A SUMMARY OF THE EPIDEMIOLOGY OF AFRICAN CASSAVA MOSAIC VIRUS

C. Fauquet and D. Fargette

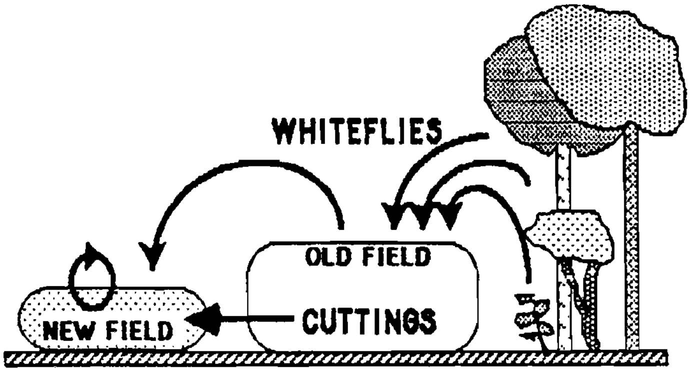
Laboratoire de phytovirologie, ORSTOM, BP V 51, Abidjan, Ivory Coast.

The first aim of the Laboratory of Plant Pathology in Adiopodoumé (Ivory Coast), when it was created by the ORSTOM in 1969, was to describe the predominant tropical viral diseases of the African continent (7). At the end of this preliminary phase of etiology, we decided in 1979 to focus our attention on one of the most serious viral diseases identified in this continent - the African cassava mosaic virus (ACMV).

Justifications. The economic importance of the disease was the determining factor when we decided on the choice of the program. The cassava crop is the most important food crop in Africa. Over 50 million tons of fresh tubers are produced each year. African cassava mosaic disease is not the most spectacular disease of cassava, when compared to bacterial blight, mealy bug, mites and antrachnosis. However, since ACMV occurs each year and is widespread over the whole continent, it is therefore likely to be the most devastating disease of cassava. The first objective of our program is to understand the epidemiology of the disease and to propose sound measures of control.

ACMV is a geminivirus transmitted by the whitefly *Bemisia tabaci*. Whitefly-transmitted geminiviruses are now known to be responsible for an increasing number of viral diseases in tropical regions. Although large advances in the etiology and pathogen characterization of these diseases have occurred recently, comparatively little attention has been devoted to the epidemiology of the disease. The second objective of our program is to provide some basic knowledge which could help in understanding other whitefly transmitted geminiviruses. ACMV is endogenous to the African continent, however similar symptoms have been described in India, but so far it has not been detected in South America.

Overview of the problem. The disease is transmitted in two different ways, by the whitefly *Bemisia tabaci*, and by man through the cassava cuttings. Cassava was first introduced into Africa in the 16th century, free of virus but today it is almost 100% infected. What is actually the real important vector - whitefly or man?



The answer to this question is essential because it determines two very different strategies for the control of the disease: 1) if man is the main vector, an educational program should be initiated to improve the distribution and choice of healthy cuttings, 2) if whitefly is the main vector, cultural practices and resistant clones should be developed to lower the impact of the disease.

Statement of knowledge in 1980. From the beginning of the century, the symptomatology of the disease had been extensively described in every country of the continent. The transmission patterns were studied mostly in East and West Africa (4,6,14). Adult and larval stages of whiteflies transmit the disease in a persistent manner, but there is no transovarial transmission. The ethology of the vector was quite unknown, with only a few studies done on the population dynamics of the insect (10,12). Two strains of the virus, a mild and a severe one, have been known in East Africa for a long time (1), and two serologically related strains were recognized (3): one originating from the east of Kenya and the other one from the west of Africa (13). It was only in 1983 that Bock (2) confirmed the geminivirus etiology and proposed changing the previous name of "Cassava latent virus" to "African cassava mosaic virus." Selection programs were initiated in 1947 in East Africa (11) and carried on in Kenya and Nigeria (5,8,9). All these programs produced resistant clones to ACMV, but the type of resistance was unknown. An extensive study of ACMV epidemiology was carried out in Kenya from 1973 to 1983 (1). From these experiments it was concluded that man is the main vector of the disease in Kenya and that whitefly spread was limited. Thus, control of the disease could be achieved simply by a distribution of healthy cuttings combined with some survey of the fields and eradication of newly infected plants. However, the results of this work could not be extended directly to the whole continent and additional studies on ACMV epidemiology needed to be carried on in other countries. For all these reasons we decided, in 1979, to develop a research program on the epidemiology of ACMV in the Ivory Coast.

RESOURCES AND DIFFICULTIES

Plant material. Epidemiological studies are usually based on trials where recontamination of healthy cassava plants is followed. The first difficulty in developing an epidemiological program on ACMV was to find large amounts of healthy material: all the cuttings available were infected due to vegetative propagation of the host and consequent virus transmission. Sophisticated techniques, such as meristem culture or thermotherapy combined with in vitro culture have been successfully applied to cure some cassava clones. However, with these techniques, only limited healthy material could be provided. A natural phenomenon - we called it reversion - occurs in the fields: a percentage of diseased plants give rise to some healthy stems. Although it occurs at a very low percentage, it allowed the selection and multiplication (in special conditions), within 3 years, of six different healthy clones with enough material to plant up to several hectares. In addition, we introduced some healthy resistant clones from Kenya and Nigeria. Our germplasm now totals about 50 clones. These clones from other countries provided us the opportunity to compare our results with those obtained in different countries.

The virus. In 1980, the geminivirus named "Cassava latent virus" was only suspected to be the causal agent of the disease, so we were not sure until 1983 that we were working with the actual causal agent. The ACMV is difficult to purify and poorly immunogenic, thus the antiserum is not sensitive and the usual serological technqiues are of limited value. The biological assay by mechanical inoculation from cassava to tobacco, even if it were feasible to perform, does not detect all infected clones. All these constraints led us to develop an ELISA test to evaluate the virus concentration. However, the extent of the surveys (several thousand plants are checked each week) explains why field surveys had to rely on symptom assessment. This method is not ideal because, after inoculation, there is a latent period before symptom appearance. The length of this period depends on the clone tested and on climatic conditions. This unpredictable length of the latent period causes some uncertainty about the real level of infection, as it is never certain that a symptom-free plant is also a virus-free plant.

The vector. The difficulties faced with the vector result from obstacles encountered in handling and sampling due to its small size (1 mm long) and from the lack of basic knowledge about its biology and ecology. Species of *Bemisia* can be recognized only at the pupal stage. So, we can never determine to which species an adult whitefly belongs. The ethology of this vector has not been extensively studied in any region of the world. We overcame these difficulties in studying the movements and behavior of the vector because, on cassava, a very high percentage of pupae are *Bemisia tabaci* so we could estimate that the adults were present in the same proportion.

METHODOLOGY

Cassava growth is highly dependent on the environment and on the cultural practices. The variability of the cassava growth pattern causes obstacles; laboratory experiments, conducted under controlled conditions to test the influence of factors such as symptom expression or clone susceptibility to whitefly inoculation could be misleading, as the cassava growth is very different from its growth in a field. However, most of the experiments were carried out in the fields. We balanced the difficulty of uncontrolled conditions by conducting many experiments, taking into account many variables and using multivariate analyses.

RESULTS

We present the results of our program in eight different subjects, taking into account the vector, the virus and plant, in the environment of the Ivory Coast.

Ecology of ACMV. The effect of the virus on cassava yield and the effect of the reservoirs on contamination are described. The relations between the "actors" are presented and show a noticeable connection: the greatest number of vectors are feeding on the leaves that are the most susceptible for acquisition, and which contain the highest virus concentration. Nevertheless, the percentage of viruliferous whiteflies is extremely low: 0.18-0.67%.

Field dispersal of Bemisia tabaci, vector of ACMV. This study describes the different aspects of vector landing, multiplying, moving and leaving the field. It shows the important effect of the wind direction and intensity on these movements. These results explain different aspects of the epidemiology of ACMV.

Spatial pattern of ACMV spread. As a consequence of the vector ethology, the dispersal of ACMV in the fields follows a gradient in relation to the prevailing wind. This gradient remains all along the time of the culture and exists in very different field environmental conditions.

Automatic mapping of the spread of ACMV. The application of the theory of the regionalized variables allows us to explain, describe and map automatically the development of the viral disease. It presents a practical interest in that estimating and mapping the spread of ACMV can be done with a sample of 7%.

Primary and secondary spread of ACMV. Compared to the ACMV secondary spread, the primary contamination is the most important. A practical result of this finding is the implication that removal of diseased plants would not allow the maintenance of healthy plantations in a considered region.

Development of ACMV at a regional level. This study demonstrates that the contamination of different fields is neither exclusively depending on the number of whiteflies, nor on the plant growth of cassava, but also on the environment of the field. The presence of diseased cassava up-wind from the field is the determining factor for its contamination rate.

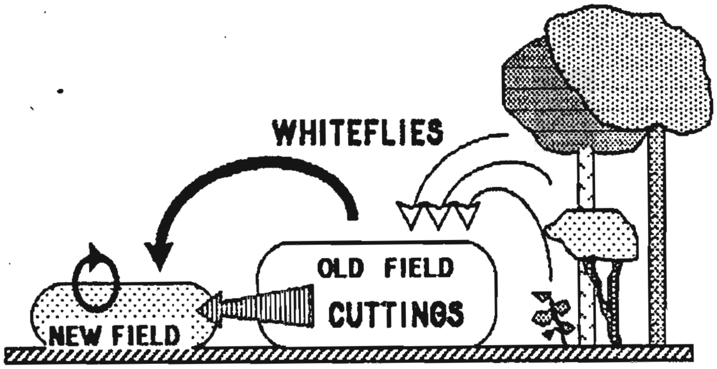
Temporal pattern of ACMV spread. This experiment, conducted 5 years, shows the annual fluctuation of the inoculum pressure, of the whitefly population and of cassava growth. Temperature is the most important factor acting on all these variables. The interrelations of these variables and of climatic factors were studied and it is possible, within the experimental conditions, to forecast the development of ACMV accurately within 2 months and roughly on a yearly basis.

Multicomponent resistance of cassava to ACMV. Field resistance is mostly the expression of symptom resistance, but other components exist. Among them, one is the vector resistance which has never been suspected nor used and which is, furthermore, almost independent from the other components, suggesting that independent genes are involved and allowing new selection schemes for ACMV resistance to be devised.

DISCUSSION-CONCLUSION

One objective of our program was to understand the development and provide knowledge on the epidemiology of whitefly transmitted diseases, such as ACMV. The disease spread in space and time is now well known and we are able to describe and understand the development of ACMV. The most efficient climatic factor predictors are temperature and wind. Both are acting on the vector and consequently on the disease. Almost all the movements as well as the behavior of Bemisia tabaci, are in relation with the direction and intensity of the wind. We think that these results are a general feature whatever the region considered. The temperature is acting on the population dynamics of the vector and also on the growth of cassava. Though the action of temperature on the growth of the vector populations might be a general feature, the prevalence of this factor, obtained in our region, cannot be extended to other regions without experimental confirmation. In other aspects, experimental results have shown the influence of the plant growth on the susceptibility to the inoculation and on the behavior of the vector.

The crop losses due to ACMV are of considerable importance and could easily justify this study. They are higher in the case of viral transmission through the cuttings than in the case of whitefly transmission. Even if the plantation is recontaminated during the culture, planting healthy cuttings is a positive action with regard to the production. This is in favor of a sanitation program which requires healthy cuttings. The main reservoir of virus and vector is, actually, most probably cassava itself (see figure below). This result also favors sanitation techniques.



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The determination of the most important vector depends on the local conditions; it might be man or whiteflies, or both. In consequence, in each region, it is necessary to determine whether or not it is feasible to grow healthy plantations. The results obtained on the eastern coast of Kenya or in the center of the Ivory Coast support this conclusion, but those obtained in the south of the Ivory Coast show their relativity. This is naturally dependent on the field resistance of the cassava clone multiplied. The cassava resistance to ACMV is multicomponent and, particularly, we have demonstrated the existence of a vector resistance which remains unexploited in the selection programs to the ACMV.

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