Ecology and Control of Fusarial Wilt of Banana

Shin-Chuan Hwang

Department of Plant Protection, Taiwan Banana Research Institute
Pingtung, Taiwan, R.D.C.

摘　　要

黃新川（1985）香蕉黃葉病之生態與防治　（香蕉研究所）

目前臺灣香蕉發生黃葉病（病原菌：*Fusarium oxysporum* f. sp. *cubense* 生理小種 4）的蕉園面積每年達 1,500 公頃以上，發病株數於 1968年僅有 1,500株，到 1983年增至 500,000 株。本病病原菌普遍分佈於高、屏兩縣，局部性分佈於彰化、南投、和嘉義等縣。本病遠距離傳播主要以流水和病苗爲媒介，在蕉園內則可依賴灌溉水，除萌作業和種植病苗而擴散。溫度會影響本病的發生，將組織培養蕉苗接種後，在不同溫度條件下生長兩個半月後，調查發病率分別爲 17°C～10%，21°C～14%，25°C～17%，29°C～40%，32°C～58% 。傷害蕉株的根部會促進發病，在一田間試驗，在人爲傷根情況下接種後發病率爲67% ，但在根部沒有傷口之對照處理發病率僅有38%。從塊莖傷口接種則不能引起感染。病園土壤施加石灰沒有抑制發病的效果，但病園與水稻輪作後發病率呈明顯的下降，輪作水稻一年後發病率從原先之30～50%降至8.1～17.6%，輪作 2.5～3年後再降至 0.8～6.3% 。病園與旱作如甘蔗或向日葵輪作則無治病效果。病原菌主要分佈於病園土壤深度 20公分以內之表土層，在此深度以下則不能分離到病原菌。病園經輪作水稻一年之後，尚有 2%病菌族群密度殘存於深 3 公分以內的表土，但在 10 公分深以下其密度已降低到不能偵測的程度，輪作水稻 2 年後即不能從表土分離到殘存的病原菌。在抗病選種試驗中，從疫區蕉園遴選 3,000 餘株健康臺蕉測定，結果顯示都不具有適當程度的抗病性。以組織培養蕉苗做測定材料，第一年於抗病檢定園分批種植共計 13,878 株，得到 17 株沒有得病。

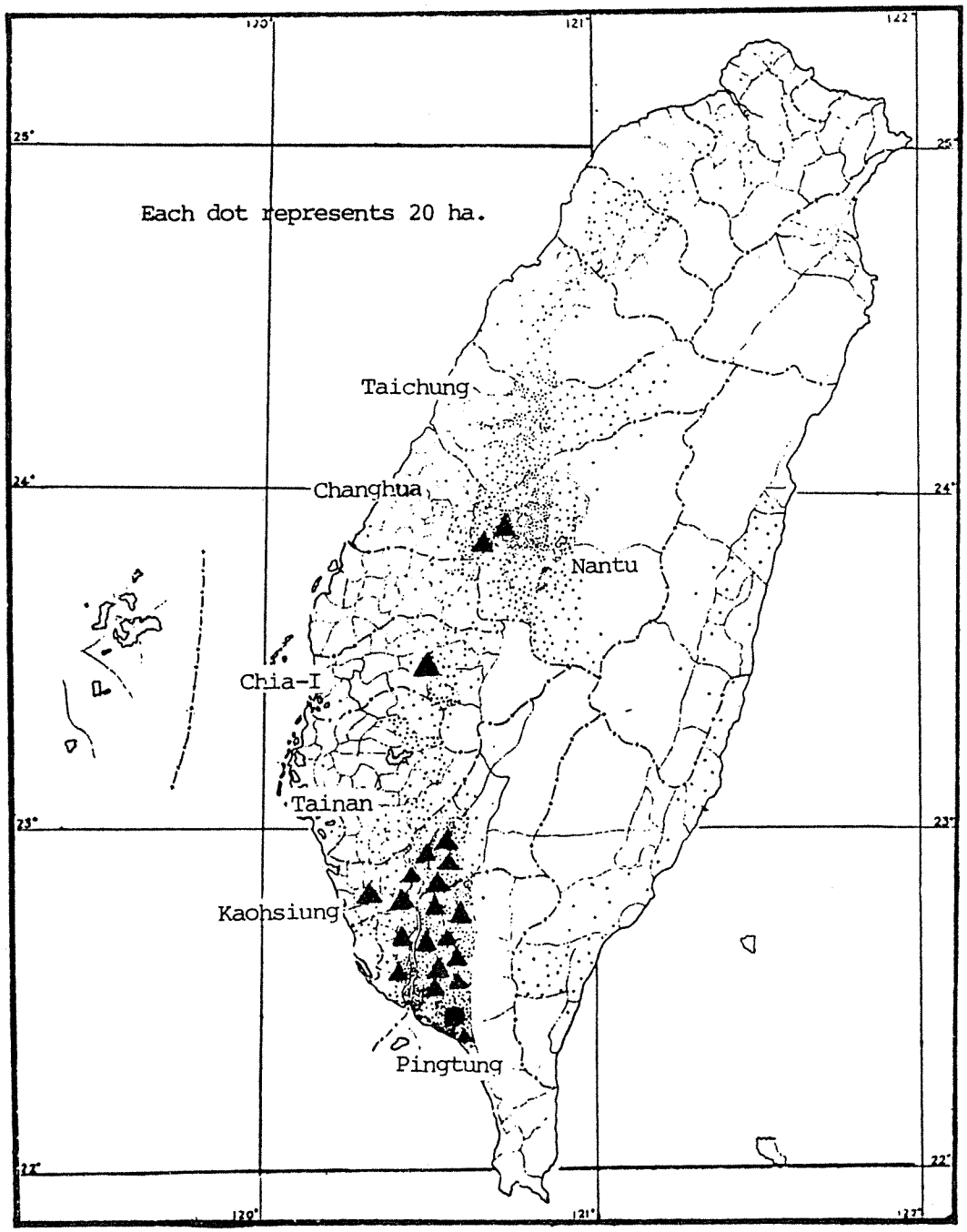
ABSTRACT

Fusarial wilt of banana (*Musa* AAA 'Giant Cavendish' and 'Robusta'). caused by *Fusarium oxysporum* f. sp. *cubense* race 4, is affecting more than 1,500 hectares of banana plantations annually in Taiwan. Cases per year increased from 1,500 in 1968 to more than 500,000 in 1983. The fungus was widely distributed in Pingtung and Kaohsiung counties, and also appeared

sporadically in Changhua, Nantu, and Chia-I counties. Long distance spread of the disease was mainly associated with movement of water and infected suckers, while disease spread within the field was mainly attributed to the irrigation water, pruning practice and planting of infected suckers. Disease incidence is affected by temperature. After 2.5 months of growth at various temperatures, percentages of infected banana plantlets were 10% at 17°C, 14% at 21°C, 17% at 25°C, 40 % at 29°C, and 58% at 32°C. Mechanical wounding of roots increased wilt incidence. In a field trial involving 60 plants tested, 67% of the plants became infected when inoculation was made under wounded conditions, as compared to 38% under unwounded conditions. Inoculation of wounded rhizome failed to establish infection. No reduction in disease was evident with soil liming. A substantial reduction in disease was found following rotation with rice. After one year in rice wilt incidence was reduced to 8.1-17.6% from a level of 30-50% originally, and after 2.5-3 years it was reduced further to 0.8-6.3%. Upland crops such as sugar cane and sunflower were not effective as a rotating crop. In the diseased orchard, the pathogen was distributed primarily in the upper 20 cm of surface soil, and was not detectable in soil beneath this depth. After one year in rice, 2% of the original fungal population remained surviving in the upper 3 cm surface soil, while it was not detected in soil below 10 cm in depth. After 2 years in rice, population of the fungus in surface soil was decreased further to nondetectable level. In a screen-for-resistance test conducted under field conditions for which more than 3,000 survivors had been selected from severely diseased orchards, none displayed any desirable level of disease resistance. In a mass screen program for testing banana plantlets derived from meristem culture under greenhouse or field conditions, 17 clones remained wilt-free from a total of 13,878 plantlets of Taiwan Cavendish screened in the first year.

INTRODUCTION

Fusarial wilt of banana, caused by *Fusarium oxysporum* f. sp. *cubense* (E. F. Smith) Snyder & Hansen, was the most devastating disease affecting commercial banana production in the Western hemisphere between 1900 and 1960. Over a period of 60 years, the disease had destroyed about 100,000 acres of banana plantations and influenced the economy of many countries[19]. Finally, it forced a change in banana cultivation from the susceptible Gros Michel to the resistant Cavendish varieties. Since the resistant Cavendish has been the major banana variety of world commerce, the disease is no longer a major problem in all banana growing countries, with exceptions of the Canary Island, Australia, South Africa, and Taiwan[11,20,21]. In Taiwan the disease, first noted in 1967, is most serious, and now it is affecting more than 1,500 hectares of banana plantations annually. The fungus that attacks Taiwan Cavendish was identified to be race 4 of *F. oxysporum* f. sp. *cubense*[2,21].



● Original infection centers noted in 1967.

▲ Areas with fusarial wilt of banana caused by *Fusarium oxysporum* f. sp. *cubense* race 4.

Fig. 1. The banana growing areas in Taiwan and distribution of fusarial wilt of banana.

With a banana trade of world commerce entirely based on Cavendish varieties today, appearance of the new race virulent to Cavendish varieties posts a threat to all banana growing countries. The outcome could be as disastrous as it once was in South and Central Americas if the disease is not contained. For the control of fusarial wilt in Taiwan, a great deal of effect has placed on the part of resistance selection, and its preliminary results were presented in this report. The spread of disease and the effect of such factors as temperature, soil liming, and mechanical wounding on wilt incidence were studied. Control through crop rotation was attempted.

OUTBREAK, SPREAD, AND DISSEMINATION

Of the approximately 8,000 hectares of banana grown in Taiwan, about 5,000 are grown for export in the South, and another 3,000 are grown mainly for local consumption in the more northern central district around Taichung (Fig. 1). The first cases of fusarial wilt on the Taiwan Cavendish cultivars were found in 1967 in Chiatong district of Pingtung county. The disease continued to spread but was confined around this area in the subsequent 5 years, the affected area increasing from 0.27 to 130 hectares in this period. In 1972, the disease appeared in Kaoshu, about 47 kilometers north of the original infection center.

In 1973, new infection centers were noted in Kaohsiung county. An emergency control measure was proposed for the first time and put into enforcement in the same year. Farmers were paid compensation to destroy diseased fields and to convert them into paddy rice. In 1978-1979, the disease was noted in Chia-I and Changhua counties in the more northern central part of Taiwan. The wilt pathogen attacking Taiwan Cavendish in these two areas also was race 4 of *F. oxysporum* f. sp. *cubense*[3,5]. It was found that the disease was spread from southern part of Taiwan to Chia-I via planting materials. But the route through which the disease was transmitted to Changhua, about 200 kilometers north of banana growing areas in the South, was not understood. At present, about 1,500 of the 5,000 hectares in southern Taiwan are affected. Within the 1,500 hectares about 10-15% of the plants are diseased. Cases per year had increased from 1,500 in 1968 to more than 500,000 in 1983.

Disease appearance is seasonal. The first cases were noticed in October and incidence increased from November through February the coldest month of the year. According to Su *et. al.*[21], the incubation period was longer than 6 months. Disease incidence is affected by temperature, When plantlets derived from meristem culture, 7-10 cm in height, grown in pot (9 cm high, 10 cm wide) containing soil with 500 propagules/g soil of wilt pathogen, were placed in growth chamber for 2.5 months at various temperatures, percentages of plantlets infected were 10% at 17°C, 14% at 21°C, 17% at 25°C, 40% at 29°C, and 58% at 32°C. Results indicate a higher temperature favors disease development, and in the field most infection occurs in the hot, rainy summer. In Central America, wilt incidence of Gros Michel was also greatest in summer months[19], and Rishbeth[14] mentioned that wilt was

less common in Jamaica above 2,000 feet during winter months when night temperature fell below 60°*F*.

Of the many ways by which *F. oxysporum* f. sp. *cubense* was disseminated, irrigation water and planting of infected suckers were the major factors responsible for long distance spread of disease in southern Taiwan. In the past, one of growers' common practices of 'eliminating' the pathogen from diseased field was to throw infected plants into the ditches or streams. Thus the pathogen in abundance was carried away by the water with subsequent outbreaks of disease along the movement of water. The fungus was frequently detectable in the stream water during the diseased season. In many instances, diseased plants were found in newly planted field as a result of planting infected suckers.

Once infected, disease spread within the field can be brought about by various ways. In some cases where the disease moved along the row, movement of irrigation water and the pruning practice were the major factors to account for this spread sequence. Since fragments of diseased tissues rich in the pathogen move easily in the irrigation ditches, disease can be spread rapidly from one plant to another along the row. Hwang and Su[4] provided evidence showing that the pathogen was carried by the pruning tool and caused infection from plant to plant as the pruning was done along the row. However, with annual replanting as a common practice in banana cultivation, the disease in most cases spread randomly in the field through the movement of infected suckers in subsequent replantings.

EFFECT OF MECHANICAL WOUNDING ON WILT INCIDENCE

It is not known how *F. oxysporum* f. sp. *cubense* initiates an infection. While some workers believed infection in the field was mainly via lateral roots[13,19,26], others believed entry occurred through wounded rhizome[1,27]. The mode of entry is also a controversial subject. For instance, Brandes[1] and Wellman[27] reported that infection occurred through uninjured roots; on the other hand, Salas [16] and Sequeira *et al*[17]. considered that mechanical wounding of mature main roots prior to inoculation was essential for infection.

Effect of root wounding on disease incidence···The experiment was carried out in a field free of disease. The suckers 120-150 cm tall from healthy mother plants were used as planting materials. Two months after planting, root inoculation was made by (A) placing inoculum in a small ditch (15 cm deep), dug 30 cm away around the rhizome, and (B) placing inoculum on the soil surface evenly distributed within 30 cm surrounding the rhizome. Many roots were cut off or damaged in the first treatment. Thirty plants were used for each treatment, and each plant was inoculated with about 900 g of chopped diseased tissues (7.5×10^5 propagules/g of diseased tissues). The inoculum was covered with soil after inoculation. About 67% of plants in the first treatment showed wilt symptom, while only 38% of plants were diseased in the second treatment after 9 months. Results showed that plants are more susceptible to fusarial wilt when their roots were

mechanically wounded. Wounding also increased the rate of disease development. The first case of wilt appeared about 3 months after inoculation under root wounding conditions, while it took about 5 months without root wounding.

Annual replanting is a common practice in banana plantation in southern Taiwan. A few months after planting the field is ploughed to make ridges for flood irrigation and drainage purpose. When the suckers are 4-5 feet tall, a bamboo prop is inserted post-like into the ground and tied to each plant. New suckers are dug out monthly up to the shooting stage. Fields are kept free from weeds by hoeing. These practices usually result in considerable root damage, and hence render the plants more susceptible to wilt. This may explain why fusarial wilt infection occurs more readily in replant suckers than in ratoon suckers, as was observed in the diseased areas.

Infection through rhizome···Three holes (3 cm deep) were excavated on each rhizome with a cork borer, and then were filled with diseased tissues. Inoculation was made either at time of planting or two months after planting, with 5 plants per treatment. None of 10 plants showed wilt symptoms by the end of harvest. In the greenhouse, banana plantlets derived from meristem culture [10], about 15 cm high, were inoculated in the same manner, and the result was also negative. Results of this study indicate that damage to the rhizome, such as tunnels made by weevil borers, is unlikely to provide entry for the wilt pathogen. It appears that in the field infection occurs exclusively from the roots.

EFFECT OF SOIL LIMING ON WILT INCIDENCE

Based on the rate of fusarial wilt spread, Stover[19] broadly divided the soils into resistant and non-resistant types. The disease spreads slowly in suppressive soils, but rapidly in conducive soils. One of the difference that distinguished these two types of soils was the calcium content. The calcium contents in suppressive soils was usually higher than those in conducive soils. It has been generally assumed without supporting evidences that calcium-deficiency in conducive soils is a contributing factor to wilt incidence. A beneficial effect of calcium on the fusarial wilt of tomato, caused by *F. oxysporum* f. sp. *lycopersici*, was shown by Jones and Woltz[9] who found that addition of lime to soil greatly decreased the incidence and severity of tomato wilt.

Because the ammonium sulfate has been extensively used as nitrogen source, the soils of banana plantations in southern Taiwan in general are lower in calcium and rather acidic. According to Stover (personal communication), the calcium level in Taiwan banana leaves was about 1/2 to 2/3 of that found in the Central Americas. The inadequate amount of calcium in soils and in plants may reduce the resistance of Taiwan Cavendishes to wilt. Field trial therefore was made to study the effect of liming on wilt incidence.

Five fields at different locations were chosen from the diseased areas. Lime (CaO) was applied at 5 tons per hectare and ploughed to the upper 30 cm of soil. The reaction of these soils before and

after liming was shown in Table 1. Planting of suckers was made at one month after liming. The results were negative as far as influencing disease incidence was concerned (Table 1). In one of these fields tested disease incidence was even higher in the limed than in the control plots. Replanting of banana was made in these field in the subsequent year and again the results were negative.

In a greenhouse assay involving the use of plantlets, Chuang (personal communication) also found that wilt incidence was not decreased with calcium content in soil increasing from 500 to 10,000 ppm. This is in agreement with those liming trials carried out in Central Americas where the Gros Michel was attacked by *F. oxysporum* f. sp. *cubense race* 1[15,18].

Table 1. The effect of soil liming on incidence of fusarial wilt of Cavendish banana

No. of plants tested	Wilt incidence (%)[1]	
	Limed plot	Control plot
155	12 (pH 7.1-7.7)[2]	11 (pH 5.7-6.3)
531	6 (pH 7.4-8.1)	3 (pH 7.0-7.8)
359	34 (pH 4.5-6.5)	44 (pH 4.2-5.5)
891	21 (pH 5.6-7.1)	24 (pH 4.3-6.4)
1050	45[3](pH 6.5-7.2)	26 (pH 5.5-6.6)

1) Data are averaged from two replicates in each field.
2) Soil pH was measured at shooting stage of banana plants, about 8 months after liming.
3) Significantly different from paired mean at 5% level by analysis of variance.

CONTROL BY CROP ROTATION

Fusarium oxysporum f. sp. *cubense* survives in soil for years. The longevity and level of population of the fungus is largely determined by such soil environmental factors as pH, soil type, and oxygen supply in soil, etc. Oxygen deficiency created by flooding or poor drainage resulted in a rapid decline of population[12]. This was once the practice in fusarial wilt control in Honduras, Panama, and other areas in South and Central Americas[19]. The banana plantations in southern Taiwan, once devastated by the wilt, were generally converted to paddy rice. The field soil was under flooded conditions for a period of about 5 months during two rice growing seasons in a year. The effectiveness of rice as a rotated crop for controlling fusarial wilt was investigated.

Replanting of bananas were made in 6 fields at different locations in the diseased area, each with 30-50% of wilt incidence upon abandonment of the banana crop. These fields had been in rice cropping continually for 1-3 years previously. Two sugar cane and one sunflower fields in adjacent area, that

also had been severely infected with fusarial wilt previously, were replanted with banana as non-flooded check. Suckers obtained from a wilt free orchard were used as planting materials. Results showed that percentages of wilt incidence in fields following rice were lower than that in fields following sugar cane or sunflower (Table 2-A). After one year in rice, wilt incidence was reduced to 8.1-17.6% from original 30-50%, and after 2.5 to 3 years it was further reduced to 0.8-6.3 %. No reduction in disease was evident in fields preceded by sugar cane and sunflower as rotation crops even for 3 years. Rishbeth[14] also reported that continuous planting of cane for 10 years did not control the disease.

Table 2-A. The effect of crop rotation on incidence of fusarial wilt of Taiwan Cavendish banana

Kind of crop and rotation period	No. of banana suckers planted[1]	Wilt incidence[2] (%)
Rice, 1 year	221	17.6
Rice, 1 year	132	9.8
Rice, 1 year	209	8.1
Rice, 1 year	229	15.3
Rice, 2.5 years	362	0.8
Rice, 3 years	320	6.3
Sugar cane, 3 years	435	38.6
Sugar cane, 3 years	616	70.9
Sunflower, 3 years	716	52.0

1) Suckers obtained from a wilt free orchard were used as planting materials.
2) Incidence of fusarial wilt of banana in these fields was 30-50% before rotating to other crops.

In another experiment, banana plantlets of 15-20 cm in height derived from meristem culture were planted to 6 diseased fields that had been in rice for 1.5-2 years previously. All these fields had a disease incidence > 20 % upon conversion to rice. Again, disease incidence was reduced to a very low level of 0-4.8% in most fields tested (Table 2-B). A 100% disease control was found in 2 fields that had been rotated with rice for 1.5 and 2 years, respectively. However, rotation of rice did not result in an effective disease control in a field located at Linpen, in which 20% of banana plants were wilted in the first year. This field was in immediate vicinity of other diseased banana fields during the testing period. Failure in disease control in this field may be attributed to the recontamination problem.

It is interesting to note that the disease usually appeared on or near the edge of former rice field. Tsai *et. al.*[25] also observed a same pattern of disease distribution in their control experiment with rice crop rotation. In preparation of

Table 2-B. The effect of crop rotation on incidence of fusarial wilt of Taiwan Cavendish banana

Location[1)]	Acreage[2)] (ha)	Rice cropping period (yr)	Wilt incidence (%)
TBRI exp. farm	0.2	2	0.3
TBRI exp. farm	0.1	2	0
Linlo	0.2	1.5	0
Wantan	0.25	2	4.8
Linpen	0.1	2	20
Chiatong	0.2	2	0.5

1) Field located at TBRI exp. farm were surrounded by other diseased banana fields, and were irrigated with underground water.
Fields located at Linlo, Wantan, and Chiatong were rather isolated, and were irrigated with surface water.
Field located at Linpen was surrounded by other diseased banana fields, and was irrigated with surface water.

2) Plantlets, 15-20 cm in height, raised from meristem culture were used as planting materials.

land for planting rice, incidentally it was found that most of diseased tissues were moved in water toward the edge when the field was plowed under flooded conditions. Consequently, the population of wilt pathogen in soil was higher on or near the edge than in the inner portion of the field. In the absence of host, the fungus was able to survive in non-flooded soil or in the roots of weeds commonly grown on the ridge[22]. This may explain why the infection first started from the edge in these fields.

SURVIVAL AND DISTRIBUTION OF THE PATHOGEN IN SOIL

With the replanting practice, abundant inoculum enters the soil from decaying diseased rhizome and pseudostem annually, and the inoculum potential in soil increases rapidly. As a result, the banana orchards in southern Taiwan, once infected, in general were destroyed in 3 years. By using the selective medium[23] for isolation from soil, the pathogen was found distributing primarily in the upper 20 cm of surface soil, and was not detectable in soil beneath this depth. Survival of the pathogen in soil is greatly influenced by the moisture. Hwang[5] reported that the fungus was able to survive for longer than one year in moderately moist soil, while it survived for 4 and 7 months only in submerged and dry soil, respectively. In a study of survival of the pathogen in the rice field, diseased soil containing 2.3×10^3 propagules/g soil, wrapped in nylon screen, were buried at various depths in soil. After one year in rice, 2% of the original fungal population remained surviving in the upper 3 cm of surface soil, while it was nondetectable in soil below 10 cm in depth. After 2 years in

rice, population of the fungus in surface soil was decreased further to nondetectable level. The yearly crop sequence in this field was rice-fallow-rice-bean during the testing period.

SELECTION FOR RESISTANCE

Appearance of the new race of *F. oxysporum* f. sp. *cubense* in Taiwan prompts the need to seek for resistant variety. The Taiwan Banana Research Institute has a collection of about 150 banana cultivars introduced from abroad. Hwang *et. al.*[6] showed that all the economic important cultivars belonging to the Cavendish group tested were susceptible to race 4 of the wilt pathogen, although some were highly resistant to race 1. Susceptibility to *F. oxysporum* f. sp. *cubense* race 4 of those introduced cultivars of economic importance, i. e. Dwarf Cavendish, Giant Cavendish, Grand Nain, Robusta, Valery, Veimama, Vietnam Chiao, and Williams Hybrid, were about the same as compared to that of Taiwan Cavendish[6]. The fact that none of existing economic cultivars tested possess any desirable level of wilt resistance suggests the need to seek resistance by other means. Due to the lack of resistant parent materials and the sterility inherited in triploids, breeding for resistance through conventional hybridization is extremely difficult and impractical in bananas. Efforts were made to seek source of wilt resistance from the somaclonal mutation occurring in nature or in meristem culture.

Selection of resistance from local commerical cultivars — Between 1974 and 1983, more than 3,000 selections were made from survivors in areas devastated by wilt in southern Taiwan. Suckers of wilt-free plant were obtained, and planted in a seriously diseased field. A sizable amount of diseased tissues was added to soil to maintain a high population of wilt pathogen in soil. Once wilt appeared at the first year the clone was discarded. From 1975 onward, only progeny showing more than 20% of disease out of 5-10 suckers tested was discarded. Clones showing 0 to 20% of disease were retained for further observation. By 1978 only 8 clones were left in the selection. In 1979, a total of 113 suckers obtained from these 8 clone were compared with 'check' plants in a grower's diseased field. Results showed that 90 out of 113 suckers were infected, and no clone remained wilt-free or had a lower percentage of wilt incidence. Several mutants of Taiwan Cavendish obtained from the local plantations were found also susceptible to the wilt[28].

Mass screen of plantlets from meristem culture — To prevent the spreading of fusarial wilt of banana by planting infected materials to the disease-free orchards, plantlets derived from meristem culture have been propagated for commercial planting in Taiwan since 1983[7]. A field survey showed that about 3% of banana plants grown from the plantlets were mutated[8]. Somaclonal mutation is an important potential source of disease resistance especially on such vegetatively propagated crops as bananas. With this rate of mutation generated from banana meristem culture, plantlets therefore are considered promising materials worth extensive screening for wilt resistance. That disease development in plantlets was faster than in suckers[24]

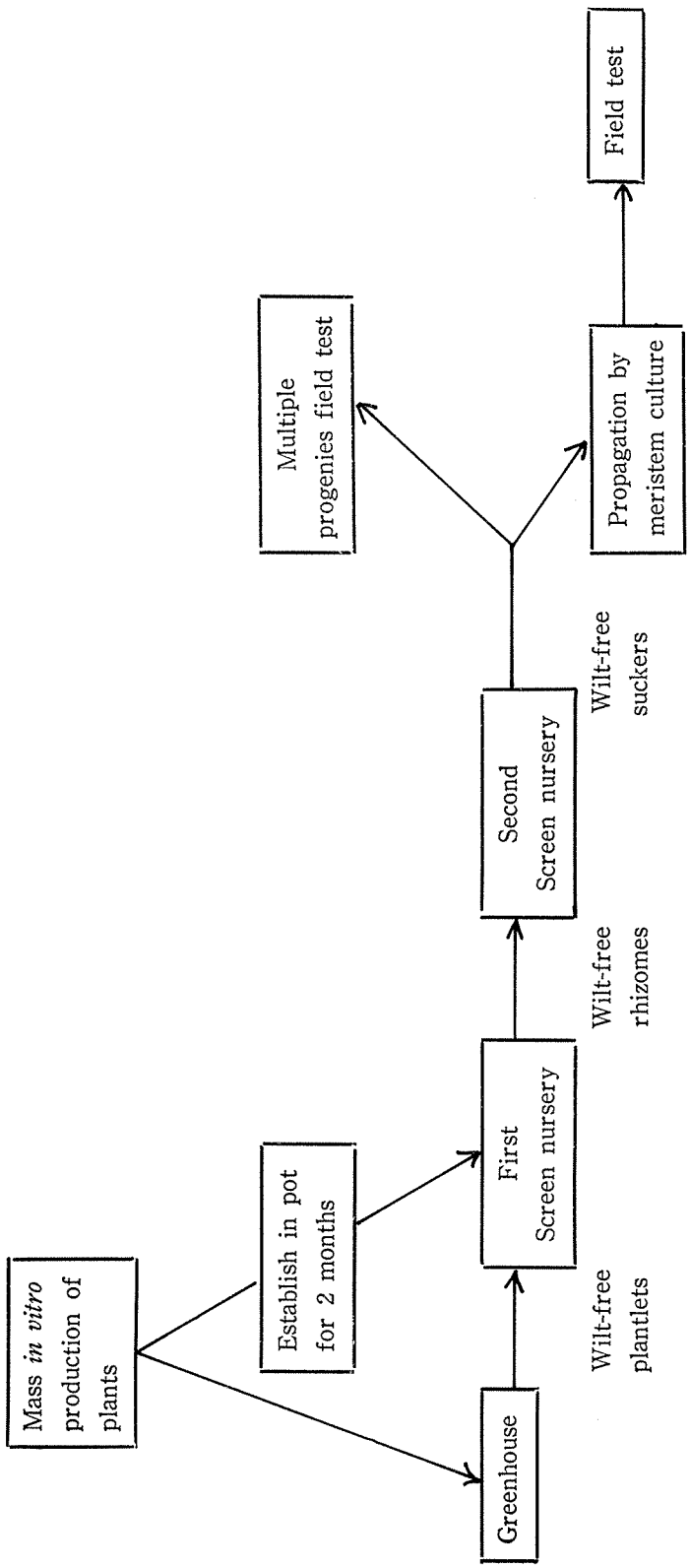


Fig 2. Screening of mass-produced *in vitro* plants of Cavendish varieties for resistance to race 4 of *Fusarium oxysporum* f. sp. *cubense*.

is also an advantage of using plantlets for screening purpose. Response of plantlets to different races of wilt pathogen was similar to that of suckers of the same variety[24].

The screen test was conducted under both field and greenhouse conditions (Fig. 2). Plantlets, propagated by the method as described by Hwang *et. al.*[7], were established initially in pot (9 cm high, 10 cm wide). The growing medium consisted of 60% vermiculite, 30% sand, and 10% organic manure by volume. Plantlets were maintained in the screenhouse for two months before transplanting to the field. The field soil had a content of fungal propagules at about 1200/g soil, ranging from 600-1500/g. Examination for vascular discoloration in the rhizome was made 4 months after planting. The plants with rhizome free from infection or with mild infection were replanted for further observation. In the greenhouse, plantlets taken out from the test tube were directly planted to the soil containing about 600 propagules/g soil, with a range of 400-1200 fungal propagules/g soil. Examination for disease was carried out after two months of growth. By using this method, a total of 13,878 plantlets of Taiwan Cavendish were screened in the first year, 17 of them remained free from infection. Further testing of these wilt-free clone is in progress.

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