in: Plant virus disease control / eds. A. Hadidi, R.K. Khetarpal, H. Koganezawa. - American Phytopathological Society Press, 1998
pp. 670-677

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CHAPTER 50

The Control of African Cassava Mosaic Virus Disease: Phytosanitation and/or Resistance?

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Cassava (*Manihot esculenta* Crantz) is an important staple food crop in many parts of sub-Saharan Africa. The main disease affecting the crop is African cassava mosaic disease (ACMD) which is caused by any of the African cassava mosaic geminiviruses (ACMVs) that are transmitted by the whitefly *Bemisia tabaci* (Gennadius). In previous papers it was stressed that ACMD is an important but generally underestimated problem in many countries and one that has received inadequate attention (23,25,26). It was also emphasized that substantial increases in productivity could be achieved by the widespread adoption of known methods of control.

The various possible approaches to controlling ACMD are discussed in recent reviews (9,11,27). The two most feasable and widely adopted methods are through the use of phytosanitation and resistant varieties. Additional information on these approaches is presented in this chapter which is based largely on experience gained in the very different conditions of Côte d'Ivoire and Uganda. However, the concepts developed are more generally applicable in developing appropriate control strategies for use elsewhere.

PHYTOSANITATION

This term is used here in a general way for the various means of improving the health status of cassava planting material and for decreasing the availability of sources of infection from which further spread of ACMD can occur through the activity of the whitefly vector.

There are three main features of phytosanitation for the control of ACMD:

- Crop hygiene involving the removal of all diseased cassava from within and immediately around areas to be used for new plantings.
- The use of ACMV-free stem cuttings as planting material.
- The removal (roguing) of diseased plants from within crop stands.

Crop Hygiene

This is a basic means of facilitating the control of many pests and diseases by removing the debris and surviving plants of previous crops to decrease the risk of carry-over of inoculum to any new plantings at the site or nearby. Little attention has been given to adopting this approach with ACMD and the benefits to be gained have not been demonstrated. They could be substantial because cassava plants, including those affected by ACMD, regenerate readily from stems left in or on the ground at harvest. Moreover, farmers often harvest piecemeal and from the most vigorous unaffected plants within a stand and then establish new cuttings in the gaps created. This means that young plants often develop beneath or immediately alongside older infected ones. These are potential sources of virus inoculum and also of other pathogens and pests including the cassava green mite (*Mononychellus tanajoa* Bondar) and the cassava mealybug (*Phenacoccus manihoti* Matile-Ferrero). There is a need to quantify the risks involved, because the only relevant information on spread of ACMD from foci within plantings has been obtained in experiments in which the introduced sources of infection were the same age as the plants being assessed (6).

ACMV-free Planting Material

Cassava is propagated routinely from hard-wood stem cuttings. Experience in Uganda and elsewhere in Africa is that farmers usually obtain these from their own plantings or from neighbors; there is also some use of material brought in from outside the locality or provided from official sources or by Non-Governmental Organizations (NGOs). In many areas there is extensive infection of the planting material with ACMD, which may have very deleterious effects. This is because plants that develop from infected cuttings are important sources of infection and they grow and yield substantially less than uninfected plants, or those infected later by whiteflies (9). Moreover, the use of infected cuttings can lead to a high incidence of ACMD and substantial crop loss, even in areas where there is little or no spread by vectors.

There are many reasons for the widespread use of infected planting material. One is that farmers are unaware of the damage caused by ACMD, in some instances because virtually all the available material is infected and there are no uninfected plants to serve as standards and indicate the potential productivity of the varieties being grown. Even if farmers are aware of the problem they seldom have access to sources of uninfected material, either because this is not available or because they cannot afford the cost.

There are obvious advantages to be gained from the general adoption of ACMV-free cuttings as planting material, which would greatly enhance productivity and decrease the extent of infection in the locality and the opportunity for further spread by vectors. This is a basic approach to disease control and one that has been widely adopted with many vegetatively-propagated crops (12). However, little attempt has been made to promote the use of ACMV-free stocks of cassava, other than to meet the requirements of Plant Health Authorities responsible for regulating the movement of vegetative material between countries and continents.

It is sometimes argued that specialist expertise and sophisticated facilities are required to obtain ACMV-free material by meristem-tip and/or heat therapy. 'Foundation' plants obtained in this way could then be subjected to rigorous tests for ACMV and other viruses and maintained in insect-proof conditions to prevent contamination by vectors. There are also those who advocate setting up expensive schemes for the production and distribution of ACMV-free planting material of cassava similar to those used in developed countries for potato and many horticultural crops (12). These involve the periodic replacement of the stocks being grown as those being used become infected and less productive.

Such costly and elaborate schemes may eventually be adopted with cassava, but they are currently impracticable and inappropriate, given the huge quantities of planting material required, the limited budgets available for extension-type activities and the poverty of many of those growing cassava. Nevertheless, there is abundant evidence from experience in Kenya, Côte d'Ivoire and Uganda that big improvements in the health status of the planting material that is available to farmers can be achieved by simply selecting cuttings from symptomless plants and raising them at sites where there is little or no spread by vectors and where roguing is practiced routinely. This was the approach adopted in the 1980s in Kenya (3) and Côte d'Ivoire (10), where substantial quantities of ACMV-free material were raised for use in epidemiological trials. However, arrangements were not developed for more extensive propagation and distribution to farmers on a large scale.

Such schemes have since been developed in Uganda where there is now a huge demand for planting material of improved virus-resistant varieties to replace the local mainly susceptible ones that have been severely affected during the current epidemic (18,28). About 17,500 ha of virus-resistant material are now available at various propagation sites in different parts of the country and these are being used to supply ACMV-free cuttings to farmers. Three main approaches have been adopted in building up this system of multiplication, involving institutions, groups of farmers operating together and individuals. Each system has advantages and disadvantages, as discussed by Otim-Nape *et al.* (18). The experience is that with each system some additional re-selection and roguing is necessary, even if the initial selection of cuttings is done under optimum growing conditions. The amount of roguing required depends on the susceptibility of the variety and the inoculum pressure prevailing at the propagation site. This explains why the need for roguing has been much greater at sites in central and eastern Uganda where ACMD spreads rapidly, than in southern areas around Lake Victoria where until recently little or no spread occurred.

Current operations in Uganda require a substantial commitment of staff and resources and a large budget, some of which is being provided by outside donors and NGOs, including the UK Gatsby Charitable Foundation. One of the objectives of current work is to develop simple but effective measures that can be adopted readily by farmers and practiced routinely on a sustainable basis without the need for continued financial, technical and logistical support that will be difficult to provide. The basic concept rests on the assumption that farmers can obtain an average of about ten hard-wood cuttings from each mature source plant used to provide planting material. Thus sufficient uninfected cuttings could be obtained from existing stands in which the incidence of ACMD does not exceed 90%, provided that the uninfected plants can be identified with reasonable certainty.

This is an important proviso because there are several reasons why this is seldom feasible. Firstly, symptoms on mature plants of the type used routinely to provide cuttings tend to be inconspicuous and may be completely absent if there has been much leaf abscission during prolonged periods of drought. Moreover, symptoms may be masked or obscured by the damage due to cassava green mites, or cassava mealybug, or by zinc or other mineral deficiency symptoms (1). Another difficulty is that symptoms of ACMD may be absent or restricted to only a few shoots of plants infected at a late stage of growth by whiteflies. Nevertheless, many of the cuttings collected from such plants contain ACMV and soon develop shoots that express symptoms.

There is a particular difficulty in areas where much of the cassava is harvested and consumed during the prolonged dry season, some weeks or even months before new crops are established following the onset of the rains. This is the situation in many dry savannah areas including parts of Tanzania, Malawi and northern Ghana, where stems have to be collected at harvest and retained without leaves until required for planting. Stems are frequently collected from plants that are almost leafless or seriously affected by cassava green mite and selection of ACMV-free material is difficult or impossible. In such circumstances there may be scope for adopting the practice recommended in India, where farmers are advised to inspect plants at the time of optimum growth and symptom expression. All ACMD-affected plants are then marked with paint so that they can be avoided later when cuttings are collected for further plantings (16).

Even the most rigorous selection regimes are not completely effective and some infection is to be expected, even in cuttings collected solely from symptomless healthy-looking plants. The proportion is likely to vary depending on such factors as variety, environmental conditions, the intensity of pest attack and the overall infection pressure in the locality. However, only limited evidence is available and few attempts have been made to encourage farmers to select cuttings from symptomless plants. This is a serious omission as there are likely to be substantial benefits from adopting such practices, especially in areas where conditions for crop growth are favorable, uninfected plants are readily available and the inoculum pressure is generally low. In such circumstances farmers could soon achieve a big improvement in the health status and productivity of their plantings at little cost or inconvenience and with substantial benefits. This explains why the approach was advocated for use in Zanzibar (29) and later in the important cassava-growing areas of coastal and western Kenya once uninfected plants were selected and it was shown that the inoculum pressure in these areas was generally low (3,20). There are similar opportunities elsewhere in Africa, including those parts of Malawi, Zambia, Zimbabwe, Burundi, Rwanda, Tanzania, Cameroon and Chad, where rates of spread are low and uninfected plants can be found without difficulty and sometimes predominate (25, 26).

The scope for selection in areas of relatively high inoculum pressure is unclear and further experience is required before definitive recommendations are possible. It seems inevitable that latent infection will cause greater problems and that the overall approach will be less effective. Whether it will be rendered ineffective, except with resistant varieties or when combined with subsequent roguing, has not been determined.

There have been few attempts anywhere in Africa to exploit the benefits of selective propagation and cuttings are frequently taken from obviously infected source plants by farmers and also at official propagation sites and for use in agronomy or other experimental trials. A change from such unsatisfactory practices is long overdue and there is also a need for socio-economic assessments of current methods and farmers' attitudes to cutting selection. Preliminary studies of this type have been made already in parts of Uganda and show that some farmers select the plants from which they obtain cuttings and may do so rigorously on the basis of plant vigor, or the absence of symptoms, or some combination of the two (18). This suggests that other farmers could be persuaded to do so if they are provided with sufficient education and training, together with clear evidence of the benefits to be gained. Evidence of this type has seldom been sought, and is an obvious priority in any further research if current attitudes are to be changed and progress is to be made.

Roguing

Roguing is a well known means of disease control of wide applicability (22). It has been recommended repeatedly as a means of controlling ACMD, but there is little experimental or other evidence to indicate the effectiveness and applicability of this approach, or the most appropriate procedure to follow. This emphasizes the need for additional research and for more detailed assessments of roguing than any yet undertaken.

There is general agreement that roguing should be adopted as an essential feature of official schemes for the selection and maintenance of ACMV-free stocks for release to farmers, as discussed earlier. In these circumstances the health status of the material is of paramount importance and it is accepted that some losses are inevitable during roguing operations. Stringent roguing regimes are justified and it is appropriate to follow the recommendation that plantings should be inspected at least weekly for the first two to three months of growth, so as to find and remove any infected plants that occur (11).

The situation is very different in farmers' plantings, where other considerations apply and there is a general and understandable reluctance to remove any plants that might contribute to yield. Frequent roguing is certainly not justified where there is little spread of ACMV into or within plantings by whiteflies. Moreover, roguing is inappropriate and ineffective and leads to a progressive and unacceptable decrease in stand in areas of high inoculum pressure where much spread occurs. This was demonstrated in each of the only two experiments on roguing to have been reported. At a site in the lowland forest area of Côte d'Ivoire, the spread of ACMD was rapid and the final incidence of infection was similarly high (77-78%) in rogued and unrogued plots of the same range of varieties (4). Rapid spread also occurred in a second experiment in the same locality where the final incidence was 67% in rogued and 87% in unrogued plots established with ACMV-free cuttings of a local Ivorian variety (6).

Another argument against roguing is that there is evidence from Côte d'Ivoire, Kenya and Uganda that the spread of ACMV is mainly between cassava plantings and not from internal foci within them (3,6,17). This suggests that roguing has little effect in reducing spread within treated fields and so is of little or no benefit to those adopting the practice, although it can be expected to decrease the risk of spread to other plantings nearby. From this it can be inferred that roguing is likely to be most effective when practiced by groups of farmers or throughout whole localities. This was the approach recommended and adopted in Uganda in the 1950s when resistant varieties and the use of roguing were introduced as the official control policy and strictly enforced by local authority statute (13).

Such drastic measures are no longer appropriate or acceptable to farmers and they cannot be enforced. Consequently, the current approach in Uganda is to develop simple, less demanding procedures that can be used by farmers to sustain the health status of the material being grown, at little inconvenience or expense. One possibility is to rogue once or twice soon after planting as the cuttings begin to sprout and infected ones usually develop conspicuous symptoms. Roguing can be done quickly and easily at this early stage of growth and there is still time to fill the gaps created by planting additional cassava or other crop plants. Any later infections that occur are allowed to remain, which also avoids gaps and the decrease in yield that is otherwise likely to occur because of the reduced stand. This is because plants infected during growth by whiteflies sustain little or no reduction in yield, although it is important to avoid propagating from such plants as the cuttings obtained would be affected much more severely. (9,24).

Another possibility being investigated in Uganda is to compare selection and roguing to determine their effectiveness in maintaining the health status of plantings when used singly and also in combination. It is already apparent that farmers will adopt these techniques if provided with sufficient training and justification (17). However, the situation in many parts of Uganda is unusual in that the current epidemic of ACMD has caused such severe damage that farmers are desperate to maintain production by whatever means available. Consequently, they are willing to make considerable effort to safeguard cassava, which is their main staple food. It remains to be established whether farmers will respond similarly in endemic areas where ACMD is a long-standing and so less obvious problem and where acceptable, albeit sub-standard, yields are obtained without any evident need to change variety or to use specific control measures.

RESISTANT VARIETIES

Although what is now known as ACMD was first reported in 1894 it did not become a serious problem until the late 1920s and early 1930s, when agriculturists in East, Central and West Africa and also in Madagascar became aware of the need for ACMV-resistant varieties. Attitudes at the time were clearly influenced by the successful deployment of resistant varieties to combat the threat posed by sugarcane mosaic virus disease (21). Various largely unsuccessful attempts were made in several countries to identify ACMV-resistant varieties from those being grown at the time in Africa, or that were imported from elsewhere. Much greater success was achieved by crossing cassava with *M. glaziovii* Muell.-Arg. to produce hybrids that were back-crossed to cassava to produce progeny having satisfactory root yield and quality. This approach was adopted independently in Tanzania and Madagascar (14) and Tanzanian seed of resistant genotypes was introduced to Nigeria where selections were made and ultimately used as sources of resistance in the IITA breeding program (2). This began in 1971 and it is now the largest and most influential in Africa as it supplies parental material, seed and breeding lines to many national programs (15).

The ACMV-resistant varieties selected in Tanzania, Madagascar, IITA and elsewhere in Africa have several important characteristics which seem to be closely associated and may be manifestations of the same basic virus resistance mechanism:

They are resistant, but not totally immune to infection with ACMV. This means that the proportion of plants infected depends on the prevailing inoculum pressure, but is consistently less than in susceptible varieties of the same age exposed to similar amounts of inoculum.

- They develop symptoms of ACMD that are less conspicuous than those of sensitive (intolerant) varieties.

- The symptoms are often restricted to certain shoots or branches and become inconspicuous or disappear as the plants age. This means that resistant varieties tend to be less severely affected by ACMD than sensitive ones, as several different studies have shown a general relationship between symptom severity and yield loss (24).

- ACMV is less completely systemic in resistant varieties than in susceptible ones. An important consequence of this effect is that a substantial proportion of the cuttings collected from infected plants are free of ACMV, even if taken from plants that were infected as cuttings or at an early stage of growth by whiteflies. This is the so-called 'reversion' phenomenon which has long been known and is likely to be of crucial epidemiological importance, as indicated by recent modelling studies (7,8). However, the phenomenon has not been adequately studied and remains poorly understood.

- Resistant varieties contain lower concentration of ACMV than susceptible ones, as demonstrated serologically by Fargette *et al.* (5). This suggests that resistant varieties are of limited potency as they are poor sources of inoculum from which vectors can acquire and transmit virus to uninfected plants. Moreover, the general adoption of such varieties is likely to lead to a decrease in the amount of inoculum present in the locality and so restrict spread of ACMV to any susceptible varieties being grown.

A likely consequence of these features is that stands of the most virus-resistant varieties sustain little damage or yield loss due to ACMD, even under conditions of very high inoculum pressure. This is to be expected because only a proportion of the plants are infected and those infected sustain little damage and lead to little further spread. Moreover, ACMV occurs in only a proportion of the cuttings collected from infected plants of resistant varieties so that the incidence of ACMD in the cuttings is usually less than in the stand from which they were collected. This 'cleansing' effect is likely to be further enhanced if infection decreases vegetative vigor, or farmers discriminate in favor of vigorous and/or symptomless plants when selecting cuttings for new plantings. For these reasons the incidence of infection is unlikely to increase progressively in successive cycles of propagation, as might otherwise be expected with a vector-borne virus of a vegetatively-propagated crop.

These suppositions are consistent with the results of modelling studies using realistic estimates of host-plant resistance, the extent of reversion, the intensity of cutting selection and rates of spread (7,8). The simulations indicate that the incidence of infection increases in successive cycles of crop production to reach asymptotes at long-term equilibrium values that can be substantially less than 100%. The actual incidences depend on the values of the parameters adopted and are influenced by seasonal and other environmental factors that determine host susceptibility, vector populations, inoculum pressure and the extent of reversion.

There is little experimental data to confirm or deny the validity of the modelling approach and the concept of equilibrium. Such evidence will be difficult to obtain as it will require long-term trials with different varieties in a wide range of agro-ecological environments. There is also a need for additional quantitative information on the reversion phenomenon and on the effects of ACMD on the yield of mixed stands of infected and uninfected plants of a wide range of varieties including the most resistant ones (24). Until such information is available there will be continuing uncertainty on the role of ACMV-resistant varieties and the most appropriate ways in which they should be deployed. For example, it is unclear whether reversion or resistance to or tolerance of infection is the main feature of ACMV-resistant varieties that is being exploited or whether it is some combination of the two. It is particularly important to determine whether phytosanitation is justified or advantageous with such resistant varieties. This is a long-standing issue yet to be resolved. One view is that selection and roguing are not required if the varieties being grown are sufficiently resistant. The other is that a yield penalty is incurred unless phytosanitation measures are adopted. The issue will only be resolved by assessing the performance of a wide range of varieties in different environments with different levels of inoculum pressure. The crucial question is whether equilibria occur at which the incidence and severity of ACMD are sufficiently high to decrease the productivity of entire stands in which competition and compensation effects could be important. One possibility is that phytosanitation is appropriate and beneficial for the less resistant varieties, but not for the most resistant ones. This leads to a possible paradox if it is shown that phytosanitation is only effective with the most resistant varieties with which it has the least beneficial effect. Such outcomes would have a considerable impact on attitudes to control and lead to complications if the most appropriate strategy depends on the variety adopted and the circumstances under which it is grown. This would be a difficult approach to introduce to extensionists and farmers, many of whom have still to adopt even the simplest recommendations on selection and roguing.

DISCUSSION

This chapter is concerned mainly with general concepts and some of the statements and inferences are not supported by detailed references or data. This is because few relevant studies have been carried out, or the results apply only to certain areas or have not been published. Moreover, the attitude of farmers to the various control measures is crucial and yet their role has seldom been considered.

It is particularly important to determine the extent to which attitudes towards the control of ACMD are influenced by the practice of harvesting and eating leaves, which are an important part of the diet in Zaire, Cameroon and some other cassava-producing countries. It has been claimed that consumers prefer ACMD-affected leaves for their superior taste or palatability, or because they require less cooking oil when being prepared for consumption. However, no data are available from carefully controlled experiments involving representative consumers and it is important to develop protocols for preference trials that exclude the possibility of subjective bias. It will also be necessary to consider symptoms of different severity, because small severely damaged leaves which have a reduced lamina and high fiber content are unlikely to be sought, whereas those with slight symptoms may be favored on taste, sweetness or other criteria. This may explain why breeders in Zaire select genotypes that display mild symptoms of ACMD rather than those with severe symptoms or that remain completely symptomless (15).

As argued previously there is an urgent need for additional research on this and other topics which should be carried out across the whole of the very diverse range of agro-ecological environments in which cassava is grown in Africa and where ACMD is prevalent (24). It is particularly important to consider areas of both high and low inoculum pressure and to carry out experiments in different seasons and over several years to ensure the general validity of the results obtained. Moreover, the studies should be done in close collaboration with farmers and extensionists on representative holdings so that the control recommendations that emerge are relevant, practicable and appropriate in relation to current farming practices and socio-economic circumstances.

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