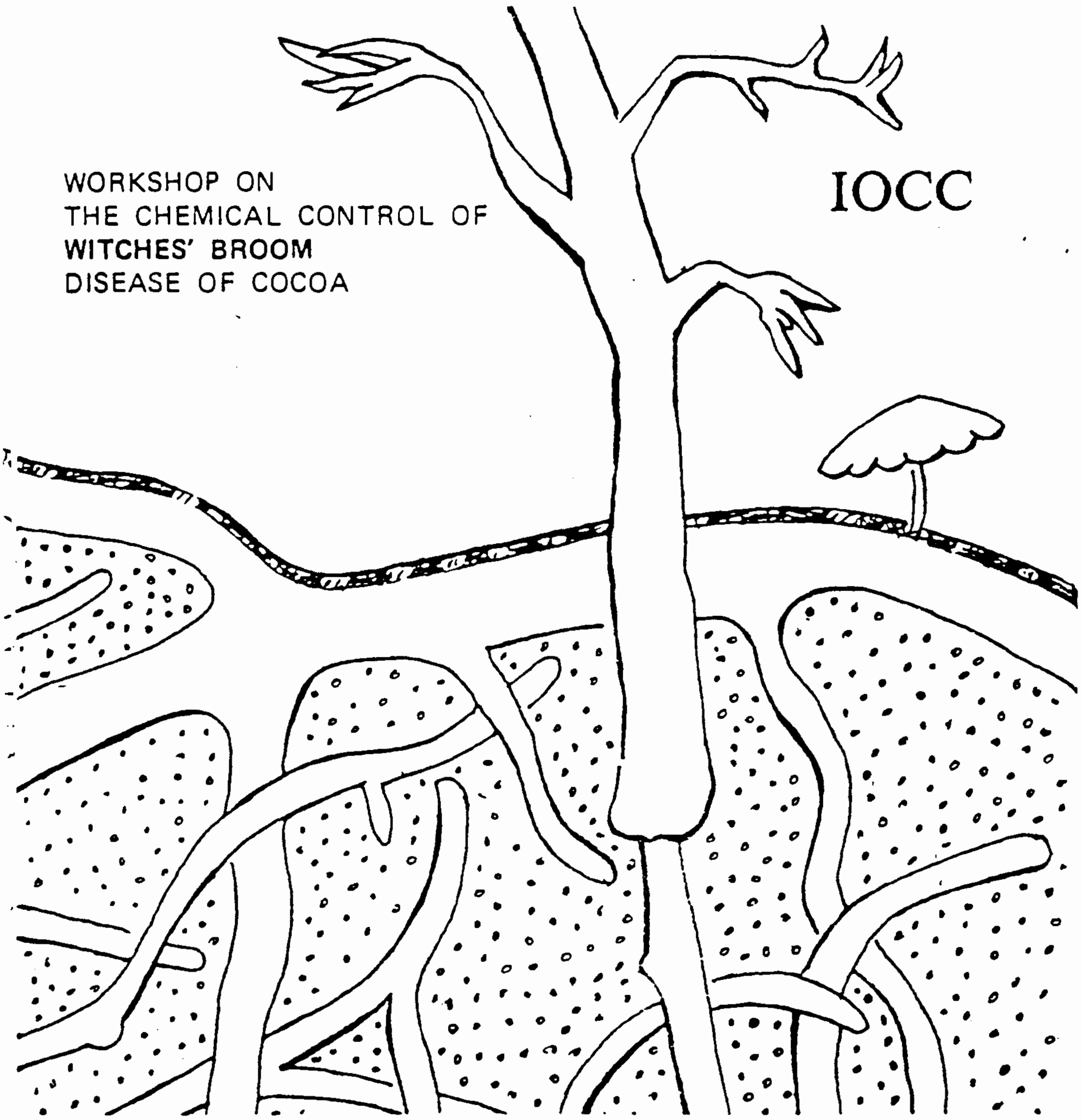
MANAGING WITCHES' BROOM DISEASE OF COCOA

REPORT OF 2nd WORKSHOP
OF INTERNATIONAL WITCHES' BROOM PROJECT

17 - 18 October 1985, Wageningen, Holland

WORKSHOP ON
THE CHEMICAL CONTROL OF
WITCHES' BROOM
DISEASE OF COCOA

IOCC



INTERNATIONAL WITCHES' BROOM PROJECT

(IWBP)

IWBP is an international project funded by chocolate manufacturers in Europe and North America with a number of International Agencies and with the governments of 4 cocoa producing countries. It proposes to conduct fundamental research at a total of 11 centres in Europe, Latin America and the United States aimed at a reduction of the devastation caused by Witches' Broom disease of cocoa due to the pathogen <u>Crinipellis</u> <u>perniciosa</u> (Stahel) Singer.

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REPORT OF THE 2ND IWBP WORKSHOP

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C O N T E N T S

1. INTRODUCTION TO IWBP

Almost one-third of the world supply of cocoa is produced in the Americas but in many countries maximum production is severely curtailed by Witches' Broom (WB) disease. It occurs in the upper Amazon region of Brazil, in Bolivia, Colombia, Ecuador, Grenada, Guyana, Peru, Surinam, Trinidad and Venezuela. This widespread distribution also places at risk other areas where it is not yet present, such as Bahia, Brazil - the second largest concentration of cocoa plantings in the world - or proposed new plantings of cocoa such as in Amazonia, Brazil. In the Brazilian Amazon pod losses have reached 95 per cent on occasions, and almost all infected pods are a total economic loss. Moreover, there is NO assurance that its absence from cocoa producing countries outside the Americas will continue.

These features make a co-ordinated, multi-centre, multi-national research program on WB a top priority and so this project proposal was formulated by scientists in countries where the disease is important. The pathogen (*Crinipellis perniciosa*) causes over-development of cocoa meristematic tissues leading to hypertrophied and proliferated growth, to give the characteristic "Witches' Brooms" (Escoba de Bruja/Vassoura-de-Bruxa/Balai de Sorciere). It also infects many pods. Infected pods fail to ripen and the beans either become liquified or adhere to the pod husk and are commercially valueless. In view of this serious threat, the International Office of Cocoa and Chocolate (IOCC) is funding a US $ 700,000 multinational research project over a period of about 5 years from 1st July 1985. The objective of the Project is to develop practical and reliable economic methods of managing the disease in a number of cocoa growing environments. To achieve this, two broad studies commenced on 1st July 1985. The first on epidemiology of the disease and second on chemical control.

1.1 Epidemiology

To examine systematically, infection dynamics of Witches' Broom disease relative to time (both seasons and years) with respect to critical environmental factors. More specifically to quantify the dynamics of inoculum production, infection court phenology and subsequent disease incidence and severity with respect to climatic parameters. Although there have been many useful investigations on certain aspects of the life cycle and behaviour of the Witches' Broom pathogen, there is still no detailed published work for any cocoa growing region on the quantitative development of a Witches' Broom epidemic.

A pilot scheme at Ouro Preto do Oeste, Rondonia, Brazil has attempted to develop methods which answer the three questions basic to any epidemiological study namely:

- how much inoculum of C.perniciosa is generated within a cocoa farm infected with Witches' Broom?

- what proportion of the susceptible tissue becomes infected by this level of inoculum?

- which meteorological factors influence the production of inoculum and the infection of cocoa?

Although the full results of the pilot scheme have not yet been analysed, the data collected already indicate the most important parameters to be measured and their potential for answering the questions posed above.

A standard methodology and associated equipment to measure the infection dynamics were agreed at the 1st IWBP Workshop and this is reported fully in this document in Section 5 of the Report of 1st Workshop of the International Witches' Broom Project published by IOCC in August 1985. The 1st IWBP Workshop was held at INIAP-EET, Pichilingue, Quevedo, Ecuador from 1st-5th July 1985. [Copies of the Report are still available from Drs. A van Tulder, Director General, IOCC, Avenue de Cortenbergh, 172, Brussels, 1040, Belgium]. The agreed Protocol with the standard experimental methodology is reproduced in full in that Report. Epidemiological studies following the agreed standard methodology to collect the broadly based epidemiological data will now be carried out in Colombia, Ecuador, Trinidad and elsewhere in Brazil. It is obviously essential that all participating institutions and individuals follow the agreed procedures so that data from all the centres are genuinely comparable. IOCC will be providing funds for these studies on that basis and the results of the first twelve months' activities will be reviewed at the 3rd IWBP Workshop to be held in July 1986 in Manizales, Colombia which will be hosted jointly by Instituto Colombiano Agropecuario (ICA) and IOCC.

1.2 Chemicals

To examine and evaluate the reaction of Witches' Broom to all available systemic, protective and eradicative chemicals including application to the soil and the effect on basidiocarp development on brooms sprayed when green. Plant growth hormones will also be examined as they may have a useful role in disease control. Work will comprise initial laboratory and glasshouse screening, followed by field evaluation in areas of high and low Witches' Broom incidence. Preliminary discussions on the methodology and initial preparation of another Protocol in draft form were the objective of the 2nd IWBP Workshop which is the subject of this Report.

It is then proposed that an economic management system to control the devastation of this disease will be developed, based on the findings of both the above studies. The proposals for this work remain to be elaborated at a future date.

2. Background to 2nd IWBP Workshop .

The first study of the infection dynamics was discussed in considerable detail at the 1st IWBP Workshop. A detailed methodology and experimental Protocol was agreed at that time and reproduced in the Report of the 1st Workshop. The organisation of IWBP, the responsibilities of the various Project officers and committees, the sponsoring agencies and the experimental Protocol are all fully described in that report.

The second broad study involving examination and evaluation of the reaction of a wide range of fungicides and growth hormones remained to be progressed. It was therefore decided by the Project organisers to invite all interested agrochemical companies to participate in a Workshop on the 'Chemical Control of Witches' Broom Disease of Cocoa'. A brochure by way of an invitation to any interested company was prepared and issued worldwide through the good offices of GIFAP (International Group of National Associations of Agrochemical Manufacturers) who also included a mention of the Workshop in the

GIFAP Bulletin, July/August 1985. Their assistance is acknowledged with gratitude. The International Agricultural Centre at Wageningen was considered to be an appropriate venue and our thanks go to the responsible authorities there for allowing us to use the facilities.

3. Narrative Report of the 2nd IWBP Workshop

Participants assembled at the International Agricultural Centre, Wageningen, Netherlands in the morning of Thursday 17th October 1985. They included representatives of a number of agrochemical companies and some members of the Project Scientific Committee of IWBP. The names, addresses, telephone and telex numbers of participants are attached as Appendix A to this report. The 2nd IWBP Workshop started at 14.00 hours on Thursday 17th October 1985 and the Programme is attached as Appendix B. The objectives of the Workshop were discussed and adopted as follows:

> "Bearing in mind that disease management is the final objective of IWBP and that a major programme of collection of epidemiological data on Witches' Broom disease is now underway, the objectives of the 2nd IWBP Workshop were agreed to be as follows:
>
> 1. Define the scale of the problem of Witches' Broom disease of cocoa and the potential market for an effective agrochemical;
>
> 2. Identify the role of, or target for, a fungicide or other bio-active compound in the control of Witches' Broom;
>
> 3. Attempt to define standard screening techniques for candidate chemicals;
>
> 4. Elaborate a systematic and co-ordinated screening programme and identify the participating centres at which the programmes could be conducted."

A following presentations were made and the texts of these follow, abridged where necessary for the purpose of this report.

1. 'The Cultivation of Cocoa' by H.Toxopeus, a plant breeder with a number of years experience of cocoa breeding, presently based at SVP, Wageningen, member of IWBP Project Scientific Committee.

2. 'The Epidemiology of Witches' Broom' by B.E.J. Wheeler, reader in plant pathology at Imperial College, London with considerable research experience and author of a number of published papers on Witches' Broom disease of cocoa, member of IWBP Project Scientific Committee.

3. 'Possible Strategy in Chemical Control of Witches' Broom Disease of Cocoa' by Louis Pereira, Head Plant Pathology Division, CEPEC, Brazil, most recently working on chemical control of Phytophthora pod rot of cocoa in the development of the Single Application Technique.

4. 'Some Comments on Pesticide Application Techniques for Cocoa' by Nigel Scopes, International Liaison Officer at the Commonwealth Institute of Biological Control, England, who was unfortunately not able to attend the Workshop but who has had a recent opportunity to study Witches' Broom disease in Rondonia.

5. 'Some Economic Information on Cocoa Production in South American Countries affected by Witches' Broom Disease' by S.A. Rudgard, IWBP Liaison Officer, and R.A. Lass, Executive Chairman, IWBP.

4. Presented Papers

4.1 The Cultivation of Cocoa
by Hille Toxopeus

Cocoa is largely grown from seeds sown in pots in a nursery and planted in the field when about 6 months old during the onset of the rain season. For good growth the cocoa plants require a sheltered environment which is created by growing temporary shade crops. As the cocoa trees develop, this shade is reduced, eventually disappearing as the cocoa closes its canopy. At this stage the plantation requires some permanent (overhead) shade, the plants of which are usually planted together with the side shade. Figure 1 is a schematic representation of the essential elements of a high yielding mature cocoa plantation:

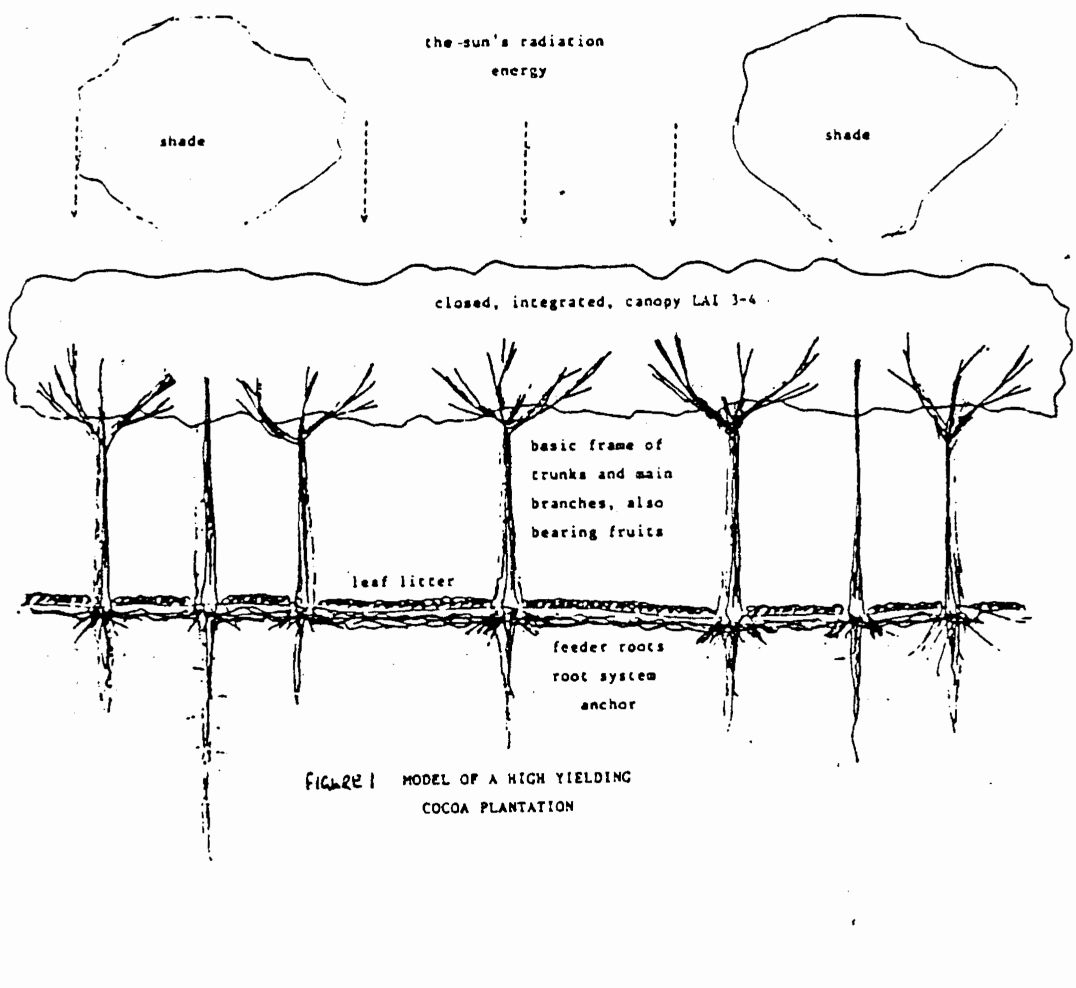


FIGURE 1 MODEL OF A HIGH YIELDING COCOA PLANTATION

The integrated canopy of leaves will, with a leaf area index (LAI) of 3-4 absorb about 95% of the incoming radiation, part of which is intercepted by the overhead shade. This radiation fuels the photosyntheic mechanism which enables the leaves to produce carbohydrates. The carbohydrates are the primary materials for the synthesis of the cocoa butter (fat) contained in the beans and nearly 50% of the weight of cured beans is made up of fat. In biochemical terms synthesis of fat from carbohydrates requires much energy.

The cocoa beans are produced in pods which grow from successfully pollinated flowers. Pollination is effected by small insects, usually midges that accidentally brush off pollen onto the pistil whilst feeding inside the flower. Flowers arise from flower cushions on mature wood of the trunks and branches. It takes 5-6 months for a pod to grow to maturity and ripen. Generally speaking the life of a leaf is one year. Although there are peaks in the number of falling leaves, the tree is not deciduous. The dropped leaves make for a thick leaf litter which, in conjunction with the very low light intensity in the plantation largely prohibits weed growth. The decaying leaf litter merges gradually with the top soil, which is rich in organic matter and well sheltered against the eroding effects of insolation and heavy rainfall.

The topsoil is well rooted with the lateral, feeder roots. The firm tap-roots anchor the trees firmly in the soil and absorb moisture from lower down the soil profile. Fertilisers can be deposited on top of the leaf litter and the nutrients are released gradually in the top soil.

4.2 Epidemiology of Witches' Broom

by Dr.B.E.J. Wheeler

The Disease

Witches' broom is hardly a new disease as it was first reported from Surinam in 1895. It can be extremely destructive, having signficantly reduced cocoa production in Surinam, Ecuador, Trinidad and Grenada, and it now threatens new plantings in the Brazilian Amazon. It is not yet found in the main producing area of Brazil, Bahia, but is a potential threat there as well as to all other cocoa areas outside South America.

The name "Witches' Broom" is derived from the resemblance of infected vegetative shoots to the mythical brooms used by witches. Brooms also form on flower cushions and on seedlings and there is considerable variety in symptom expression. Infected pods develop an external necrotic lesion associated with much internal damage, often leading to complete loss of the beans.

The Fungus

The disease is caused by a basidiomycete fungus first described in 1915 by Stahel as *Marasmius perniciosus.* It was later transferred by Singer (1942) to *Crinipellis* and is now known as *C. perniciosa.* The fungus is endemic to forests of the Amazon basin, occurring on wild cocoa, related species of *Theobroma* and *Herrania,* lianas and also woody species from the understorey.

Within this collection there are a few morphological differences which have resulted in the designation of three varieties: Stahel's fungus,var. *perniciosa*; an Ecuadorian form,var. *ecuadoriensis*; and a yellow form,var. *citriniceps*. Variations in pathogenicity are more important. Three pathotypes have been described: a cocoa strain found in *Theobroma* spp. and *Herrania* spp.; a liana strain; and a solanaceous strain recorded from *Solanum* spp. (e.g. *S.rugosum*). On cocoa itself there are two pathotype populations: one form in Ecuador/Colombia Bolivia; the other form in Venezuela/Brazil/Trinidad. These two are distinguished primarily by their behaviour on Scavina 6 cocoa.

Experience in Rondonia suggests that cocoa plantations newly established in areas cleared from the forest probably become infected by inoculum from outside the plantation. This is thought to come from wild cocoa or other *Theobroma* spp. However, once the disease is established, inoculum produced within the plantation is of over-riding importance.

Production of Inoculum

Cocoa can only be infected by basidiospores of the fungus which are deposited by the mushrooms or basidiocarps. Green vegetative and cushion brooms never produce them, and there is a dormancy or incubation period of 2-16 months after broom necrosis before basidiocarps will form, even if conditions are ideal.

In a general way, the production of basidiocarps on dead brooms is associated with periods of rain, although the controlling factor is alternate wetting and drying. Under these conditions successive flushes of basidiocarps are produced. Given suitable conditions of wetness, other factors which influence productivity are the type of cocoa, temperature and light. Brooms can remain on trees over a two year period. Some fall to the ground and may continue to produce basidiocarps, though often they produce less and at slightly different times to those still on the tree.

Basidiospores are released at night, with a peak usually betwen 24.00h and 03.00h. The number of spores released is considerable, and concentrations of $2,000/m^3$ of air have been detected at peak times by spore traps in Rondonia. Typically they travel only a short distance and, although most sediment out near the release point, some longer distance spread does occur.

Infection

Basidiospores can only infect young tissue, so infection is associated with growth flushes of cocoa, i.e. vegetative buds, flowers and young pods. The number of these therefore constitutes the total number of infection courts. Given a film of water, spores germinate rapidly and may infect within a 3-4 hour period.

The mycelium grows intercellularly once infection is established. This form, the parasitic form, has never been grown in culture. When the broom dies, this mycelium gives rise to a thinner type which becomes intracellular and degrades the host tissue. This form can be grown in culture but all attempts to infect cocoa with it have failed. The fungus is eventually present on the tree in two forms. Within infected tissue which has died, it is present in a saprophytic form which colonizes the tissues and, during periods of rain, gives rise to basidiocarps. In infected living tissue, it is present as parasitic mycelium. Both forms are within the host plant, only the basidiocarp is on the host surface.

4.3 Possible Strategy in Chemical Control of Witches' Broom Disease of Cocoa
by J.L. Pereira

Introduction

Certain plant diseases have made their impact on the welfare of mankind and to this day remain classic examples. Of these *Phytophthora infestans* of potatoes and *Hemileia vastatrix* of coffee receive special attention, when during the period of their first appearance lack of epidemiological data and lack of a freely available suitable fungicide, contributed to the disasters. However, in the case of *Plasmopara viticola* downy mildew of grape vine, Bordeaux mixture played an important role in reducing losses. In the same way, *Phytophthora infestans* and *Hemileia vastatrix* are manageable pathogens today, due to the availability of a host of fungicides. The recent discovery of coffee leaf rust in Brazil caused alarm but in reality was not devastating.

The economic effects of the reduced losses and the cost of control (when available) should be considered on different groups: the producer, consumer, agri-industry and society at large, (Ordish, 1952; Ordish and Dufour, 1969). Witches' Broom (caused by *Crinipellis perniciosa*) is a disease that has demonstrated its importance in Surinam, Ecuador, Trinidad, Brazil, Colombia and Venezuela and continues to pose a serious threat to the cocoa growing region of Bahia, Brazil which accounts for 95% of cocoa production from the second largest world producer.

Witches' Broom is not a new disease, having been described in 1915 (Stahel, 1915), neither has the fungus been insufficiently investigated (Evans, 1978. Evans, 1980) nor is there a complete lack of basic epidemiological data on which to formulate a control programme. However, there is an absence of a reliable means of containing the disease. Fungicides, anti-fungal compounds or biocides usually have a buffer effect on the first impact of plant disease, providing a relatively stable system of crop production and paving the way to integrated control involving other control strategies. In the case of Witches' Broom this is not so despite various attempts.

In a preface to the paper by Baker and Holliday (1957) three phases of investigations into Witches' Broom were determined; first, Stahel's essential work in Surinam following the discovery of the pathogen and description of its life history; second, Baker and his co-workers in Trinidad studying factors controlling development of the fungus; finally, the stage initiated by Pound on the discovery of high natural resistance occurring in certain Amazon populations of wild cocoa followed by the breeding programme in Trinidad. There now appears to be a need for a fourth phase based on previous experience with new epidemiological data and more recent advances in the chemical industry - a truly international thrust directed at chemical control. This is contrary to the opinion in 1957 (Baker and Holliday, 1957) that 'spraying against this disease must not be given undue weight'. Today the importance of an integrated strategy involving fungicide sprays cannot be ignored. Absolute rules describing disease control cannot be easily defined because control of disease is directed at populations of two different organisms in a changing environment (Fry, 1977). While it is not intended to play down the role of disease management involving host resistance or cultural practices such as pruning and spacing urgency demands that chemical control must have high priority since other strategies may contribute little, if anything, to curtail a sudden major outbreak of Witches' Broom in Bahia, Brazil or in West Africa.

Disease Losses

The negative effect of each symptom of Witches' Broom on the growth and production of the cocoa tree has to be identified and its relative importance assessed. Disease losses may be considered into two groups;

1) Basidiospore infection of meristematic tissue giving rise to characteristic brooms due to hyperplasia and hypertrophy. These symptoms may vary on terminal or lateral shoots depending on the cultivar, type of tissue involved and its stage of development (Evans, 1981). Losses at this point may be classified as a progressive physiological depletion of the reserves of the tree through sinks of quick growing non-productive tissue. There are trees of less than 10 years old in Rondonia, Brazil, completely depleted due to unchecked broom formation. The removal of brooms could increase input cost by about 20 per cent. Phytosanitary control needs 30-80 man-hour/ha depending on level of infection. (Andebrhan pers.comm.). In

severe cases drastic pruning would be necessary which in fact remodels the architecture of the tree. Work in Ecuador by Maddison and Mogrovejo (1985) showed that the disease interferes with the establishment of plantations and application of prophylactic measures at the nursery stage was recommended.

2) Loss of pods. This includes reduction of potential crop by infection of flower cushions resulting in abnormal flowers, parthenocarpic pods (chirimoyas) and cushion brooms. The other losses are those of the developing crop, particularly cherelles that are highly susceptible until 2-3 months of age. Evans (1981) correctly pointed out that C. perniciosa is a major pod pathogen in its own right and that in Rondonia (Brazil) potentially high-yielding cocoa farms may show over 90 per cent pod infection. Mixing beans from infected pods with healthy beans also affects the quality of the export crop.

Earlier Attempts at Chemical Control

As early as 1915 Stahel made reference to the use of fungicides, predominantly Bordeaux mixture, for the control of Witches' Broom disease. Later Stell (1932) recommended field application of fungicide and Dale (1946), Thorold (1953) and Holliday (1954) showed higher yields and a reduction in broom formation after chemical sprays. The fungicides tested by these authors included cuprous oxide, copper oxychloride, lime sulphur and two organo-metallic products (tetramethyl thiuram disulphide and zinc dimethyl-dithiocarbamate). Pod infection levels were reduced to between 36-70 per cent in some cases.

Eradicants, directed at sporophore production on brooms left on trees were examined by Desrosiers and Bolanos (1952). They showed a significant reduction in percentage of brooms producing sporophores, and also the number of sporophores produced per broom by spray application of phenolic or crezolic water soluble compounds. Recently, fungicides with systemic properties were screened in Brazil (Anon, 1984), and a Brazilian PhD student attempted to elucidate some of the precise action of these products on the fungus.

Strategy of Control

The title of this paper admits a need for further knowledge to make a proposal for a clear cut strategy. Witches' Broom does not differ from other disease situations where a sound knowledge of the host, the pathogen and its behaviour with a specific environment is essential to formulate a spray programme. Identification of critical parameters and interactions with the phenology of the cocoa tree have been and are receiving special attention.

In any one year disease losses are related to the amount of inoculum at the beginning of that season and so may be classified as a simple interest epidemic. When the disease is characterised over a number of years a compound interest model becomes relevant. During a survey in 1982 to determine the impact of Witches' Broom on new cocoa plantings in the Amazon region of Brazil, progressive increase in disease from the sixth year after planting was noted. The nature of the disease epidemic may demand strategies to reduce the amount of initial inoculum or reduce the rate of epidemic development.

Experiments on chemical control should extend for a period of 3-5 years. The influence of the disease in any year would be related to the incidence in the previous year and the degree of control during the present year would influence the number of brooms in the following year. The cumulative effects of treatment must be part of the objective of a control strategy. Plantings surrounding the trial area contribute inoculum, and the range of viable spore dispersal will determine distance of trial sites from other cocoa (work in progress - Dr S Rudgard, Ouro Preto, Rondonia, Brazil). Field recording in an experiment should quantify two or more disease units (shoots, developing pods or flower cushions) to distinguish between the disease cycles (brooms) and direct crop loss (fruit).

Dimond _et al_. (1952) classify chemothereputants in three groups of chemicals; those that counteract the toxin produced by the pathogen, those that alter the metabolism of the host to give resistance to the infection and finally those true systemics that enter the plant and translocate to the site of infection to act directly on the pathogen. The mechanism of the first group is unknown. The second stimulates the plant's natural defences, is presently commercially available and proven in the control of _Phytophthora_ pod rot for cocoa (Figueiredo _et al_.,1984). However, this action is probably limited to Peronosporales. In the third case recently developed fungicides, which are inhibitors of sterol biosynthesis, deserve further investigation. Triadimefon has shown promise in Witches' Broom screening tests. The mechanism should receive more attention to complement or substitute for protectant fungicides.

Since disease losses are attributed to brooms by depletion of the resources of the tree and pods by lowering of production the precise timing for protecting both these sites could be determined by examining their annual distribution. The numbers of infected brooms and flower cushions shows a steady increase from November to about April with a peak in June (Figure 2.1). The numbers of infected fruit show a similar pattern (Figure 2.2). A simplified strategy could involve protectant (copper) sprays from about December to July to protect susceptible tissue from infection during the period of basidiospore production (Andebrhan, 1982). Such schedules have been examined for cocoa. They are expensive but Phytophthora pod rot control in certain areas of Bahia, Brazil, requires the same number of copper sprays and is justified economically. If such a schedule attained its objectives then it is likely that it would have been widely adopted by farmers particularly in potentially high yielding cocoa in Rondonia, Brazil. Therefore, because farmers have not adopted it the efficacy of such a spray programme remains in doubt.

FIG 2

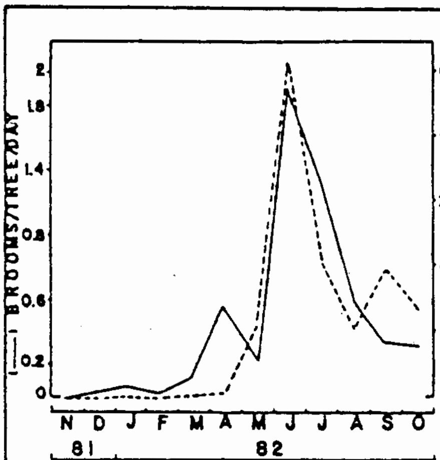


Fig.2.1
INFECTION RATE OF BROOMS AND FLOWER CUSHIONS,
Ouro Preto (RO) Brazil.
(after Andebrhan, 1982)

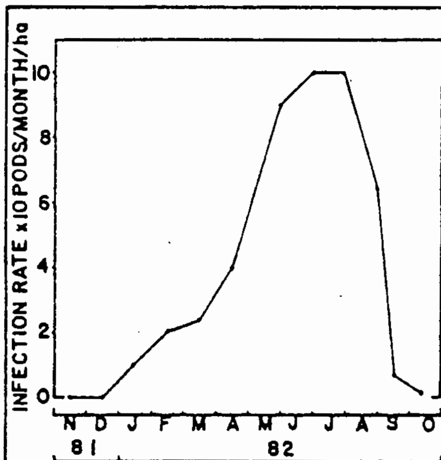


Fig.2.2
INFECTION RATE OF PODS/MONTH,
Ouro Preto (RO) Brazil.
(after Andebrhan, 1982)

An alternative proposal could be to have two schedules, one aimed at brooms and the other at pods.

Since broom development coincides with the appearance of a flush and subsequent infection by basidiospores originating from previously formed brooms, the chemicals in the first schedule could aim to restrict the colonization of the young flush tissues. Different modes of fungicide action have to be considered. It could be useful to have a protective cover of fungicide to prevent spore germination or a systemic fungicide to be drawn into the transpiration stream and carried into the meristematic tissue thus acting on intercellular mycelium. An eradicant product could be used finally to complete the schedule. In the case of Rondonia a low cost, wide spectrum protective fungicide such as copper could be applied early in the season, probably January/February, thereby preventing spore germination and repeated invasions of the same pod. A rapid increase in brooms and infected flower cushions occurs in May. Another mode of fungicide action is the proposed involving one or two sprays of a systemic fungicide with known selectivity on C. perniciosa to act on intercellular mycelium in infected brooms or flower cushions. Triazoles, triadimefon ('Bayleton') or carboxylic acid anilides, possibly oxycarboxin ('Plantvax') and piracarbolid ('Sicarol') may be considered in view of their control of basidiomycetes. These products might be considered in a tank-mix to avoid a build up of resistance and incorporate two modes of action simultaneously. Under field conditions pathogen resistance to the carboxins has not been found (Schmeling and Kulka, 1966). These products might be applied in a tank-mix with copper. At peak infection but before necrosis of brooms or before pruning, a single spray of an eradicant fungicide might be applied to destroy mycelium in brooms or flower cushions. In this case phenolic, crezolic compounds or newer eradicant products could be considered. It is worth mentioning that triadimefon also has excellent eradicant activity. However, we still require a product to stimulate the plants' natural defence mechanism against basidiomycetes. This product could be applied early in the schedule, as in the case of Phytophthora pod rot in Bahia (Pereira, unpublished data). We challenge the fungicide research chemists to provide us with such a product.

The second spray schedule could be designed to maintain production using a copper base fungicide, from bud burst on flower cushions for 3-4 months. This has been proved objective with a single application to control Phytophthora pod rot (Pereira and Lellis, 1984). The intrinsic factors that support the Single Application Technique in the control of Black Pod are similar to those in Witches' Broom. Therefore, loading the canopy with a single massive application (about 12g Cu++/tree) as in Phytophthora pod rot control would permit redistribution of the fungicide following similar pathways as the fungus. Figure 3 attempts to demonstrate this schedule.

Fig. 3 A TENTATIVE STRATEGY IN CHEMICAL CONTROL OF WITCHES' BROOM

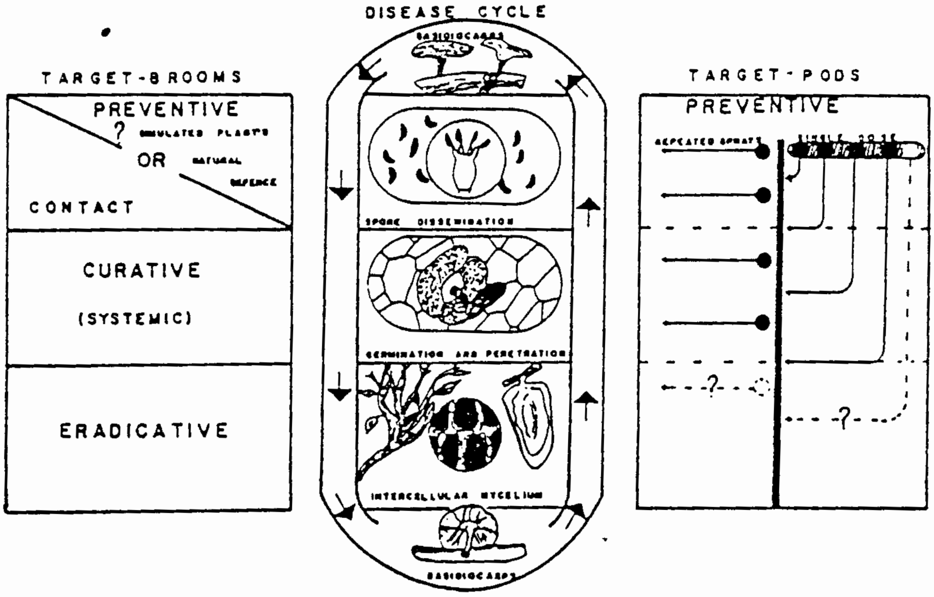
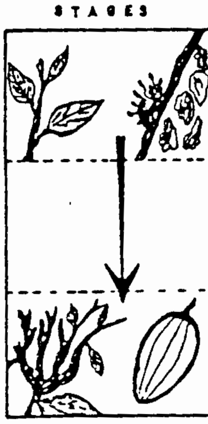


Fig4 A COMBINED SCHEDULE FOR BROOMS AND PODS IN CHEMICAL CONTROL OF WITCHES' BROOM.



STAGES	MONTH	MODE OF ACTION	POSSIBLE FUNGICIDES
	1	PROTECTIVE Single aplication, contact effect on spores for 3-4 months	Copper or similar
	3-4	CURATIVE Systemic on mycelium (and eradicant?)	Triazoles or carboxylic acid anailides or similar
	5-?	ERADICATIVE Before broom necrosis or pruning	Phenolic or cresolic compouds or newer eradicants

In practice, one does not expect to operate two separate spraying schedules and adjustments will be made depending on flushing and flowering periods in various countries, incorporating the principles of the two schedules as much as possible. This appears to be possible in the case of Ouro Preto, Brazil and a tentative schedule combining the two schedules is shown in Figure 4. It starts with a single application, aimed at loading the canopy with a contact fungicide. Before this application ceases to have effect, one or two systemic fungicide applications are made. These products may have eradicant properties and would link well with the next application, that of the truly eradicant chemical.

It is not intended to make recommendations for specific products in this paper nor will the full economic implication of the schedules be evaluated. The aim of this paper is to propose a schedule compatible with the pathogen's behaviour. At a later stage field trials will be needed to make substitutions of fungicides of higher efficacy, the technology of fungicide application and in the physio-chemical properties of spray and spray distribution patterns. All of these will influence greatly the economics of application. Phytotoxicity and residue properties of all these chemicals would have to be confirmed before any of them could be recommended.

Other Considerations

The degree of survival of the fungus through the dry season on previously infected brooms or fruits determines the inoculum potential at the start of a new disease season. In the control of *Venturia inaequalis*, benzimidazole fungicides when applied during the previous growing season have positive effects on reducing initial inoculum of ascospores ejected from perithecia in decaying leaves (Burchill, 1972; Ross, 1973). Investigations in this direction with reference to brooms require more attention. There are limitations of screening fungicides *in vitro* especially since the mode of action involved in the eventual use of the fungicide may not be clearly demonstrated in tests for systemic compounds (Pelletier, 1977).

The action of triarimol, triforine and triadimefon on sterol metabolism of fungi (Lyr, 1977) needs further study in the case of Witches' Broom. A typical property of basidiomycetes is the formation of chitin as a cell wall constituent, and phosphorganic fungicides ('Kitazin' and edifenphos or 'Hinosan') that act on chitin synthesis could have a positive role in the control of this disease.

Basic physiological studies on apoplastic movement could clarify the translocation pathways for systemic fungicides in the plant and show that brooms have a higher transpiration rate resulting in a differential sink as compared to normal shoots. Some host/pathogen interactions mentioned by Dimond and Rich (1977) also deserve examination. Host tissue often reacts to systemic fungicides and these changes may enhance control through production of fungitoxins, a physical barrier of stomatal closure, other alterations in vascular anatomy or modifications in cell walls. In the same way, other compounds of a hormonal nature may retard meristematic activity or offset flushing for periods when basidiocarp production is insignificant and may contribute to chemical control.

The mode of action of mineral oils in disease control systems is not fully clear, but it is possible that photosynthetic and transpiration rates are reduced by their application (Calpouzos, 1968). This effect on Witches' Broom disease may be worthwhile investigating.

Conclusion

In a control programme effective cultural practices or resistant genotypes contribute to integrated control. Persistent pruning as practised by the BrazilianJapanese community at Tome-Acu, Para, Brazil merits praise but the process is labour intensive and only made possible by the particular social system in that area. A search for truly resistant genetic material requires more time, and so there exists an urgent need for a strategy in chemical control of Witches' Broom, be it as a stop gap or as a routine measure economically acceptable to commercial farming in the longer term.

This paper has attempted to trace a strategy for chemical control. An advance in this field requires international cooperation and full support of the agricultural chemical industry.

Acknowledgement

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4.4 Some Comments on Pesticide Application Techniques for Cocoa
by N Scopes

The development of improved pesticide application techniques is relevant for both pest and disease control, but the overriding problem of reducing disease loss necessitates emphasis in this area. To this end, efforts to reduce pod disease by techniques applicable to small farmers in developing countries demand that chemical studies centre on the use of copper fungicides which are cheap and available worldwide.

It is important to increase our understanding of the etiology of the important pathogens of cocoa to facilitate improved pesticide performance. Such an approach should enable long-lasting benefits to be obtained for the cocoa growing industry and help to keep production costs low. A relevant programme would have 5 components:

1. Improving spray coverage on pods;
2. Basic studies to evaluate the relation between spray deposits and the efficiency of disease control on pods;
3. Studies to improve retention of pesticides on pods.
4. Fungi occur within the tree canopy and are redistributed down by rain, many remaining in the leaf litter. The value of canopy spraying to study the effectiveness of redistribution of pesticide, as well as ground treatments need to be studied so that an integrated approach to spraying may be developed;
5. Study the environmental consequences of alternative spray programmes;

These headings will now be discussed in turn.

1. <u>To improve spray coverage on pods (field studies)</u>

There have been no significant advances in the equipment used by cocoa farmers in the last 30+ years and it is essential that new technologies be evaluated.

a. Evaluation of current application equipment and methods (mistblowers, knapsack units, foggers, etc);
b. Evaluation of air assisted spinning disc units and electrostatic unit and comparison with conventional systems;
c. Translating the information gained into practical methods for the farmer;
d. Study of the likely environmental impact of proposed spray systems;

2. <u>Efficiency of pod spraying (laboratory studies)</u>

The cocoa pod is a dynamic, continuously growing target, thus an understanding of the behaviour of a pesticide deposit on the pod surface is important.

a. Detailed study to determine the requirements of an ULV spray for protection. It will be necessary to develop an assay system which will define the number of drops per unit which are required to protect against disease. Variations in the effects of concentration and formulation of the deposit must be understood;

b. Study the performance of different patterns of spray deposit in relation to growth of the pod;

3. <u>Retention of spray residue on cocoa pod (laboratory and field studies):</u>

Fungal attacks are prevalent during wet seasons, thus any deposit should persist despite heavy rain.

a. Evaluate rainfastness of current copper formulations.

b. Evaluate the benefits (if any) from spray additives i.e. polybutenes. Studies would include rainfastness and redistribution.

c. Ecological consequences of the use of additives.

4. <u>Value of non-pod spraying (field studies)</u>

Disease causing organisms may occur in the leaf litter under the tree as well as within the canopy. Reductions in the overall inoculum must play a part in disease control.

a. Relate canopy spray treatments (application method and frequency) to practical disease control. How do different application systems affect redistribution by rain?

b. Evaluation of ground spraying with fungicides for the reduction of inoculum in the soil and prevention of disease spread by rain splash;

c. When primary data are collected, relate the relative values of pod, canopy and ground spraying to develop an integrated approach;

5. Environmental effects

All spray programmes have ecological consequences and it is important to predict the consequences of any new approach to pesticide use, especially when chemicals are applied to soil.

a. Experiments to obtain some understanding of the soil flora and consequences of spray programmes on the flora and fauna of cocoa plantations.

4.5 Some Economic Information on Cocoa Production in South American countries affected by Witches' Broom Disease

by S A Rudgard and R A Lass

Witches' Broom disease occurs in countries that between them account for 35% of world cocoa production (Gill and Duffus Report 321, December 1985), though not all the cocoa in these counties is affected by the disease and pod losses vary according to regional management practices. Before considering the more theoretical aspects of chemical control of Witches' Broom (Section 5), it is necessary to have an understanding of cocoa production in the principal South American countries involved, and discuss some economic aspects of market size for agricultural chemicals and spray costings.

4.5.1 Cocoa Growing Regions

Much cocoa in South America is grown on large holdings. Most holdings are between 15 and 30 hectares, but there are plantings up to several hundred hectares in some of the more traditional cocoa regions. Plantations are normally scattered over large areas, seldom being planted as a monoculture over a whole region. Currently there are over a million hectares in South America and the West Indies (Table 1), at least half of which is not affected by Witches' Broom (Figures 5 to 8) and accounts for about 65 per cent of South American production. This disease escape is partly geographical and partly climatic, although there is no reason to suppose that exclusion will be permanent. The potential losses could be devasting were Witches' Broom to reach Bahia, Brazil (18 per cent of world production).

Table 1 - Economics of Cocoa Production for Principal South American Producers and Estimated Losses to Witches' Broom Disease

Country	Production (M.tonnes)	Area[a] (ha)	Yield (kg/ ha)	Growers' Receipts	WB Losses[c] ($ million)
Brazil(e)	67,500	90,000	750	89.6	38.4
Colombia	40,000	90,000	520	68.0	29.2
Ecuador	70,000	290,000	240	92.8	39.8
Trinidad	2,000	7,000	290	4.4	1.9
Venezuela	18,000	83,000	210	26.1	11.2
Total	197,500	560,000	-	280.9	120.5
Brazil[d]	325,000	550,000	590	507.0	-

a. area of mature productive cocoa
b. estimated using percentage of World Price of $2400/tonne
c. estimated at 30%, therefore 30/70 of actual turnover
d. area free of WB at present; States of Bahia and Espirito Santo
e. Amazonian Region

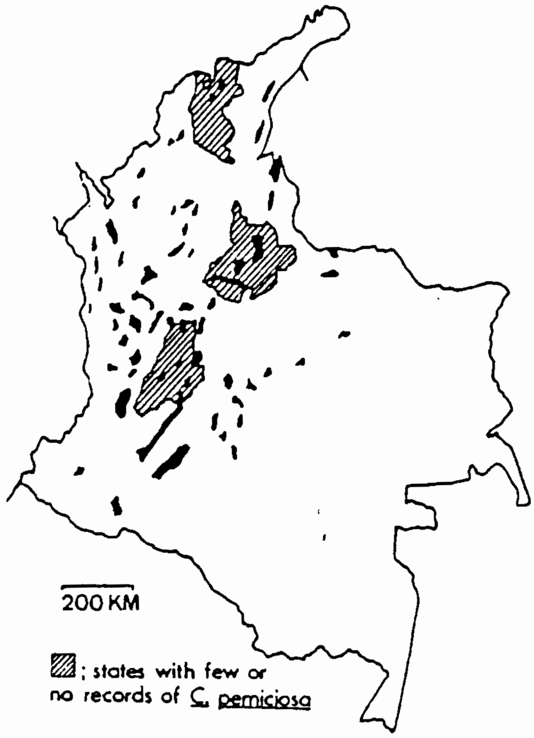
FIGURE 5 BRAZIL

COCOA GROWING REGIONS

▨ ;areas from which *C. perniciosa* is absent

FIGURE 6 COLOMBIA

COCOA GROWING REGIONS



▨ ; states with few or no records of *C. perniciosa*

FIGURE 8 VENEZUELA & TRINIDAD COCOA GROWING REGIONS

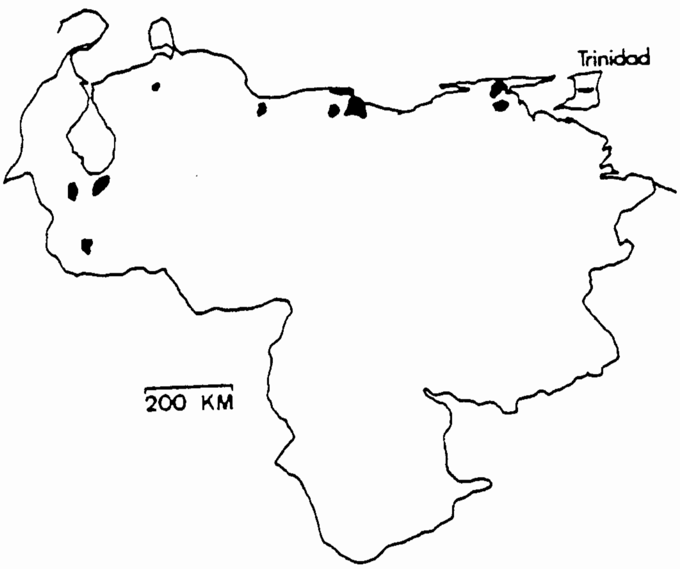
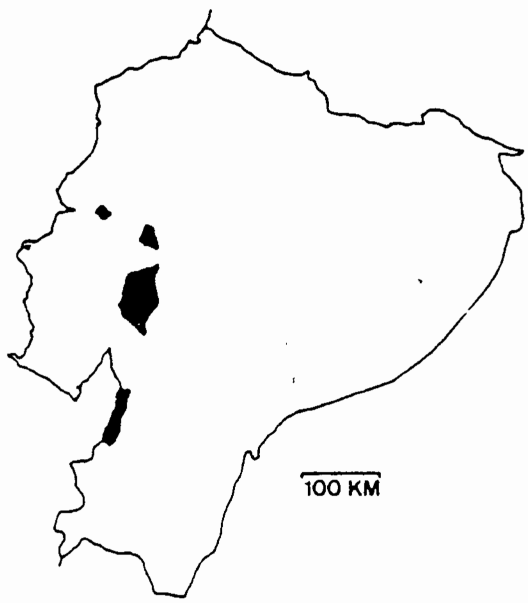


FIGURE 7 ECUADOR

COCOA GROWING REGIONS



Several planting projects (e.g. Surinam, and Uraba, Colombia) have been abandoned because of WB; others continue but with severe disease levels and very low production (e.g. Ecuador). With the colonisation of the Brazilian Amazon some 90,000 hectares have been planted in a very short time, although that figure would undoubtedly have been much higher had it not been for Witches' Broom.

4.5.2 Production

Many factors affect the productivity of cocoa in South America, and it would be wrong to imply that Witches' Broom was the sole important agent. Total production is more than 500,000 metric tonnes (Table 1), but yields vary from 750 to 210 kg/hectare. There are few reliable estimates of losses to Witches' Broom over entire regions. In Colombia and Brazil good yields are maintained even with high disease pressure.

Average losses in these regions are probably about 30 per cent (official sources), though where no cultural control is applied upto 90 per cent lossses can occur. Yields in Ecuador, Trinidad and Venezuela could probably be greatly improved with better disease management, although paricularly in Ecuador another pod disease (*Moniliophthora roreri*) also causes severe losses.

An estimate of growers' receipts is US $281 million for those areas affected by Witches' Broom (Table 1), whereby the grower receives between 55 per cent and 65 per cent of the world price (currently around $2,400/tonne). Supposing losses were fixed at 30 per cent overall, an oversimplified estimate, this would mean that $120 million of potential earnings are lost annually. Given that no grower would expect to invest more than a third of his potential yield gain in spraying, the potential market for agrochemicals could be estimated at around $20 million having accounted for application costs. These figures are only rough guidelines.

4.5.3 Spraying

There are no comprehensive data on the cost-effectiveness of spraying fungicides against Witches' Broom disease. Metallic copper sprays are used against *Phytophthora* pod rot in Bahia, Brazil, and from these data dosages may be estimated for use against *C. perniciosa.*

The cost of a single application of 25 kg/ha of copper is $94.32/ha, and if two sprays of a systemic fungicide such as Bayleton at 1 kg/ha each were added, this figure would rise to $149.58/ha. Planting density in Bahia is about 800 trees/ha.

Minimum yields were calculated using the above costings for several rates of pod loss (Table 2), whereby application would only be justified with at least 85 per cent reduction in pod losses. Referring to current yields per hectare, Ecuador, Venezuela and Trinidad would all need to have at least 50% losses to justify spraying with copper at these costs. Obviously spray trials in the different countries would allow for different costs of chemicals, labour etc.

Table 2: Cocoa Yields necessary to sustain two spray programmes at various rates of pod loss to Witches' Broom

(Necessary yield/kg/hectare)

Per Cent Losses	Single Treatment 1 (a)	Single Cu Treatment 2 (b)
10	1,750	4,040
30	460	1,050
50	190	450
70	08	190

a. Treatment 1: Single application Copper at 25 kg/ha; Cost of applications = $94.32/ha

b. Treatment 2: Single application Copper and two applications systemic (such as Bayleton) Cost of applications = $149.58/ha

4.5.4 Conclusion

A sizeable market exists for an already developed fungicide should it be found to be active against Witches' Broom.

Spraying costs would not be unrealistic given the rates of pod loss known to exist in certain regions, and it remains to be seen whether preliminary trials bring to light any promising candidate chemicals.

5. Discussion on Control of Witches' Broom Disease of Cocoa

The discussion on these presented papers extended over many hours. The debate was both interesting and stimulating and all the participants are to be thanked for their active participation. This discussion led to the preparation of the following statement by Drs. Pereira and Rudgard. Unfortunately shortage of time prevented this text being adopted by the meeting but the broad outline was discussed in open session. Management of any disease involves several control processes. Of these, host resistance, cultural methods and chemical control should receive attention. This Workshop and research programme emphasised chemical control as an immediate means of containing the disease, thereby creating economic stability for the development of other measures. Cultural control is routinely applied in certain cocoa areas but at a substantial cost to the grower, from which it is clear that an additional control strategy is required. We hope that chemical control can become part of an economic management strategy.

5.1 Disease Management by Use of Chemicals

5.1.1 Identification of Disease Losses

Two target areas requiring attention were defined:

Pods — due to their importance as a source of income they must receive attention. This is especially true for the recuperation of heavily infested areas. Total prevention of pod infection is not a feasible goal, but a large (e.g. 85 per cent) reduction in pod losses should be the objective.

Brooms — both for their depletion of host resources and perpetuation of the disease cycle by the production of basidiocarps. They have always been previously considered more important than the pods in development of disease control strategies.

5.1.2 Fungicidal Action against WB

Pods — by complete coverage with commonly-used protectant compounds, thus controlling penetration by the fungus and therefore pod infection directly.

Brooms — a. affecting production of basidiocarps by the application of fungicides to dead brooms. Decrease and/or delay in sporulation have been reported by some workers.

b. involving some speculative research with curative or eradicative fungicides. The size of the canopy precludes the use of protective fungicides to cover the large number (often more than 700) buds available to the fungus. The application of systemic chemicals after infection has taken place requires their effective penetration into the plant. Spraying of systemics onto infected seedlings has never succeeded in suppressing broom formation, but some success was reported using soil drenches. Distribution of chemicals within the plant is dependent on transpirational movement, which means that they may not be available in the correct part of the plant in sufficent quantities. Most biotrophic hyphae of Crinipellis are found in the pith, cortex and vascular rays, whilst some can be found in the phloem. Mycelium is intercellular, deriving nutrients through host walls by means of concentration gradients. Fungicides will be transported in the xylem and they will somehow have to move into the intercellular spaces where the hyphae are present. Concentration of active ingredient of the chemical depends on the effectiveness of transpiration as a means of transport. Systemic compounds such as metalaxyl have been used in cocoa and can be translocated. Other compounds will be tested.

5.1.3 Action of Plant Growth Regulators on WB

Plant growth regulators have often proved difficult to apply in tropical crops and their effects have not been consistent. They have a potential role in the control of WB either by suppressing or reducing broom formation, or modifying cocoa phenology to reduce periods of susceptibility.

5.2 Considerations in the Screening of Fungicides

i. Compounds already freely available on the market should be tested in a systematic manner;

ii Protocols should be developed separately for each compound between IOCC and each manufacturer;

iii Intermediate test procedures should be devised between laboratory/nursery screens and large-scale field trials involving inoculations of seedlings or small plants to induce broom formulation;

iv The presence of residues in processed cocoa beans should be examined;

6. Proposed Strategies

Fungicides tested in the past were often expected to give protection through the whole season irrespective of their specific mode of action on one stage of disease development. Limitations in the mode of action of fungicides were considered as an important influence in a schedule covering the complete disease cycle.

For example: copper fungicides on Phytophthora were tested for many years over the whole disease season, when they only provided protection of pods prior to penetration of the fungus. We must ensure a similar situation does not develop for Witches' Broom control.

It is important to note that, systemic (or curative) fungicides have a specific role with regard to intercellular mycelium.

Eradicant compounds are designed to prevent basidiocarp production in the subsequent season.

A schedule was therefore devised involving different modes of fungicidal/chemical action using presently available chemicals. This is presented below for further consideration. It will be discussed in full by the Project Scientific Committee at the 3rd IWBP Workshop due to be held in Manizales, Colombia from 8th July 1986.

6.1 Protective

6.1.1 Metallic

Compounds:	Copper	-	cuprous oxide copper oxychloride copper hydroxide Bordeaux mixture
	Tin	-	fentin acetate (recently introduced)
Mode of Action:			Spraying trunks and pods, although care must taken in evaluation of cushion infection. The natural redistribution of compounds may be examined in terms of protection of pods and cushions.
Formulation:			most commonly wettable powders.
Notes:	i.		wide spectrum - also act against *Phytophthora*
	ii		no problem with resistance
	iii		can work in a single application, with natural redistribution within the tree

6.1.2 Organic

Compounds	-	Captafol (tradename Difolatan, Chevron Chemical)
	-	Chlorthalonil (tradename Daconil 2787, Diamond Shamrock)
	-	Mancozeb (tradename Dithane, Rohm & Haas)

Mode of Action: Applications to trunks and pods on a monthly basis, anticipating also that this would deposit fungicide in the canopy. There will be different erosion and redistribution characteristics to the metallic compounds (i.e. copper). These will have to be determined if a single application technique is to be considered.

Formulation: most commonly wettable powders.

Notes: - not so effective against <u>Phytophthora</u>.

6.1.3 <u>General Points:</u>

High disease pressure is needed if the relative effectiveness of different compounds is to be measured. Normal treatments (phytosanitary prunes) need to be carried out in experimental plots, although inoculum sources such as unpruned trees may be left between plots. Spray applications should start at the beginning of the infection season.

6.2 <u>Curative</u>

Compounds: i. Triazoles, e.g. Triademefon (tradename Bayleton, Bayer AG) Propiconazole (tradename Tilt, Ciba-Geigy AG)

ii Others Oxycarboxin (tradename Plantvax, Uniroyal); IBP (tradename Kitazin, Kumiai); Edinfenphos (tradename Hinosan, Bayer AG); Dodemorph (tradename

	Morpholine, BASF; Tridemorph (tradename Calixin, BASF, Ciba-Geigy)
Mode of Action:	Application onto trunks and pods, establishing penetration of chemical into cushions. Deposition on vegetative shoots within the canopy is equally important. This will stop early growth of the fungus. There may be some protective effect, although the triazoles have more of a disease-stop effect.
General Points	Synergistic effects of mixtures of protectant and systemic fungicides have been reported. These should be investigated with regard to WB control, using combinations of the metallic and systemic products mentioned in paragraphs 6.1 and 6.2.

6.3 Eradicative

Compounds:	Phenolic and crezolic fungicides. Others to be suggested/developed.
Mode of Action:	Application on dead and dying brooms and infected cushions, thereby inhibiting or totally preventing basidiocarp production. Acts as a supplementary reduction of inoculum, used in conjunction with a phytosanitary prune. Otherwise called a chemical prune on suspended or fallen brooms. These compounds would be applied at different times from protective sprays.
General Points:	Problems may occur with phytotoxicity and residues in beans - particularly with phenolic and crezolic compounds. Previously mentioned curative compounds (especially triademefon) may be considered in certain cases to have eradicative properties.

6.4 Plant Growth Regulators

Compounds: Suggestions awaited.

Mode of Action: Application onto test seedlings, at least initially, may reduce brooms due to their much greater vegetative activity. In general, they might retard meristematic activity and/or offset periods of vegetative growth.

7. Proposed Research Programmes

Research into fungicidal materials will use various screening techniques. Work will be done at several centres and protocols will be devised to ensure that tests are comparable. Specific tests will be used to examine different modes of action and evaluation of trials will use experience gained from epidemiology experiments.

Chemical treatments will initially be directed to pods and cushions, owing to the need for a short-term solution to high disease losses.

Programme I: Evaluation of protective/curative fungicides on pods and cushions:

Tested: In field

Location: *either* based in four countries contributing to IWBP (an ideal solution)
or two sites:

i. Rondonia - where pod infection is very high and commercial cocoa very uniform.

ii. Ecuador - where pruning is unlikely to be adopted, and *Moniliophthora* is present.

Programme II: Evaluation of fungicidal activity on canopy infection:

Phase 1. Eradicative - in controlled trials, application on inoculated seedling or small and dead brooms;

Phase 2 Curative - effect of infection on canopy, using intermediate tests on small trees;

Phase 3 Wider range of products - often in preliminary (in vitro) screens - also plant growth regulators.

Location: either based at two sites in South America, with more than one pathotype represented.

or based at one European/north American site where all pathotypes can be used.

8. Conclusions

The main objective of the 2nd IWBP Workshop was to identify the potential role for the use of chemicals in the control of Witches' Broom disease of cocoa. It was felt by the meeting that research on chemical control of Witches' Broom has a firm place in IWBP, and the research programmes will be finalised over the next few months.

Priorities for research were identified, and possible modes of action of fungicides/plant growth regulators thoroughly discussed. Some candidate chemicals already on the market have been identified, and further suggestions of compounds in development may be forthcoming. It is proposed that the Project Liaison Officer will visit the various chemical companies involved to finalise details of availability, formulation etc of the suggested compounds. An outline of a testing programme has been proposed in this Report and will be full discussed at the 3rd IWBP Workshop to be held in Manizales, Colombia from 8th July 1985. Protocols with a number of individual chemical companies will be finalised and screening centres and staff requirements will be identified by the Project Scientific Committee. The details of these discussions will be published in the Report of the 3rd IWBP Workshop in 1986.

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APPENDIX B

PROGRAMME FOR WORKSHOP ON CHEMICAL CONTROL
OF WITCHES' BROOM DISEASE OF COCOA

2nd IWBP Workshop

Wageningen, Netherlands
International Agricultural Centre

Thursday 17th October 1985

1200 - 1400	Registration
1400 - 1415	Opening of the Workshop by R A Lass, Executive Chairman, Witches' Broom Project Management Committee
1415 - 1445	The Cultivation of Cocoa by Ir H. Toxopeus, SVP Wageningen, member of the Project Scientific Committee
1445 - 1500	Epidemiology of Witches' Broom by Dr B.E.J. Wheeler, Imperial College University of London, member of the Project Scientific Committee
1500 - 1630	COFFEE BREAK
1530 - 1600	Possible Strategy in chemical control of Witches' Broom by Dr J.L. Pereira, Head Division of Plant Pathology - CEPEC/CEPLAC - Brazil
1600 - 1700	Discussion

1700 - 1715	Summary by R A Lass
1900 - 2000	Cocktails at the Hotel t'Paviljoen - Grebbeweg 103-105, 3911 AV Rhenen
2000	Dinner for all participants in the Hotel t'Paviljoen

Friday 18th October 1985

0900 - 1030	Problems and scope of Biocides
1030 - 1100	COFFEE BREAK
1100 - 1200	Problems and scope of biocide application
1200 - 1230	Conclusions