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Cassava Bacterial Blight: A Manageable Disease

Cassava, *Manihot esculenta* Crantz (Euphorbiaceae), is a starchy root crop that is among the most important tropical foods. World production is estimated to be 120 million tons annually. Because the roots are 65% water, annual production is equivalent to 42 million tons of dry matter or 40–50 million tons of grain (although cassava is lower in protein). About 80% of the cassava produced is consumed by human beings and constitutes the principal carbohydrate source for more than 500 million people in developing countries. In the countries of tropical Africa, for example, cassava provides an average of 230 calories per person per day; in Zaire, the average daily intake is over 1,000 calories. The remaining 20% of cassava produced is used for animal feed and industrial purposes (1).

Cassava was domesticated in Brazil some 5,000 years ago. In Mexico, remains of cassava leaves have been found that are 2,500 years old, and cassava starch has been identified in human coprolites that are 2,100 years old (7).

Cassava is grown between 30° north latitude and 30° south latitude under very broad climatic and edaphic conditions. The plant is completely domesticated and shows a high degree of local adaptation. Cassava is a perennial and is multipled by cuttings from the woody stem. The large, swollen true roots, resembling sweet potatoes, may be harvested 7 months after planting in warm areas. Where temperatures are low, however, harvest may be delayed for 18 months or longer. The world average yield is 9 t/ha, but yields of only 4–7 t/ha are common in many areas. Under semi-commercial conditions, yields of 40 t/ha are obtained (1).

On a dry matter basis, cassava roots contain 92.5% carbohydrate and 3.2% protein; starch and sugars predominate, comprising around 90%. Leaves contain 7% protein on a fresh weight basis and 20–30% on a dry weight basis and are an important source of protein for people of several African countries, who consume the leaves as a vegetable or in salads and soups. Cassava leaves compare favorably with soybeans in protein quality and are considerably higher in lysine, although deficient in methionine and tryptophan.

Many cultivation systems have been developed—mixed cropping, in particular—that generally maintain stable, although low, yields. Recent economic difficulties, especially in developing countries, have stimulated policymakers to reevaluate native crops as substitutes for foreign food imports. Partly as a result of this, cassava cultivation has been expanding rapidly, with concurrent increases in international exchange of planting material over the past 20 years. New areas with large monocrop cassava plantations are being established, and with this change, pathological and entomological problems are flourishing and causing heavy losses in many countries.

Cassava bacterial blight is, perhaps, the disease that has caused more damage to the crop than any other disease during the past two decades. Today, as the result of several research and extension programs to develop and apply integrated control measures, the disease is considered to be of minor importance in many cassava-growing areas where it previously caused near-catastrophic losses.

Symptoms

Cassava bacterial blight was first reported in Brazil in 1912 and has since been reported in almost all countries of Asia, Africa, and Latin America where cassava is cultivated (2,10). Reportedly, only members of the genus *Manihot* are affected. Losses in cassava have ranged from 12 to 90% (10). In Zaire, where the plant's leaves are an important source of protein for human food, the cassava bacterial blight epiphytotic from 1970 to 1975 resulted in starvation (R. Zeigler, *personal communication*).

The combination of cassava bacterial blight symptoms—angular leaf spotting and blight, wilting, dieback, gum exudation, and vascular necrosis—is unique among diseases caused by plant-pathogenic bacteria. Primary symptoms, resulting from planting infected material, are wilting of the young germinated sprouts, followed shortly by dieback. Secondary symptoms are usually angular leaf spots, followed by blight, defoliation, wilting of the immature shoot, and finally dieback. Initially, leaf spots are water-soaked angular lesions clearly distinguishable on the abaxial surface of the leaves (Fig. 1). These spots become brown or dark brown and are sometimes surrounded by distinct yellow halos, depending on susceptibility of the cultivar. Spots enlarge and coalesce, forming a large, necrotic blighted area. Necrotic areas spread over the entire leaf, and the leaf withers and dries. Vascular tissues of infected petioles and stems die and appear brown. Leaves connected

with these dead vascular strands wilt and may remain attached to the stem for a short time but later fall. A sticky, yellowish exudate often collects in droplets on leaf spots, mostly on the lower leaf surface and along veins or veinlets. This gum is also characteristically exuded from cracks that develop on young infected stems and petioles. The gum dries to form a glistening, yellowish deposit.

Vascular strands of infected stems become discolored. Young stem tissues may rot, particularly those surrounding areas of secondary infection. Rotting is faster in young (green) stems than in more mature ones, and old stem tissues remain apparently healthy even though, in susceptible cultivars, the vascular tissue may be discolored. Rotting of young stem tissues results in a characteristic dieback symptom, restricted to the immature stem portion of the plant.

Symptoms on the fruit, or seed balls, are water-soaked expanding spots. Heavily infected seeds from such fruit may be deformed, with necrotic areas on the cotyledons and endosperm and corrugation of the testa. Very few of these seeds germinate.

Generally, roots of infected plants remain asymptomatic. In some susceptible cultivars, swollen roots may show dry, rotted spots around the dead vascular strands. This rotting is usually restricted to the vascular tissues, however, and root tissues remain apparently healthy.

The aerial portions of young plants may be destroyed by infection (Fig. 2). The plants usually produce new shoots from the stem, either above or below the ground. These young shoots are extremely susceptible and rapidly become infected during the rainy season, maintaining inoculum in the environment for secondary infections.

Fig. 1. Leaf spots and blight typical of cassava bacterial blight caused by *Xanthomonas campestris* pv. *manihotis*.

Losses

Losses induced by cassava bacterial blight vary throughout the world and can be very high. When cuttings from an infected plantation are planted in a clean plot, losses can reach 30%. If environmental conditions are favorable and control measures are not adopted, losses can reach 80% by only three cycles. Generally, losses correlate with the number of infected cuttings of a susceptible clone used for planting. Sometimes, however, weak pathogens such as *Colletotrichum* spp. and *Choanephora cucurbitarum* invade blight-infected tissues, and losses can exceed 90% during the first cycle (*unpublished*). During the epidemics in Zaire in the 1970s, 75% of the fresh roots were lost (1). Total damage was much more important, however, because the protein-rich leaves were destroyed. During that time, losses in Central Africa were as high as 80% (10). In 1974, cassava bacterial blight reduced yields by approximately 50% in a large plantation (more than 10,000 ha) in Minas Gerais, Brazil, where infected cuttings had been planted. Losses in other Latin American countries ranged from 5 to 40% in 1975. Losses in Asia have not been estimated because the pathogen was introduced only recently, probably in the mid-60s.

No important outbreaks have been reported since 1980, but cassava bacterial blight is still endemic in areas of Latin America and Africa, causing losses of some significance. The disease is of only moderate importance in Thailand and China.

Etiology

The causal agent was first named *Bacillus manihotis* Arthaud-Berthet,

Fig. 2. Field of cassava with aerial portions of plants destroyed by cassava bacterial blight. Plants tend to sprout, but some new shoots are also infected.

Fig. 3. Shoots of cassava rooted 15 days after immersion in sterile water under fluorescent light (approximately 1,800 ft-c) at 24 C.

Fig. 4. Root yield of clone resistant to cassava bacterial blight and developed by CIAT's Cassava Improvement Program.

then *Phytomonas manihotis* (Arthaud-Berthet & Bondar) Viegas, the name included in the sixth edition of *Bergey's Manual*. The name was later changed to *Xanthomonas manihotis* (Arthaud-Berthet) Starr and finally to *X. campestris* pv. *manihotis* (Berthet & Bondar 1915) Dye 1978 (6). The bacterium grows on sucrose-containing media, producing nonpigmented colonies. The slender, gram-negative rod bears a single polar flagellum. Except for lack of pigmentation, most physiological and biochemical characteristics are those of xanthomonads (6).

The bacterium normally penetrates the host via stomata and epidermal wounds. The organism invades and destroys the spongy mesophyll, then enters the vascular tissues, enabling the bacterial cells to move systemically throughout the plant. Movement into the stem and petioles is thought to occur primarily through the xylem vessels and, possibly, through the phloem. Movement through the pith tissues has also been reported. Artificial inoculation experiments have shown that establishment of bacteria requires at least 12 hours at 90–100% relative humidity with an optimum temperature of 22–26 C.

Infection is more common in, and frequently limited to, young plant tissues; in susceptible cultivars, the organism causes extensive breakdown of parenchymatous tissues. In general, symptoms develop 11–13 days after infection. In highly lignified old stems, the bacteria remain restricted to the vascular tissues, surviving for up to 30 months. The lignified secondary wall and also the middle lamella of mature vessels are thought to be a barrier the enzymatic systems of the bacterium cannot overcome.

Seed balls may be infected by splashing rain, mechanical inoculation, or translocation of the pathogen through the xylem vessels. A high percentage of seeds collected from plantations affected by cassava bacterial blight are symptomless carriers, with the bacterium dormant in the embryo. The seeds germinate normally, but the stems and leaves show symptoms (2,9).

Epidemiology

The use of infected stem cuttings is largely responsible for the carry-over of the pathogen from one growing season to the next and for dissemination to different areas. Cassava bacterial blight probably was introduced into Africa and Asia and spread within Latin America by this means. The use of infected seeds is also responsible for disease dissemination to different countries, especially where seeds from breeding plots have been exchanged without appropriate phytosanitary precautions.

Within fields and production areas, the most important means of spread are splashing rain and contaminated tools. The former accounts for the increase in disease severity during the rainy season, and the latter contributes to the survival and spread of the pathogen within an area and from season to season. Tools are particularly important, since planting material is prepared simultaneously with the harvest and the pathogen may be spread to uninfected cuttings as planting stakes are prepared from apparently healthy mature stems harboring the pathogen. Similarly, because wounds facilitate infection, the movement of man and animals through plantations, especially during or after rain, may contribute to pathogen spread.

Less important means of dispersal have been advanced and demonstrated under experimental conditions. Although the pathogen survives poorly in soil, contaminated soil and irrigation water may play a minor role as sources of inoculum for root infection during cultivation. The pathogen may survive epiphytically on many weeds, which may serve as inoculum sources if not properly controlled. Insects may account for up to 10% of within-plot spread but are probably important only over short distances.

Disease development slows during dry periods. Little bacteria-containing gum is exuded, and spread is halted because inoculum and conditions favoring penetration are lacking. The bacteria remain viable in affected plant tissues and previously exuded gum, however, and become active with the onset of rainy periods. The severity of cassava bacterial blight is enhanced by wide fluctuations in night/day temperatures during the rainy season, especially in the range of 15 to 30 C. This explains the low to moderate severity of the disease in areas with relatively stable temperatures, such as the Amazon basin of Brazil and Colombia. This phenomenon, although not well understood, has allowed researchers to forecast the relative importance of the disease on a regional basis and to develop practical recommendations for control.

Control Measures

Losses caused by cassava bacterial blight have been dramatically reduced in recent years by a combination of cultural practices, varietal resistance, biological control methods, and sanitation measures. Application depends to some degree on the presence of the pathogen and the risk of an epiphytotic, given the environment and infrastructure in the target area.

Cultural practices. These are implemented to delay the spread of the pathogen or even to eradicate it. Results of crop rotation or fallowing have been very successful if the new crop is planted with uninfected cuttings. All infected plant debris should be incorporated into the soil, where survival is poor, or removed and burned. An interval of 6 months is sufficient to prevent carry-over of the pathogen in the soil. Weeds must be eliminated, however, because the pathogen survives a long time on many weeds that grow naturally in cassava plantations.

Planting time may be manipulated to reduce losses. Cassava is often planted at the beginning of the rainy season. After a few rains, the plantations are established, but conditions are then optimum for infection and pathogen spread. By planting toward the end of the rainy season, the plantation can be established in a relatively healthy condition. Plant growth is continuous but slow during the usually cool dry season in temperate areas. By the onset of the dry season, plants have accumulated pectin and cellulose and thus have become resistant to cassava bacterial blight. At this point, the disease is fairly mild and inoculum potential is decreased to minimum levels. With the beginning of the rainy season and warmer temperatures, plant growth and inoculum potential increase, but inoculum is not as effective because plants are older and ready to harvest in only a few months.

Clean planting material is essential, and a successful means of producing

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bacteria-free cuttings for propagation has been developed (9). Infected clones or stocks can be cleaned by rooting bacteria-free stem tips from infected or uninfected plants (Fig. 3). Planting these healthy cuttings can exclude the pathogen from an infected plantation where crop rotation or fallowing has been practiced.

Pruning most of the aboveground portion of infected plants to delay spread of the disease and secondary infections is sometimes effective. Success depends on the susceptibility of the cultivar and the interval between initial infection and pruning. Results are best with resistant and moderately resistant cultivars that are only lightly infected. Pruning has little effect on severely infected susceptible cultivars because new shoots rapidly become reinfected, necessitating regular and extensive pruning that greatly reduces quality as well as yield of roots. Pruning may also be used to slow down the spread of the pathogen under conditions favoring only moderate disease development.

Varietal resistance. A major part of the breeding work at the International Institute of Tropical Agriculture (IITA) in Nigeria and the Centro Internacional de Agricultura Tropical (CIAT) in Colombia is the development of lines resistant to *X. c.* pv. *manihotis*. Both institutes report that resistance is multigenic and maintained over time and locations (5,8). Many sources of resistance have been found, but about four cycles of evaluations are required to adequately differentiate escapes from truly resistant clones.

Even though several methods for screening for resistance to cassava bacterial blight have been developed to identify lines with integrated resistance to other production constraints, field evaluations in areas where the disease is endemic have given the best overall results. For an important subsistence crop such as cassava, stability of yield takes precedence over resistance to individual pathogens present at a given evaluation site (7,8). Lines obtained by a holistic evaluation system have shown stable resistance and yields since being selected (Fig. 4) (8).

Biological control methods. In the eastern plains of Colombia, clones susceptible to cassava bacterial blight rarely survive the disease pressure of the rainy season. Recently, however, foliar applications of *Pseudomonas fluorescens* and *P. putida* strains significantly reduced the number of angular leaf spots per leaf and the number of blighted leaves per plant on susceptible clones (4). Yields of these clones increased an average of 2.7 times when beneficial bacterial species were applied four times a month during the growing season. The future use of these biocontrol agents in commercial plantations is being investigated at CIAT.

Sanitation measures. The exchange of cassava stem cuttings is probably the major means of disseminating cassava pathogens and pests (9). The introduction of the bacterial blight pathogen into Africa and Asia is an important example of this. Some cassava pathogens can also be disseminated by the interchange of seed (2,9). Several sanitation measures, in addition to those legally established by quarantine regulations, could reduce the risk of disseminating cassava bacterial blight by means of propagative material. The recipient country should be cautious in accepting such material from countries or areas where cassava bacterial blight exists. The need for as well as the genetic advantages of an introduction should be carefully analyzed before approval is granted.

Vegetative or sexual propagative material should be collected only from healthy plants in plantations apparently free from cassava bacterial blight. Before such material is collected, a plantation's overall sanitary condition should be determined by more than one inspection during the middle to the end of the wet seasons, when disease, if present, is most severe. Any abnormal seeds or cuttings should be discarded.

Cassava cuttings should never enter international exchange. Vegetative

material should be introduced only as meristem cultures and then only after sufficient tests have been done to determine the sanitary conditions of the introduced material. Introduction of viruses, especially, should be avoided.

Particular care should be taken when introducing cassava seeds. Hot water and dry heat treatments have been used in attempts to eradicate the cassava bacterial blight pathogen from seeds. Hot water apparently is ineffective, and the best way to avoid disseminating cassava bacterial blight and other seedborne pathogens seems to be treatment of the seeds with dry heat after careful visual and density selection (9).

Where Control Has Succeeded

The control methods developed from research activities conducted over the past 15 years have been so successful that the disease has been eradicated in some areas and the incidence reduced to subeconomic levels in other areas. In Caicedonia, Colombia, one of the most productive cassava-growing areas in Latin America, cassava bacterial blight was eradicated by removing affected plantations from production for 6 months and planting clean cuttings obtained by the shoot rooting system. A similar system was used in 1971 to eradicate the pathogen from CIAT headquarters.

Cassava production in Cuba has increased from 7–8 t/ha to more than 20 t/ha, mostly because of measures applied to control cassava bacterial blight (1), i.e., timing the planting season and carefully selecting planting material from the native susceptible clone Señorita. The planting season was changed from March–April to September–October, the onset of the dry season. Planting material was selected from only the most lignified portion of the stem, about 1 m from the base—the most resistant to cassava bacterial blight because of lignification and high accumulaton of pectin and cellulose. Even though Cuban cassava plantations are still affected by the disease, severity remains low to moderate up to harvesttime.

In the eastern plains of Colombia, cassava bacterial blight and other diseases were so severe that yields were less than 7 t/ha. Thanks to sanitation practices and a breeding program, commercial plantings of selected cuttings of resistant, improved clones now yield 20 t/ha. Resistant clones developed by IITA are being planted in Nigeria, Zaire, and other African countries (3), reducing disease damage and increasing yields. Colombia, Brazil, Cuba, and Malaysia have massive production programs for distributing disease-free cuttings to farmers (1), with the aim of increasing yields by reducing cassava bacterial blight incidence. Similarly, interested countries can now obtain improved propagative material, i.e., heat-treated seeds and plantlets developed from meristem cultures (9).

Control of this bacterial pathogen on cassava, a staple crop, is of great importance for the poorest people living in developing countries. Even though the disease is being controlled successfully in several areas, extension agents must continue to implement programs in areas where cassava bacterial blight is endemic. The goal of all cassava researchers should be to preserve the relatively stable crop system, because yield stability is crucial for cassava growers. This can be achieved by defining diverse approaches to disease control, then integrating these approaches into production realities dictated by the environment, the cultivars, and the socioeconomic status of the producers and consumers in the target area.

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