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DISEASES INDUCED BY PROCARYOTIC PATHOGENS

Towards an Integrated Management of Citrus Greening Disease

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ABSTRACT. During the past two decades, reliance on insecticides and chemotherapeutic compounds for controlling the psyllid-borne citrus greening disease (CGD) has led to the neglect of nonchemical methods. Integrated management based on chemical, biological and environmental actions should be developed. The impact of intervention must be evaluated with reliable epidemiological indicators in order to assess or eventually revise the whole strategy of control.
Index words. chemical, biological and environmental integrated methods, psylla vectors, greening organism (GO).

The incidence of citrus greening disease (CGD), a psyllid-borne bacterial malady, is becoming very high in many countries of Africa and Asia. Nowadays, CGD has a great socioeconomic impact in the African countries south of the Sahara, as well as in the Middle East and Southeast Asia. Official estimates indicate that at least 10 million trees have been destroyed in the Philippines and Indonesia alone in established orchards (1, 10) and more than 1 million trees were lost in the southeastern part of Africa. But the overall figure is probably closer to 50 million trees. Recent experience shows that new spread of the disease could have been reduced by appropriate environmental safeguards. Transport of contaminated plants, for instance, has been one of the major factors of disease spread into new areas.

During the two past decades reliance on insecticides for controlling the psylla vectors, and on chemotherapeutic compounds for curing the greening organism (GO) has led sometimes to neglect of nonchemical methods. Indeed, biological techniques will often prove more difficult to implement than chemical ones, and their outcome is somewhat less predictable in the immediate future.

Full chemical control of CGD has occasionally sustained competitive citrus production within intensive farming (e.g. large estates in southern Africa), but these techniques are most often beyond the reach of small farmers and they have not been applied as successfully in Asia. Scarcity of citrus fruits in many countries has brought about the proliferation of poorly managed nurseries, sometimes resulting in a dramatic upsurge of CGD. There is a real threat that CGD will expand and reach new citrus areas if integrated pest management (IPM) is not carefully applied.

IPM relies on three main categories of action: chemical, biological and environmental. In the case of an insect-borne disease, the target is to reduce vector populations and their contact with infected host plants. IPM is making full use of all available methods of control, including environmental management. The impact of intervention must be evaluated with reliable epidemiological indicators, and the whole strategy must be reassessed or revised if no appreciable reduction of disease transmission is occurring.

EPIDEMIOLOGICAL ASPECTS

Rate of expansion. In spite of short outbreaks of its psylla vectors during spring flush, CGD is a fast expanding disease. In Reunion Island for instance, where disease-free planting material was distributed in the 1960's, 70% of the trees became unproductive 6 yr after planting, and the annual rate of contaminated plants recorded every year, increased exponentially (2).

Recent evidence obtained from Saudian and Nepalese citrus orchards has shown that entire economic loss of mandarin and orange trees takes place within the 6-8 yr following a psyllid-borne CGD invasion (4, 8).

Epidemiological indicators. Epidemiological evaluation is an essential element for conducting an IPM programme in contaminated areas and making correct interpretation of the operational control activities.

Reliable and accurate epidemiological indicators can be used for both the disease and its vectors. They include:

1) The use of proportional scale for canopy rating of the symptoms on target trees or target orchards (2).
2) Several techniques of sequential sampling of insect vectors in target areas, using yellow traps with sticky bands (9), or mouth aspirator techniques (3), or even vacuum aspirator procedures. Mark-release-capture techniques could also be tested. The aim is to obtain the best possible assessment of the current psyllid situation, and detect changes in vector outbreaks.

Regular monitoring of both greening symptoms and vector population is essential whenever an IPM plan is being developed.

Epidemiological circumstances. Proper and efficient IPM relies on the knowledge of local ecosystems. Environmental modifications or manipulations can be decided according to the complex of insects and plants which interact in a given situation.

The final strategy should be adapted to specific cases, and among factors to take into account are:

1) Whether the existing inoculum is strictly localized or wide spread
2) Presence or absence of wild rutaceous plants for psylla build-up
3) Presence or absence of parasites/predators attacking the vectors
4) Presence or absence of secondary parasites
5) Climatic conditions regulating the psylla outbreaks and the symptom expression of the disease.

In fact, all the interacting factors that cause the psyllids to build up and become infected should be evaluated, since the vectoring capacity of the insect is directly responsible for the spread of the disease.

CHEMICAL APPROACH

Insecticidal control of the vector. Citrus psylla populations fluctuate violently and are usually at their highest peak for a short period of time during spring flush. Insecticidal control of the vector can be organized rapidly at critical periods, and produce quick results at reasonable cost. Systemic insecticides such as dimethoate, methyl demeton, phosphamidon, monocrotophos or aldicarb are effective against larval and adult stages. Soil applications are generally deleterious to nontarget insects, i.e. natural enemies, and provide a safer protection of foundation stocks, nursery trees or young orchards. Aldicarb applied at 0.75 g/m^2 will provide insecticidal action for 4 months. Direct spraying of monocrotophos in a ring application on the trunk of the trees has also given good chemical protection at low cost (6).

Antibiotic therapy. Symptom remission is easily obtained by injecting tetracycline into diseased trees. The economic life of the tree may be extended for several years. Low solubility of terramycin or tetracycline HCl, and phytotoxic side-effects, have limited the use of these formulas. A new highly purified tetracycline [N-pyrrolidinomethyl tetracycline (PMT)] with higher solubility, presently allows the versatile technique of using 20-ml syringes for injecting concentrated solutions (5), instead of the former large volumes of dilute solution applied with pressurized bottles.

The danger of relying on a strictly chemical approach is the need for repetitive treatments, and, in the long term, the risk of vector resistance to pesticides and GO tolerance to antibiotics. In fact, these methods must be incorporated within a comprehensive disease control programme integrating biological and environmental methods.

BIOLOGICAL MANAGEMENT

Increasing attention is being focused on biological techniques. This kind of approach is generally less familiar to decision makers, and therefore does not yet enter into the scope of current criteria.

Biological control of the vectors. Biological methods for controlling psyllids, consist of the utilisation of natural enemies, essentially parasitic wasps. So far, no application of microbial insecticides such as *Bacillus thurigiensis*, nor special genetic methods such as the sterile male release technique, has been successfully tried on the CGD vectors.

Parasitic wasps that attack psylla nymphs exist. The latter are quickly reduced to their exoskeleton. After casting its pupal exuvium, and discharging a meconium, the adult parasitoid wasp will cut its emergence hole through the mummy of the nymph. Both the exit hole and the meconium are typical of a given wasp species.

Many ecological factors make it difficult to achieve substantial reduction in psylla populations by biological methods alone. Nonetheless, the recent introduction of two *Tetrastichus* species into Reunion and Mauritius Islands resulted in the successful establishment of these active ectoparasites with a subsequent sharp reduction of the outbreak of *Diaphorina citri*, the Asian vector, and the elimination of *Trioza erytreae*, the African vector (3). This success was due mostly to the absence of secondary parasites attacking these *Tetrastichus*. The active searching behaviour of these chalcidoid insects has indirectly prevented the spread of the GO biomass, because of the drastic reduction of the two psylla vectors (2). Percentages of parasitized psylla nymphs rose from virtually zero to 95%. These results were obtained with an initial release rate of 30 to 50 adults wasps per km^2 of citrus area.

The introduction of exotic natural enemies and their inundative release is likely to reduce psylla buildup in the countries deprived of efficient chalcidoid parasites and not harbouring secondary or tertiary hyperparasites.

Breeding citrus for resistance to greening. CGD badly affects the most popular varieties of oranges, mandarins, tangelos and grapefruits. However acid citrus, especially limes, have been found more tolerant. A breeding programme was initiated using lime trees as female parents, particularly the monoembryonic Tahiti lime. Edible hybrids close to oranges or mandarins, and fairly tolerant to CGD have been obtained (7). Other breeding programmes using backcrosses with trifoliate orange are also under way, and seem to give promising results at least in the case of the African greening.

Genetic engineering. Proteins exist that can inhibit or kill the GO. If genetic engineering succeeds in incorporating foreign genes into host plant and coding for such proteins, resistance against GO might be obtained (4).

ENVIRONMENTAL MANAGEMENT

Environmental management must be applied in conjunction with other control methods as a component of the integrated control strategy. It requires a planning of man's activities for preventing vector propagation and plant-vector-pathogen contact.

Nurseries and foundation stocks. Several countries have been contaminated recently by the introduction of infected nursery trees harbouring the GO and/or its vector(s). Strict control of nurseries through registered disease-free certification scheme is essential for avoiding the spread of CGO.

Healthy foundation stock is a prerequisite for launching a citrus rehabilitation programme, since CGD is graft-transmissible.

Transport of nursery trees from contaminated to healthy areas must be prevented.

Planning orchard situation for zooprophylaxis. There are circumstances where the vector habitat is widespread. However, certain rutaceous preferred host plants such as *Clausena anisata* for *Trioza erytreae,* and *Murraya paniculata* for *Diaphorina citri*, must be detected. These plants may constitute large reservoirs of vectors. Such vegetation pockets and natural psylla reservoirs should be mapped in order to establish new orchards as far as possible from these areas. The use of such preferred host plants as windbreaks should be avoided. Psylla vectors are weak flyers and generally do not travel long distances in the absence of host plant continuum, except when transported by man.

Selecting climatic conditions. *Diaphorina citri* mortality increases with higher rainfall and relative humidity, but is very low under hot and dry climates. Therefore, *D. citri* seasonal fluctuations will be greater under monsoon climates with an important rainy season, and proper timing of insecticide applications might prove more effective in wet climates.

Trioza erytreae, on the contrary, cannot establish itself in hot and dry climates and thrives only in cool and humid areas. In Africa, citrus orchards should be established at low or middle elevation where *T. erytreae* cannot breed. Furthermore, the African form of GO is inactivated under warm conditions so that appropriate selection of altitude may constitute an excellent safeguard against the disease.

Eradication. Although requiring higher initial expenditure, the cost of eradicating contaminated trees might be offset by the economic benefits arising from improved environment. Such a programme can take place for the removal of isolated pocket areas, or when the poor vector capacity has limited the percentage of contaminated plants. An eradication programme must be complete, effective, as well as socially acceptable and economically sustainable.

CONCLUSION

Simple and effective management methodologies should be integrated in the psyllid-borne CGD control programmes. The latter must be organized within multidisciplinary teams and, if possible, in the scope of an intercountry action.

Continuous expansion of CGD into traditional citrus areas is often accelerated by inappropriate cropping techniques. Ultra high-density plantings, for instance, used by many Asian farmers for compensating short production life of CGD-affected trees, have brought about intensive exchange of planting material, and higher risks of disease spread. Yet insufficient attention has been paid to phytosanitary control and environmental issues, and there is a need for training courses and technical workshops related specifically to the psyllid-borne CGD. Transfer of new ideas and approaches should assist local scientists, decision-makers and planners.

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