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Problems of resistance of spider mites against miticides

In previous European Mite Symposia I have had the honour of introducing the discussion on resistance problems of mites. The organizers of this Symposium have asked me again to take over this charge, which I have accepted in spite of the fact that I cannot submit a substantial contribution of my own research work to you.

In 1962, at the last European Mite Symposium in Lausanne (GASSER, 1962) we discussed the definition of resistance and tolerance, the genetics, biology, and ecology of resistant strains with all the contradictory observations, which are difficult to explain. Furthermore, we spoke about vigor-factors and the influence of the host plants on mite population, and finally we discussed the control of resistant spider mites and the way to keep the activity of the existing poducts as long as possible.

What has happened in the field of resistance since 1962?

I think the situation has gotten even worse, especially during the dry year of 1964. The resistance of *P. ulmi* K. and *T. urticae* K. against phosphate insecticides-acaricides, as well as against selective acaricides, spread out in all intensively cultured orchards, in vineyards, in hop plantations and in flower cultures (MATHYS, 1965). Frequently cross-resistance is observed between acaricides of the same chemical group, as well as of compounds with no chemical relation. As a matter of fact it is often very difficult to predict the success of an acaricide against resistant mites.

For this reason DITTRICH (1962) proposed the institution of mobile laboratories with the possibility of testing resistance and cross-resistance of mites in a given orchard and thus to determine the control measures in a short time. Besides these more practical aspects the examination of the spectrum of resistance and cross-resistance of a great number

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of mite strains under known conditions could perhaps increase the theoretical knowledge of the resistance problem.

I think that at the moment there is no acaricide on the market which does not show somewhere a more or less pronounced resistance, mainly arisen from cross-resistance. However, this cross-resistance is unpredictable. The fact that certain phosphate-resistant strains of *P. ulmi* may be sensitive to a new phosphate, whereas other strains are resistant right from the beginning, can always be observed. Ultracide, for example, showed only a weak effect on resistant strains in the Rhone-Valley, but gave excellent results in certain orchards on phosphate-resistant strains in France and in South Africa. Another example is the sensitivity of these Rhone-Valley strains to chlorobenzilate and chloropropylate (GASSER and GROB, 1963). Tests carried out in 1952 proved a clear superiority of chlorobenzilate, whereas the results noted in the same region 10 years later were in favour of chloropropylate, in spite of the fact that in the meantime mainly phosphate had been used.

Concerning cross-resistance, HANSEN et al. (1963) came to the following conclusions: Malathion and methyl-demeton are the strongest selectors, selecting not only for high levels of phosphate resistance, but also producing slight resistance to chlorobenzilate, Aramite and Kelthane. On the contrary, chlorobenzilate was the weakest selection agent, influencing phosphates and Kelthane. Parathion is the easiest, chlorobenzilate the most difficult to select against. Every selection agent increased parathion resistance. Some selection agents are more efficient in selecting for resistance to chemically unrelated or related compounds than to themselves. Kelthane for example is a more effective selector for producing methyl-demetone resistance than it is for Kelthane-resistance. It is even more effective than methyl-demetone in selecting methyl-demetone resistance. This is also the case for parathion and malathion resistance. Methyl-demetone selection produces higher levels of resistance to parathion and malathion than these products themselves. Some of the selection agents appear to have reciprocal selectivity, as for example, Aramite, which raises the level of phosphate resistance and vice versa. With other selecting agents this reciprocity is lacking, as they select only in one direction. The selection with chlorobenzilate raised the Kelthane resistance slightly, but Kelthane selection had no influence on chlorobenzilate resistance. The same relationship exists between Aramite and chlorobenzilate. WATSON et al. (1963) found a strong cross-resistance between the selecting agent parathion and sulfotepp, a related phosphate acaricide, and a lower level of cross-resistance or vigor tolerance to chemically unrelated compounds such as Kelthane. JEPPSON (1963) describes cross-resistance of different selective acaricides and organophosphates on citrus red mite as well as on the pacific mite. The only acaricides which did not develop an apparent resistance on these two mite species were 2-cyclohexyl-4,6-dinitrophenol and its dicylohexylamine salt, which have both been used for many years on citrus in Florida and California.

One method of controling cross-resistance in mite populations is the combination of different acaricides, which can have not only an additive, but also a potentiation effect. In our tests we observed such potentiation with chloropropylate + tetradifon or with ultracide + + chlorobenzilate. If these combinations permit the retention of the activity of the one or the other acaricide, they cannot prevent the development of resistance as shown by the tests of ASQITH (1962). A Kelthane-resistant population of *P. ulmi* in a Pennsylvanian apple-orchard showed resistance to Kelthane and Tedion, but not to the mixture, although probable development of resistance to it after exposure for a few more generations was indicated. Five trees, receiving the mixture of Kelthane and Tedion within four successive seasons showed resistance in varying degrees. Five trees, receiving alternate applications of the two products during four season, showed degrees of resistance on four, but none on the fifth tree. Similar observations have been made with Dimethoate, Tetradifon-Dimethoate mixtures and Dimethoate-Kelthane mixtures (ASQUITH, 1964).

In 1965, my colleagues Dr. H. GROB and M. A. RUZETTE compared some experimental compounds with about 20 commercial acaricides and acaricide combinations in two locations of the Rhone-Valley. The resistance and cross-resistance status showed a remarkable change since 1963, which was probably favoured by the good breeding conditions during the dry year of 1964.

Once the infestation had started, by the end of June or beginning of July, the invasion could not be stopped by one single treatment with a product or combination, and only a few products showed a sufficient effect after two treatments within 10 days.

This situation is probably not only characteristic for the Rhone-Valley and it is obvious that other control methods must be studied. During the last years, numerous antimitotic substances have been tested as chemosterilants for insects, especially by co-workers of USDA (LINDQUIST, 1961).

If we consider that male spider mites are haploid and are produced only by unmated females or from unfertilized eggs of mated females, a chemosterilant treatment may be particularly interesting in preventing females from producing female progeny. SMITH et al. (1965) report on results of investigations carried out in order to determinate the response of *T. telarius* and *T. cinnabarinus* to apholate. Untreated females of *T. telarius*, mated with males dipped into 0,5 % apholate in a alcohol-water solution, produced male progeny and dead eggs, but no female progeny. Females exposed to a 2 % apholate dip produced no viable eggs. Adult females feeding on lima bean seedlings previously dipped into 1 % aqueous apholate ceased oviposition after a few days and became sterile. Most adult males fed for 24 hours on apholate treated foliage were sterilized. Females, which had been allowed to feed on residues of apholate and which had then been mated with normal males laid fewer eggs, of which numerous were sterile. Some females of this progeny developed apholate sterile characters, though they had been reared from eggs laid on untreated foliage. Apholate residues on foliage have an adherence of at least 4 days.

In order to determine the variation in different mite strains, the prevention of population build-up of 3 resistant strains and one non-resistant strain of *T. telarius*, as well as a non-resistant strain of *T. cinnabarinus*, was compared on apholate treated lima beans. There was only a slight variation of these strains.

These results are rather optimistic. However, we know that in tests carried out with antimitotic compounds on insects big differences in sensitivity of various strains have been observed and that resistance had already occurred.

As shown by HARRIES (1960, 1961, 1963) the oviposition of *T. telarius* and *P. ulmi* can also be inhibited by fairly low concentrations of a number of antibiotics, as for example cycloheximide and its several derivatives, streptovitacin A, Antimycin A, Hygromycin B, amphotericin and cytovirin. At higher concentrations, the antibiotics caused some mortality of the adult mites, especially antimycin A. The most active materials, for instance cycloheximide and cytovirin, showed systemic activity, but were phytotoxic on peaches, apples and pears. The mode of action of the antibiotics in sterilizing the mites is unknown. They may act directly by interfering with some process necessary for the division and growth of egg cells or elimination of the gut essential flora and fauna or some intracellular symbiontes which may be necessary in the synthesis of proteins or other metabolic essentials, such as enzymes, vitamins or hormones.

Considering that chemosterilants, if they are of practical value, would encounter the same difficulties from the resistance as well as from the toxicological and residue standpoint, as is the case for acaricidal compounds, radiation methods have also been initiated. HENNEBERRY (1964) reports on tests where *T. telarius* were exposed to gamma radiation from a cobalt-60 source, which delivered approximately 280 r/min. If this method has only theoretical value for the control of spider mites for the moment, the results are nevertheless interesting. Females, mated to gamma-irradiated males produced fewer female progeny and more non-viable eggs as the dosage of radiation increased. At a dosage of 32 kr male progeny and non-viable eggs, but no female progeny, were obtained. Virgin females exposed to gamma radiation and mated with untreated males produced fewer males and females, as the dosage increased from 1 to 24 kr. After exposure to 32 kr they produced only non-viable eggs. Surviving female progeny of males irradiated at 8 kr or more were incapable of reproduction. Female progeny of males irradiated at only 2 or 4 kr produced fewer males and females and more non-viable eggs than female progeny of untreated parents. Sperm inactivation or death of males was observed at doses of 96 kr and above.

At our last meeting we also discussed the influence of plant nutrition on the increase of mite populations, i.e. the indirect influence of pesticides on the physiological behaviour of the host plants. Since then, research on these questions has produced no progress. Only HENNEBERRY (1963) has reported, in continuation of his earlier work (HENNEBERRY, 1962), that fecundity of *T. telarius* on lima beans was positively correlated with absorbed nitrogen and negatively correlated with absorbed phosphorus and total carbohydrate present in the leaf tissue. More mite progeny were produced on leaves left intact on plants than on discs excised from the same plants with lesser nitrogen and higher phosphorus content. These observations may probably explain some contradictory results of previous publications as regards differences in the behaviour of mites on different host plants or different varieties of the same host plant.

The influence of the carbohydrate level probably needs a more thorough investigation of its qualities. FRITSCHE, 1960, observed that the contents of the reducing sugars in the leaves of host plants play an important part in the rate of propagation of *T. urticae*. EBERHARDT and Voss (1961) showed that *T. urticae* possess a number of glucosidases, which are capable of hydrolysing various carbohydrates. Mehrotra (1963) found out that the two-spotted spider mite also contains all the enzymes, except lactic dehydrogenase, which are necessary for a successful utilisation of hexose phosphates through Embden-Meyerhof and the hexose monophosphate pathways. The occurrence of some of the enzymes of the Krebs' cycle in the two-spotted spider mite have also been shown. The knowledge of the existence of these various metabolic pathways is of great significance for the understanding of the physiology and host specificity. The possibility of various ways for the metabolism of carbohydrates permits the mites to adapt themselves to varied situations. This is also the case in the build-up of resistance.

Matsumura and Voss (1965) have shown that malathion carboxyesterase found in a cross-resistant strain of *T. urticae* has hydrolytic activities against malathion, malaoxon, parathion and a number of naphthyl- and nitrophenyl-esters. Esterases, which are capable of hydrolysing α-Naphthylacetate in *T. urticae* have also been found by Smissaert (1965); this fact is of importance in the alteration of organo-phosphate sensitivity.

As concerns the genetics of resistance, Dittrich (1963) came to the same conclusions as the one reported by Dr. Helle at our last symposium. The surprising result of his work was the discovery that resistance could be attributed to two separate genetic systems: whilst one could be removed by inbreeding, the other became apparent by the same process. Two distinctly separable classes of animals were present in his tested population. The presence of such distinct classes is generally considered to be evidence of the operation of a single genetic factor.

What are the conclusions which must be drawn from all these observations and studies?

All the acaricides, which have been developed to date select resistant strains of mites. At the same time most of them produce cross-resistance. This situation could only be changed if the industry developed effective acaricides to which the mites are not able to develop resistance or by the development of negatively correlated acaricides selecting resistant strains which are very susceptible to another acaricide. This task will not be an easy one for the industry and for this reason we all should try to extend the activity of the existing acaricides. There are perhaps some possibilities.

Compounds which easily cause cross-resistance, as can be concluded from the observations of HANSEN et al. and WATSON et al., should be eliminated from the spray program.

We should really give up the idea that we can tolerate mites up to a certain level, as long as this level is below the damage limit. Under favourable conditions an unexpected increase of a mite population in a moment when all mite stages are present on the leaves suddenly needs control measures. At this moment, the control is only effective with the best product for the given strain, which, however, very often is not known. It should be applied repeatedly and in high concentration in order to kill all the different development stages, in spite of the possibility that applications do not fit into the normal or the integrated spray program at this moment. Repeated treatments at the moment of hatching of the winter eggs of the European red mite will be more successful than the summer treatments. For *T. urticae* the treatment of weeds in the orchards against the first generation or the destruction of the weeds by herbicides is the practical consequence for an effective control.

My conclusions may be unexpected, as they are not in favour of an integrated spray program, which, some years ago, I believed to be the answer to the resistance problem. I would be glad if my paper could lead to an interesting discussion on these points.

SUMMARY

This paper summarizes the present status of mite resistance and the different trends of research since 1962 as a complement to the summaries presented at the previous European Mite Symposia.

Since 1962 mite resistance continued to spread out in the European countries, but remained restricted at all events to the species of major economic importance, such as *Tetranychus telarius* K., *T. urticae* K. and *Panonychus ulmi* (K.). The original resistance against certain phosphate compounds expanded to acaricides of the same or of other chemical groups, but the different strains show distinct and often inexplicable differences in their range of polyresistance.

Various new chemicals have been more or less successfully tested against the resistant strains. Sterilization tests by radiation or by chemosterilants were followed up, metabolism and genetic studies were continued, integrated spray programs and plant nutrition studies were tried to prevent the build up of larger mite populations.

RIASSUNTO

L'A. fa il punto sull'attuale stato della resistenza degli acari e sulle diverse tendenze della ricerca dal 1962 in poi, a complemento dei sommari presentati nei precedenti Simposi europei di Acarologia.

Dal 1962 la resistenza degli acari ha continuato a diffondersi nei paesi europei pur rimanendo ristretta alle specie di maggior importanza economica, quali *Tetranychus telarius* K., *T. urticae* K. e *Panonychus ulmi* (K.). La primitiva resistenza verso taluni composti fosforati si è estesa agli acaricidi non solo dello stesso ma anche di diverso gruppo chimico, ma i vari ceppi mostrano distinte e spesso inesplicabili differenze nell'ambito della loro poliresistenza.

I numerosi nuovi composti sperimentati contro i ceppi resistenti, al fine di prevenire la costituzione di massicce popolazioni di acari, hanno avuto maggior o minor successo. Fra le prove e gli studi l'A. ricorda la sterilizzazione con radiazioni o con chemiosterilizzanti, gli studi sulla genetica e sul metabolismo delle piante, i programmi di lotta integrata e le ricerche sulla nutrizione delle piante.

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DISCUSSION

UNTERSTENHOFER: 1) Do you know resistance of mites against dinitrophenols?

2) Have you experiences with antiresistants?

GASSER: 1) We know only by personal information of USA, that Binapacryl gave already resistance.

2) The known antiresistants did'nt show any effect on our resistant strains.

DITTRICH: Could the speaker give an example of potentiation between two acaricides?

GASSER: I gave the example of the mixture of chlorobenzilate + tedion. The two products applied separately did'nt give an effect. But the combination of the two products had a good effect as well as on eggs as on postembryonic stages.

GUNTHART: Which chemicals give cross-resistance and should be suppressed in the spray program?

GASSER: I would refer to the paper of Hansen et al. and Watson et al. and leave it to you to draw the conclusions.

GRASSI: From an industrial point of view, perhaps it is better to recommend specific pesticides which have mite depressant properties and to revert to the use of specific acaricides in the case of emergency only.

GASSER: But also selective and suppressant compounds can induce cross resistance.

UNTERSTENHOFER: It seems to me that it exists a correlation between carbamate fungicides and carbamate insecticide-acaricides.

DITTRICH: Dr Unterstenhöfer pointed out that there are acaricide resistant strains on hops in southern Germany that were never treated with acaricides. This could be consequence of cross-resistance produced by fungicide treatments since many fungicides have acaricidal effects.

HELLE: Our working hypothesis mainly deals with resistance as a response on selection. But I think that interpopulational variability is also worth to be considered in this respect.

STEINER: In einer Apfelpflanzung bei Stuttgart wird seit 1957 ein modifizierter Spritzplan verwendet. Bis heute blieb dort die Population von *P. ulmi* unter der wirtschaftlichen Schadenschwelle. Deshalb ist es für die Praxis in diesem Fall uninteressant, ob die Spinnmilben resistent sind oder nicht.

GASSER: Es ist aber zu bedenken, dass alle chemischen Eingriffe, die notwendig werden zur Bekämpfung von Insekten und Pilzen, zu Crossresistence führen können.

UNTERSTENHOFER: It would be very interesting for me to know the limit of damage. Is it the number of mites, the time of infestation?

GASSER: We do not know the damage limit in spring time. In summer time it seems to be around 25.

STEINER: Unsere Versuche finden in einer Erwerbsobstanlage von 40 ha statt, in der wir uns keinen starken Schädlingsbefall, auch nicht von Blattläusen, leisten können.