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TOWARDS INTEGRATED MANAGEMENT OF THE PESTS AND PATHOGENS OF CASSAVA IN AFRICA

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ABSTRACT

Studies on pathogenic agents of cultivated plants are generally organised on a binomial basis with examination of a host plant and specific parasites or pests. As cassava in Africa has few important pests and they display a limited range of biological features and relations with the host, it was feasible for ORSTOM (L'Institut française de recherche scientifique pour le developpement en coopératon) researchers to study each of them over a period of 25 years in Côte d'Ivoire, Congo and Togo and such work is currently in progress in Benin and France. The diseases and pests concerned are African cassava mosaic disease and its whitefly vector *(Bemisia tabaci)*, cassava bacterial blight caused by *Xanthomonas campestris* pv *manihotis*, cassava mealybug *(Phenacoccus manihoti)*, and cassava green mite *(Mononychelus progresivus)*. Research initially concerned only specific cassava-pathogen or cassava-pest combinations, without attention being paid to the system as a whole, despite obvious epidemic convergences resulting from a common environment, analogies between effects on the host plant and probable interactions between the various pests of the same crop. A biocenotic approach was developed to integrate the various research activities. It is aimed at analysis of the functioning of plant-pathogen and plant-pest systems and enables the design and evaluation of options for integrated management. 'Transversal' comparisons of cassava parasite models cover pathogenic agents (pests and diseases) and their variability, their biological cycles and the climatic factors affecting them, relations with the host (genetic variability, physiology and crop management), the effect of entomophagous species and entomopathogens on phytophagous pests and the integration potential of modelling. The ORSTOM studies show the complexity of the ecology of pathogenic agents and pests in the cassava biocenosis. The extent of the cassava cropping area and the variety of production situations, the variability of pests (phytophagous and entomophagous organisms) and diseases and the many interactions between the factors regulating epidemic mechanisms leads to a complex mosaic whose structure is described. The various sequences of analysis of a system of parasite constraints are shown in matrix form (variability of pathogenic agents, vectors and phytophagous organisms, host-parasite relation modes, epidemiology and population dynamics, modelling) for the various organisms investigated to date. The analysis reveals the fundamental achievements and gaps in knowledge and also the most appropriate areas for combining approaches. The body of knowledge assembled at different sites, during different periods and concerning a variety of organisms and the analysis of this knowledge show that it is not necessary at this stage to collect new information but to make a synthesis (modelling) that will open up original lines of research with combinations of approaches and solutions.

Key Words: **Cassava, pests and diseases, epidemiology and population dynamics, life cycles, host-parasite relations, natural enemies, vectors, modelling, integrated pest management, Africa**

RÉSUMÉ

Les travaux sur les agents pathogènes des plantes cultivées s'organisent le plus souvent selon une approche binomiale qui prend en compte une plante et un parasite ou une plante et un ravageur. Dans le cas du manioc en Afrique, pour des ennemis peu nombreux et qui offrent une palette très diverse de traits biologiques et de relations avec la plante, les recherches ont été conduites depuis près d'un quart de siècle par les chercheurs de l'ORSTOM (L'Institut française de recherche scientifique pour le developpement en coopératon) en Côte d'Ivoire, au Congo et au Togo et sont actuellement poursuivies au Bénin et en France. Il s'agit de la mosaïque africaine du manioc et de son insecte vecteur *Bemisia tabaci*, de la bactériose vasculaire dont l'agent est *Xanthomonas campestris* pv *manihotis*, de la cochenille du manioc *Phenacoccus manihoti*, et de l'acarien vert, *Mononychellus progresivus*. Les travaux se sont d'abord attachés aux seuls couples manioc-maladie ou manioc-ravageur, sans considérer le système parasitaire dans son ensemble en dépit de convergences évidentes dues à un environnement commun, à des analogies d'effet sur la plante hôte et à des interactions probables entre les différents ennemis de la même culture. Nous avons ici élaboré une approche biocénotique qui permet d'intégrer différentes actions de recherche, orientée vers l'analyse du fonctionnement des systèmes plante-parasites et plante-ravageurs et qui permet de formuler et d'évaluer les options de gestion intégrée de cette biocénose parasitaire. La comparaison "transversale" des modèles parasitaires du manioc aborde successivement les agents pathogènes (maladies et ravageurs) et leurs variabilités, leurs cycles biologiques et les facteurs environnementaux qui les conditionnent, les relations avec la plante (variabilité génétique, physiologie et conduite de la culture), l'incidence des entomophages et entomopathogènes sur les phytophages et les perspectives d'intégration offertes par la modélisation. Les études menées par l'ORSTOM mettent en évidence la complexité de l'écologie des ravageurs et des agents pathogènes de la biocénose manioc. L'étendue de l'aire de culture du manioc, la diversité des situations de production, la variabilité des parasites (maladies, phytophages et entomophages), la multiplicité des modes de relation entre la plante et ses satellites (parasites, phytophages, entomophages et vecteurs), le foisonnement des interactions entre les facteurs qui règlent les mécanismes épidémiques, font que la connaissance se présente sous l'aspect d'une mosaïque dont nous faisons apparaître la structure. Nous avons représenté de façon matricielle les différentes séquences d'une analyse d'un système de contraintes parasitaires (variabilité des agents pathogènes, des vecteurs et des phytophages ; modalités des relations hôte-parasite ; épidémiologie et dynamique des populations ; modélisation) en regard des différents organismes jusqu'ici étudiés. L'analyse révèle à la fois les acquis fondamentaux et les lacunes de la connaissance, mais aussi les domaines privilégiés d'une intégration des démarches. La masse des connaissances, obtenues dans des sites différents, à des périodes différentes et sur des organismes variés, ainsi que l'analyse qui en est faite, montre qu'il n'est pas nécessaire à ce stade de recueillir de nouvelles informations, mais de réaliser une synthèse (modélisation) qui ouvrira des voies de recherche originales dans le sens de l'intégration des approches et des solutions à apporter.

Mots Clés: **Manioc, parasites et ravageurs, épidémiologie et dynamique des populations, cycles biologiques, relations hôte-parasite, ennemis naturels, vecteurs, modélisation, gestion intégrée, Afrique**

INTRODUCTION

Studies on pests and pathogens of cultivated plants are generally organised on a disciplinary basis with separate examination of a host and its parasites and pests. For cassava in Africa, as there are few important pests and pathogens and a limited range of biological features and inter-relations with the crop, research has been carried out on each of them for nearly 25 years by ORSTOM researchers in Côte d'Ivoire, Congo and Togo, and currently in Benin and France. The diseases and pests concerned are African cassava mosaic and its whitefly vector *(Bemisia tabaci)*, cassava bacterial blight caused by *Xanthomonas campestris* pv *manihotis*, cassava mealybug *(Phenacoccus manihoti)*, and cassava green mite *(Mononychellus progresivus)*.

Research initially concerned only specific cassava-pathogen and cassava-pest combinations without attention to the host-pest-parasite system as a whole, despite obvious epidemiological similarities resulting from a common environment and analogies between effects on the host plant and probable interactions between the various pests and pathogens of the same crop. A biocenotic approach was developed recently to integrate the various research activities. It aims to analyse the functioning of plant-parasite and plant-pest systems and enables the design and evaluation of options for their integrated management.

An overall holistic view of the biocenoses of cassava in Africa is presented in this paper. Comparison of cassava parasite models covers both pests and pathogens and their variability, biological cycles and the climatic factors affecting them, relations with the plant (genetic variability, physiology and agronomy), the effect of entomophagous species and entomopathogens on phytophagous pests and the integration potential of modelling.

EPIDEMIOLOGY AND POPULATION DYNAMICS

These have been studied for both African cassava mosaic and cassava bacterial blight diseases and for mealybug and mite pests and is based on series of observations at plant, field and regional scale during successive crop cycles. It includes study of the spatial distribution of both parasites and phytophagous pests, and of the symptoms they cause, monitoring changes in prevalence and density in time and in the age structures of arthropod populations. *Bemisia tabaci* and the variegated grasshopper (*Zonocerus variegatus*) that spreads bacterial blight have been studied similarly.

Initial quantitative and descriptive approaches have led logically to questions concerning the nature of the pathogens and the homogeneity of populations, biological cycles, relations with the plant and the direct or indirect influence of seasonal factors. The results of these preliminary epidemiological studies led to observations, experiments and analyses aimed at explaining the functioning of the plant-pest systems.

CHARACTERISATION OF PATHOGENIC AGENTS

Parasites and pests of cassava occur throughout the tropical zone of Africa wherever the crop is grown. The great variety of ecological and epidemiological situations forms the basis of the investigation of population homogeneity, especially as mites, cassava mealybug and bacterial blight were introduced recently to Africa and may have formed populations genetically different from those in the region of origin.

The available results concerning the identity of the pathogens and the composition of pest populations reveal contrasted situations. There are sub-populations of *B. tabaci* (Burban *et al.*, 1992) and *Z. variegatus* (Le Gall *et al.*, 1995) that differ in host range, voltinism and enzyme profiles. Different biological features in different regions (Senegal and Central Africa) also suggest that cassava mealybug populations are polymorphic. The two African cassava geminiviruses, now recognised as being distinct, cause similar mosaic diseases in West Africa and East Africa and are distinct from Indian cassava mosaic geminivirus. By contrast, the available data suggest that populations of the bacterium *X.c.* pv. *manihotis* are genetically homogeneous (Verdier *et al.*, 1993) but that there are variations in pathogenicity (Grousson *et al.*, 1990) whose molecular basis has been identified (Verdier *et al.*, 1989). The application of molecular methods developed in ORSTOM laboratories in France to the biological material which has now received considerable study under tropical conditions will further refine knowledge of such intra-population variability.

SEASONAL FACTORS AND BIOLOGICAL CYCLES

Tropical climates differ from those of temperate regions by a generally more contrasted rainfall pattern with a dry season and a rainy season, generally higher temperature with more limited fluctuation and winds that are more regular in speed and direction.

Knowledge of the biological cycles of bacterial blight and arthropod pests is fundamental as they are principally related to the direct influence of the seasonal climatic factors of temperature, relative humidity, rainfall and wind. These must be considered in any attempt to regulate populations.

Close correlations between rainfall and development of bacterial blight (Daniel and Boher, 1985), green mites and the cassava mealybug have been demonstrated in the Congo, although blight epidemics occur in the rainy season and arthropod populations are enhanced by dry season conditions (Fabres, 1981). However, it is difficult to distinguish between a direct effect of rainfall on the organisms associated with the crop and indirect effects through host metabolism.

Although temperature is fairly uniform in the humid tropics, fluctuations occur and appear to have a substantial effect. In Côte d'Ivoire for instance, the development of African mosaic disease epidemics is determined by the interaction between rainfall and temperature (Fargette and Thresh, 1994). Disease distribution, together with that of the whitefly vector *B. tabaci,* into and within crops is closely dependent on wind conditions (Fargette *et al.,* 1985). In Congo, temperature has been shown to influence the biological cycles of the cassava mealybug (Le Rü and Fabres, 1987) and associated entomophagous organisms.

Although regional disparities make generalisations impossible, these findings lead to constructive proposals for improved population management (rainfall conditions, temperature and planting date, wind direction and windbreaks) for all or some of the pathogens and pests. They also lead to hypotheses which can subsequently be tested under controlled environmental conditions.

PLANT-PATHOGEN AND PLANT-PEST RELATIONS

As mentioned above, the host plant influences parasite dynamics through its botanical characteristics, its adaptation to the environment and its physiology in relation to cultivation practices and it seemed important to develop an understanding of these effects. The genetics of cassava is less well known than that of other tropical crops such as cotton and peanut, despite recent work by ORSTOM on intra-specific variability (Marmey *et al.*, 1994). The considerable varietal diversity should be taken into account and such work is under investigations in ORSTOM, Montpellier. Study of plant physiology with regard to both agricultural features and host metabolism has been undertaken, especially in the context of crop-pest interactions.

Relations between cassava growth, climatic factors and the development of epidemics of African mosaic disease have been demonstrated in Côte d'Ivoire (Fargette and Vié, 1994) and shown to apply elsewhere by a reassessment of early epidemiological data from Tanzania (Fargette and Thresh, 1994). In Togo, the effect of varied cultural practices on the biological cycle and epidemiology of bacterial blight was monitored for several seasons (Boher and Agbobli, 1992). In Congo, the influence of the sequence of rainy and dry seasons on plant physiology (translocation of secondary metabolites in phloem sap) has been studied (Calatayud *et al.*, 1994). The results of these approaches lead to two lines of investigation : (1) design of cultural operations, planting date and method, soil cover and irrigation; (2) assistance to breeders by demonstrating natural plant mechanisms for resistance to the mealybug (Tertuliano, 1993).

PHYTOPHAGOUS AND ENTOMOPHAGOUS ORGANISMS

An important component of cassava biocenosis is formed by entomophagous organisms (parasitoids and/or predators) of mites, variegated grasshopper, whitefly and mealybug. Studies on the latter have progressed furthest in considering indigenous Coccinellidae predators (Fabres and Kiyindou, 1985), an exotic parasitoid *(Epidinocarsis lopezi)* introduced during a continent-wide acclimatization campaign by IITA (Biassangama *et al.*, 1988) and entomogenous fungi (LeRü and Iziquel, 1990). Each entomophagous organism is a potential means of biological control of pest populations.

This ecological approach to biological regulation has enabled the integration of exotic entomophagous organisms to become a new regulatory factor in biocenosis and to measure the impact of indigenous beneficial species. As these biological agents are also subjected to the same environmental conditions as the phytophagous host, the various lines of research mentioned above have been used, leading to important conclusions concerning tritrophic plant-mealybug-parasitoid relations (Herbrecht, 1993).

The effects of plant diseases and pests on the population genetics of cassava have been poorly investigated but they are a potentially important aspect of plant-pathogen or plant-pest relations. Diseases and pests can impose a severe selection pressure on cassava, as susceptible genotypes are eliminated as a consequence of direct damage by the pests or diseases, or indirectly through the limited extent to which they are propagated compared with resistant cultivars. For instance, there are reports of a high and quick turn-over of cassava varieties in farmers' fields in response to severe epidemics of African cassava mosaic disease in Uganda (G.W. Otim-Nape and J.M. Thresh, personal communication). The scale of the genotype turn-over is likely to be highly variable among pests, periods and regions, as it would be primarily dependent of the intensity of attack, the length of the previous period of "co-evolution" and on the extent and variability of the gene pool available. This poorly documented aspect of plant interactions with diseases and pests is a fascinating area with a high potential for integrative studies. See Nweke (1994) for further information on the turnover in cassava varieties.

MODELLING

The example of considering new biological entities in parasite biocenoses illustrates the complexity of the crosswise interrelations which develop in the system studied. Management of such complex plant-parasite-pest systems is only possible by understanding the mechanisms involved at the scale of the individuals of the populations and interactions between the various components of the system. Systems analysis techniques and especially simulation methods now permit this type of quantitative analysis (Savary and Zadoks, 1991). A plant-phytophagous organism sub-system adapted to the conditions of Central Africa was modelled using data on cassava green mite applied to a cassava plant model based on agronomic features (Bonato, 1993). This is the first step towards the integration of the various data available.

DISCUSSION : CONCLUSIONS

The research by ORSTOM staff has demonstrated the complex ecology of cassava pests and pathogens in this parasite biocenosis. The vast area of cassava cultivated in Africa, the diverse production situations, parasite-pest variability (and that of entomophagous species), the numerous types of relations between plants and other organisms (parasites and phytophagous, entomophagous and vector species) and the many interactions between the factors regulating epidemic mechanisms make knowledge of the subject a complex mosaic in which we have attempted to show the main structural features.

An assessment of the research carried out to date and the results for each parasite or pest in the parasite biocenosis should reveal both the fundamental progress made and the gaps in knowledge and also the best opportunity for integrating operations. For this, the different sequences in epidemiological research are shown in matrix form in Figure 1 (variability of pathogens, vectors and phytophagous organisms, host-parasite relations, epidemiology and population dynamics, modelling) for the various organisms studied to date.

The characterisation of organisms is seen to be an important component in both virology and bacteriology, which share common biochemical and molecular techniques (Fig. 1A). The situation is different for arthropods as identification is frequently based on morphology. However, there is an increasing need to use more sophisticated techniques to assess the genetic polymorphism of animal populations and studies are required for a better understanding of relations with the host plant. This has been approached for the variegated grasshopper and the whitefly vector (Fig. 1B), which is an important and topical study as a major epidemic of African cassava mosaic disease is now spreading across Uganda and is associated with big changes in whitefly populations and behaviour (G.W. Otim-Nape and J.M. Thresh, personal communication). As the investigative techniques are similar to those used for pathogens, a common methodology can be developed.

Surprisingly, and largely for reasons of the separation between disciplines, genetic characterisation of the host plant is not performed in the same way as for pests and pathogens, although it should be done concurrently, and the knowledge available on cassava is still fairly limited. There is an urgent need for better information on the cassava plant and its genetic variability to improve knowledge on the resistance mechanisms to both diseases and pests. The plant and its genetic variability also forms an important feature in the integration of work in various crop protection disciplines.

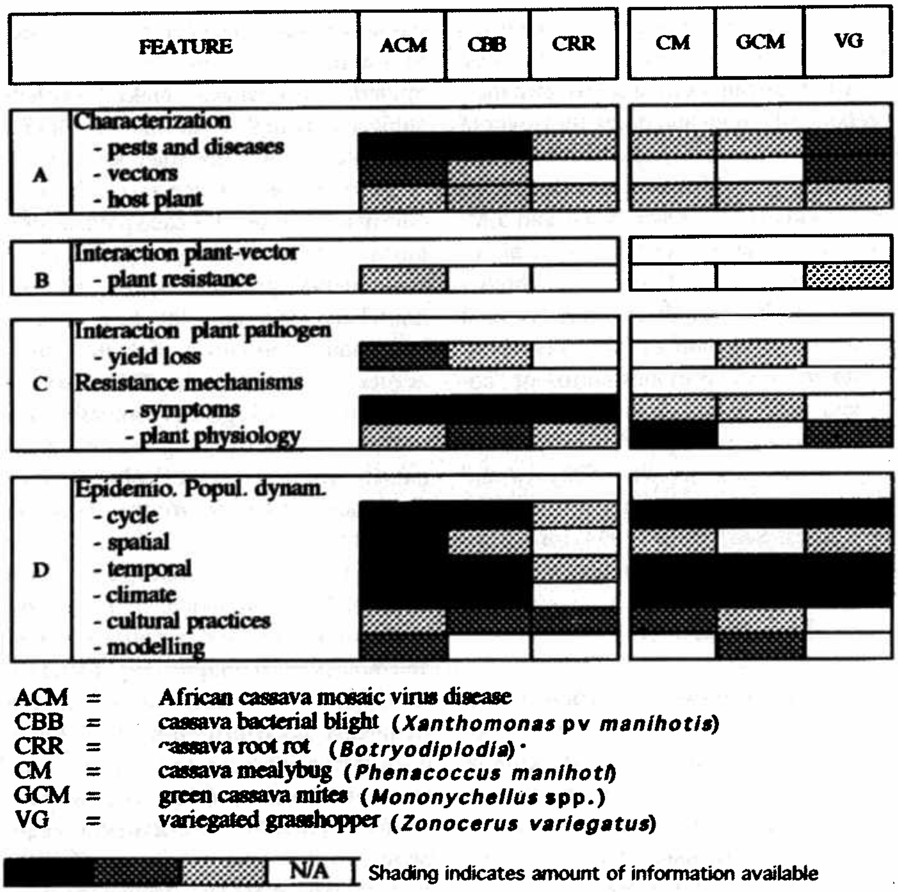

Figure 1. Matrix summarising achievements, gaps and prospects for integration in research

Study of the interactions between cassava and its pathogens requires better knowledge of the host and attention to the impact on yield of parasite pressure and phenotypic resistance phenomena (Fig. 1C). Plant pathology in general places considerable emphasis on disease symptoms, which provides a means of detecting plant resistance. This approach is less common with arthropods because it is usually substituted by direct measurement of pest abundance. Entomologists have now integrated this component with the study of changes in the biology of cassava mealybug resulting from the physiological state of the plant (Calatayud *et al.*, 1994) and the questions raised by the polyphagous nature of the variegated grasshopper (Le Gall *et al.*, 1995). There is thus similarity between the concepts and methodological approaches to the study of physiological and biochemical mechanisms in plant resistance to attack by parasites, enhancing the integration of research in this field.

The two disciplines of plant pathology and entomology should also combine to study a common component - the combined effects of parasitism and phytophagous attacks on yield. This is difficult as it requires agronomic facilities for field trials and is not well-suited to on-farm experiments. It is particularly difficult with cassava, which, although propagated vegetatively, displays considerable individual variability in root production. An effort should be made to standardise methods and experimental lay-outs. It is a major component in the integration of studies for three reasons: (1) the impact on yield results from the combined effect of the various "consumers" of the plant and the approach should be an overall integrated one; (2) study of yield involves a consideration of cultural practices as these provide scope for modifying epidemic mechanisms; (3) the most appropriate tool for investigation is the use of an agronomic model of the plant together with parasite or pest sub-models (Savary and Zadoks, 1991). As can be seen in Fig. 1, work has been performed on mites and mosaic virus disease but in different ways. The space-time dynamics of mosaic disease epidemics were simulated (Fargette and Vie, 1994), whereas a plant model and pest sub-models were used for mites (Bonato, 1993). Close cooperation between the various disciplines is essential in this field so that a common approach can be used in which all the results are combined.

Another example of possible integration is in plant health because similar techniques (heat treatment, tissue culture, rapid multiplication) can be used to eliminate several pests and pathogens. However, conflicts can arise and need to be overcome. For example, forest habitats often provide excellent nutrient and cultural conditions for plants and natural protection against bacterial blight, mites and mealybug and can facilitate the production of vigorous healthy cuttings. Yet such conditions are associated with high populations of whitefly vectors and could lead to increased problems with African cassava mosaic virus disease (Fargette and Thresh, 1994). This emphasises the need for an integrated approach to plant health.

Much work has been carried out on epidemiology and population dynamics (Fig. 1D). This arose from the fundamental character of the basic research which provided the first description of plant-parasite relations and was facilitated by ready access to field sites and the long-term presence of ORSTOM researchers in tropical areas. The body of knowledge gathered at various sites at different times and concerning a variety of organisms does not so much require fresh investigations but a synthesis (modelling) leading to original lines of research integrating approaches and solutions.

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