but no further response up to double rate.

None of the populations which had been recently exposed to Torque (A1, B1, C1, D1, E1 and E2) showed any additional response when the application rates were increased from half to double the recommended rate.

It had been suggested that the recommended rate of Torque (50g product per 100l water) was too low and that improved control would be achieved at the higher rate of 75g/100l but this was not substantiated by these results. In ten of eleven cases there was no advantage in doubling the rate from that recommended.

1.4. Effect of Torque on *P. persimilis* and related observations.

There were large differences in fecundity between individual *P. persimilis* within the stocks received from all three suppliers. As a consequence, the results had large variations and no statistically significant differences were found. These problems may be partly explained by the weather conditions at the time of delivery. The predators are known to be vulnerable to extremes of temperature and it is possible that they suffered heat stress at some stage of their journeys.

There were also large differences in mean fecundity of predators from the three suppliers. The *P. persimilis* from producers X, Y and Z laid an average of 1.6, 0.4 and 1.0 eggs/mite/day respectively during the 5 days post-delivery. These observations have implications well beyond the results of this experiment. It is clear that predators which produce four times as many eggs per day should become established in crops more rapidly and therefore control spider mite populations more quickly.

Although the results were not significantly different, there were trends worthy of discussion. The survival of all strains of *P. persimilis* declined as the rate of application of Torque increased; at three times the recommended rate the survival of progeny of populations X, Y and Z were reduced to 13%, 14% and 22% of the untreated controls respectively. However, it is the response to the chemical at the recommended application rate which is most relevant to the control of spider mites in commercial situations; at this rate survival of populations X, Y and Z was reduced to 55%, 39% and 39% respectively of the untreated controls. This was poorer than anticipated and certainly poorer than experienced in subsequent tests with population X, when 93% of progeny survived the recommended rate. The latter was done when conditions were cooler and the mites less likely to have suffered stressful conditions during transit.

These observations have prompted further studies into the quality and performance of biological control organisms with particular regard to deterioration during transit.

1.5./ 2. Effects of pre-mixing Torque with Codacide

1.5. Preliminary experiment in stage 1 of the project.

The results of the preliminary experiment in stage one of the project demonstrated that pre-mixing Torque with Codacide significantly enhanced the acaricides effect on a population of *T. urticae*. Survival of progeny was reduced from 41% to 6% at half the recommended rate of Torque, and from 45% to 5% at the recommended rate. When used alone, the adjuvant had no effect on spider mite survival.

2.1. Effect on a more resistant population of *T. urticae*

This experiment was instigated to determine whether pre-mixing Torque with Codacide would enable the acaricide to be used more successfully against the most resistant population of *T. urticae* (population A). However, these mites were not controlled, even when treated with twice the recommended rate of Torque with Codacide.

2.2. Effect of low rates of Torque on the most susceptible population of *T. urticae*.

This experiment was instigated to determine whether pre-mixing Torque with Codacide would enable the acaricide to be used successfully at rates lower than that tested in the preliminary experiment.

As in the preliminary experiment (section 1.5.), Codacide significantly enhanced the effect of Torque at half recommended and recommended rates. However, there was no significant response at quarter rate.

2.3. Effect on *P. persimilis*.

Pre-mixing Torque with Codacide had no additional detrimental effect on the survival of *P. persimilis* thus demonstrating that the control measures are compatible.

The susceptibility of other biological control agents used in IPM programmes in protected crops should also be determined.

CONCLUSIONS

The reference numbers of the following sections are consistent with those used for the Objectives, Treatments, Results and Discussion.

1.1. Response of various spider mite populations to applications of Torque at the recommended application rate.

There were significant differences in the response to Torque of *T. urticae* populations from different sources. One population was resistant, another partially resistant and two susceptible to the acaricide; in all cases reflecting the degree of difficulty encountered in controlling the pests on the nurseries of origin.

Failures to obtain control of *T. urticae* in commercial crops have often been attributed to poor application techniques but these results show that resistance to the chemical does exist and must be taken into consideration.

1.2. Response to Torque of populations of spider mites cultured from survivors of exposure to the acaricide.

Tolerant individuals may be present in populations which are apparently susceptible to Torque.

Survival of Torque treatments increased significantly in three of four spider mite populations tested following exposure to the chemical.

Resistant populations revert to more susceptible status when the chemical selection pressure is relaxed.

The resistance status of some populations in commercial crops could fluctuate considerably during a single season depending on recent exposure to the chemical.

1.3. Effect of rate of application of Torque on various populations of spider mites.

Where growers are having difficulty controlling spider mites with Torque, the problem is unlikely to be resolved by increasing the application rate within sensible limits.

1.4. Effect of Torque on *P. persimilis* and related observations.

Survival of *P. persimilis* exposed to Torque at the recommended application rate ranged from 39% to 93%. The variation may have reflected the quality of the materials tested.

There did not appear to be any additional risk to *P. persimilis* when the rate of application of Torque was increased to double that recommended. However, survival was lower at triple rate.

P. persimilis may be more susceptible to Torque under stressful conditions. This has important implications for their success in commercial crops and should be investigated further.

1.5./ 2. Effects of pre-mixing Torque with Codacide

Premixing Torque with Codacide enhanced the effect of the acaricide on susceptible populations of spider mites and provided acceptable control at rates above half that recommended.

Premixing Torque with Codacide did not provide adequate control of the most resistant population tested.

Pre-mixing Torque with Codacide had no additional effect on the survival of *P. persimilis*.

RECOMMENDATIONS

This series of experiments has shown that resistance to Torque is a reality among spider mite populations in protected edible crops in the UK. It is vital that this is managed carefully to prevent the development of complete and widespread resistance to this important acaricide.

The adoption of the following strategy should prolong the useful life of the chemical:

1. Over use of the acaricide should be avoided.

2. In chemical based control programmes, Torque should not be used continuously but in rotation with Approved acaricides with a different mode of action.

3. In IPM systems the predatory mites, *P. persimilis*, must be used as the principal control measure. Torque should be used only in difficult circumstances to redress the balance between the pest and predator. If possible, treatments should be restricted to localised areas of crop or specific parts of the plants (eg just the tops).

4. Application rates must not exceed 50g Torque per 100l water. There is no evidence to suggest that higher rates will improve the level of control and it is more important to ensure that very good spray coverage is achieved.

5. If treatments have failed and there are no obvious explanations, the resistance status of the population should be confirmed by laboratory bioassay. This will establish whether the problem is due to resistance or some other cause, such as incorrect application. Contact Rob Jacobson at HRI, Stockbridge House for further details.

6. Where resistance is confirmed by bioassay, Torque should not be used again until a re-test shows that the population has reverted from being predominantly resistant to susceptible.

7. Premixing Torque with Codacide should enhance the performance of the acaricide against all but the most resistant populations of spider mites.

   Growers should not be tempted to use lower than recommended rates of Torque when applying the chemical with Codacide.

   The product label recommends that Torque is not used with adjuvants and Zeneca Crop Protection say this could lead to plant damage. Crop safety was not examined in detail in this project and any use of Torque with Codacide is entirely at the user's risk. Growers are therefore advised to test the mixture on a few plants before making a full crop application.

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