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Global Research On Cocoa - *working with and for farmers*

Delivering Substance

We talk a good deal about what cocoa farmers need and what they need to know, but what they definitely need is for innovations to work. Farmer participatory research and training are replacing top-down extension methods, but these approaches, which rely on knowledge rippling out from trained cadres of farmers, do not always achieve results. A study of cocoa communities in Ghana, summarised first, provides insights into how farmers acquire information and who they communicate with. We also profile a chapter in a new IPM book identifying where farmer participation works best. Later in the issue, we introduce new initiatives, funded by the Bill & Melinda Gates Foundation in Africa, and ACIAR in Indonesia, to improve sustainability of cocoa production.

Copper fungicides have a long history in cocoa but poor application reduces efficacy and, in this residue-conscious world, compromises crop quality. Terry Mabbett explores how application of cuprous oxide, specifically, can be optimised for controlling *Phytophthora* diseases as well as epiphytes. Cocoa diseases are rarely out of the headlines, but some considered less significant in recent years have risen to prominence again. An article from Ghana describes cocoa swollen shoot virus and efforts to contain it.

Discoveries about the cocoa genome provide opportunities to improve germplasm, but genotypes fare differently in different environments. An article from Reading University describes how experimental approaches are increasing understanding of genotype–environment interactions, and highlights its importance in view of climate change. Lastly, there is information on INGENIC and INCOPED meetings that follow the 16th ICRC in Bali this November.

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How Farmers Learn from Each Other

Participatory approaches to farmer training and extension have been criticised for being difficult to scale up or sustain. Because it is impractical for every farmer to undertake training, the approach usually relies on trained farmers passing on knowledge (a process that may or may not be formalised) so that the impact ripples out through communities and beyond. The success of the process varies and this may be down at least in part to the effectiveness of farmer–farmer communication.

According to a paper in *Ecology and Society*[1], there is inconclusive research on farmer communication patterns. The authors conducted social network analysis in four communities in Sefwi Wiawso District in Ghana's Western Region, where farmers manage cocoa agroforestry systems in conditions of low soil fertility and face constraints in obtaining fertilisers. They report that farmers often develop ways of improving soil and crop nutrition, as well as managing upper canopy trees for shade and hence increase farm diversity and biomass inputs. Farmers also seek outside advice (e.g. from government, NGOs, radio, etc.). But who seeks advice, and how is knowledge shared?

Interviews conducted among farmers in the four communities gave similar communication structure. In each case, the authors found the advice-seeking social network consisted of (a) a small 'core' of farmers who sought information from outside and, within the community, mostly from each other; and (b) a larger 'periphery' of other farmers who sought information largely from core members, and were less-often consulted by core farmers or other peripheral members. Thus each community as a whole relies for farming advice on a small group of farmers who exchange information between themselves and also seek advice from outside sources. Although the study focused on verbal communication, farmers reported observation (and therefore geographic proximity) as an important means of knowledge acquisition: seeing neighbours' successful farming practices (usually followed up by discussion) and imitating

A multi-strata cocoa agroforestry system: how do farmers obtain information for agroforestry management?

them. Core and peripheral members were equally likely (in percentage terms) to replicate the practices of neighbours, and the authors identify local-level imitation as perhaps central to information diffusion and worthy of further study.

The study included both local farmers and new settlers and, perhaps unexpectedly, both were represented in the core.

In This Issue

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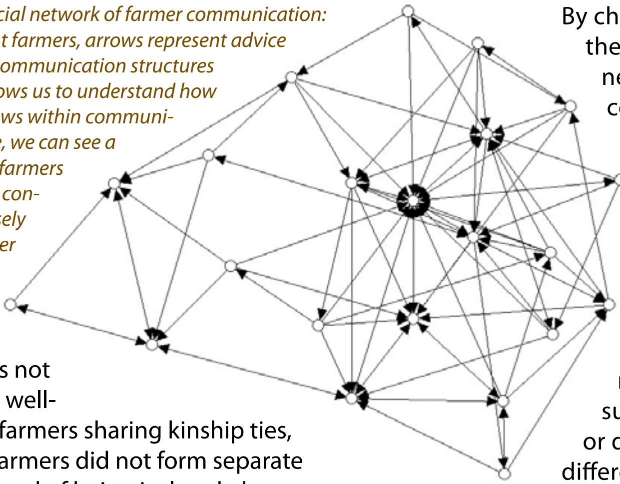

An example social network of farmer communication: circles represent farmers, arrows represent advice ties. Mapping communication structures such as this allows us to understand how information flows within communities. In this case, we can see a small group of farmers who are highly connected but loosely tied with a larger periphery of farmers.

The core was not restricted to well-established farmers sharing kinship ties, and settler farmers did not form separate clusters. Instead of being isolated, the two groups formed connections through seeking farming advice from each other. In addition, core members were more likely to be involved in community activities. The authors suggest that new settlers are less constrained by social links from changing their ways and hence adapt their practices to the new environment, while local farmers are more likely to be copied by their kinsmen; thus both have a valuable role to play in informal knowledge generation and dissemination.

In terms of who seeks information, 84% of core members sought information from outside the community, while only 32% of peripheral members did, but similar information was sought by both groups; this included (but was not restricted to) pest and disease control and planting density (which the authors sum up as "current farm problems"). Both core and peripheral groups relied on local social networks and informal information for topics such as shade management, species selection and site planting patterns ("general farm management"), presumably because they are locality specific, relying on local ecological knowledge within the community. Interestingly, 92.5% of core members across the four networks engaged in farmer-initiated field trials and on-farm experiments regarding, for example, shade species and site selection, organic matter and shade tree management, and tree and crop planting density. The high number of core members accessing external information suggests they could act as 'bridging' links between farming communities and outside institutions, providing a pathway for knowledge infiltration into the community and to the peripheral farmers who consult them. More recent research by the authors examines the larger institutional framework in which cocoa farmers function. Networks of individual farmers were investigated in terms of resource access and barriers, with regards to not only information but also credit, labour, buyers, etc.

By characterising the informal social networks of these cocoa-producing communities in Ghana, and how information moves within them, the authors have highlighted how the networks may be suited for creation or dissemination of different aspects of good and sustainable cocoa farming practice.

[1]Isaac, M.E., Erickson, B.H., Quashie-Sam, S.J. & Timmer, V.R. (2007) Transfer of knowledge on agroforestry management practices: the structure of farmer advice networks. *Ecology and Society* **12**(2), article 32.

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Cuprous Oxide in Cocoa Rehabilitation

Managed cocoa has a long and fruitful life with trees often outliving those who plant them. Initial investment is high but early reward low with trees taking 5 years or more to produce a full crop. Farmers can then profit for up to 50 years providing trees are managed and markets receptive, but it doesn't take long in the 'wilderness' for cocoa to become overloaded with insect pests, diseases and epiphytes.

It is difficult to understand why any tree crop is allowed to decline but commodity prices are fickle, often sky-high at planting and rock-bottom 5 years later. Farmers minimise inputs, harvest what they can and switch future investment into shorter-term cash crops.

Canopy and site factors make cocoa unattractive for weeds but ideal for pathogens and plants that grow on trees (epiphytes). Long-lived evergreen trees bearing pods throughout the year under high rainfall and humidity in closed-canopy environments offer ideal conditions for disease development and spread.

Rehabilitation priority is structural including replanting and simple tree height reduction by removing all growth over 1.5–2.0 m above soil level[1]. Farmers can then concentrate on 'redecoration' by spraying with copper fungicide to manage diseases and epiphytes.

FFS for Research not Extension

A new two-volume publication on integrated pest management (IPM) includes a chapter from Jeffery Bentley in which he explores the strengths and weaknesses of farmer field schools (FFS), and how their benefits can be extended[1]. Although farmers enjoy FFS and their attitudes are changed by them, they do not teach what they have learnt to their neighbours, which the FFS approach would require in order to qualify as a mass extension technique.

Bentley argues that collaborative research, as part of an FFS, can play a critical role in fine-tuning pest management strategies so that farmers find it practical to adopt them, but there are more effective methods for disseminating the results. He describes extension methods from around the world, showing ways in which traditional social situations have been adapted, how researchers and extensionists have developed innovative ways to reach farmers, and examples of mass media being harnessed.

To illustrate farmers' role in research, he describes the development of clean picking ('Re-Re') for coffee berry borer management in Colombia: the lessons apply as well in cocoa. Researchers identified an effective method of interrupting the pest's life cycle, but farmers found aspects of this impractical. However, because they had learnt about the ecology of the pest, they were able to adapt the prototype technology they had been given, and the pest was controlled.

[1]Bentley, J.W. (2009) Impact of IPM extension for smallholder farmers in the tropics. In: Peshin, R. & Dhawan, A.K. (eds) *Integrated pest management. Vol. 2. Dissemination and impact*. Springer, New York, pp. 333–346. (Volume 1 is entitled: *Innovation-development process*). The books are available online where chapters can be purchased individually.

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Copper Fungicides in Cocoa

Copper fungicides have a 100 year history in cocoa. The first to be used was hydrated blue copper sulphate mixed with calcium hydroxide (slaked lime) to overcome high solubility of the copper sulphate alone. Fixed (sparingly soluble) copper compounds include: copper oxychloride,

Epiphytic moss growth on and around flower cushions (Terry Mabbett)

cupric hydroxide, tribasic copper sulphate, copper ammonium complexes and red cuprous oxide and have been used for over 50 years.

Cuprous oxide is particulate, formulated as wettable powder (WP) or wettable (water dispersible) granules (WG) and is considered to be the most active on an equivalent weight basis, a view expressed by cocoa pathologists in Brazil[2] and supported by basic chemistry. Molecular weight and atomic mass comparisons of the three traditionally most used copper fungicides indicate why this is so. The molecular weight of cuprous oxide [Cu_2O] is 143.00 with 127.00 (88%) accounted for by the mass of two copper atoms. The equivalent figure for cupric hydroxide [$Cu(OH)_2$] is 63.5/97.5 (65%) and for copper oxychloride [$3Cu(OH)_2.CuCl_2$] is 381.00/696.00 (55%). Relative atomic masses: Copper (Cu): 63.5; Oxygen (O): 16; Hydrogen (H): 1; Chlorine (Cl): 35.5.

This is the most likely reason why cocoa pathologists in Brazil and elsewhere report cuprous oxide as most efficacious of the fixed copper fungicides and requiring correspondingly less product to achieve an equivalent level of control[2].

Copper fungicides still monopolise the market but like all synthetic pesticides are subject to increasing scrutiny. The European Union (EU) has set maximum residue limits (MRLs) for all pesticides used in cocoa and detected in consignments of beans entering the EU. Copper fungicides are among the most benign pesticides used in cocoa and none appear on the list of active substances used in cocoa but not approved for use in the EU. The MRL set for copper fungicide is 50 mg copper ions/kg of cured (fermented and dried) cocoa beans[1].

Copper fungicides may be used for organically grown cocoa within the limits laid down by organic certification authorities and manufacturers continue to invest in organic certification for their copper fungicide production facilities. Environmental studies have focussed on soil accumulation of copper through spray run-off, and from deposit wash-off by rainfall. Concern has concentrated on potential physico-chemical and biological effects including nutrient imbalance and reduction in earthworm activity, but no specific yield-limiting problems are reported.

A recent 4-year study on earthworm activity in 35-year-old cocoa in southern Cameroon showed no evidence of negative effects on litter decomposition and soil bulk density from spraying copper fungicides at manufacturers' recommendations[3]. A Nigerian study claimed copper based fungicides predispose soils to nutrient imbalances if not properly managed, but only looked at the effect of hydrated copper sulphate/calcium hydroxide mixtures[4].

Phytophthora on Cocoa

Specific diseases occur in the main cocoa producing regions but only *Phytophthora* pathogens confront cocoa wherever grown. At least eight different species are recorded on cocoa with four – *P. palmivora*, *P. megakarya*, *P. capsici* and *P. citrophthora* – most frequent and damaging. *P. palmivora* is the most widely spread, has the broadest host range and is responsible for *Phytophthora* stem canker in Southeast Asia. *P. megakarya* confined to Central and West Africa is the most aggressive with an extra disease dimension through soil-based sporulation.

Phytophthora thrives in free water and high humidity, infects most tree parts and is yield-limiting worldwide. Early mycologists described the Oomycetes to which *Phytophthora* belongs as the 'water fungi'.

Phytophthora will exploit neglected cocoa, generating and maintaining perpetually active reservoirs of inoculums on pods left on the tree or ground and on stem cankers infecting bark tissue. Epiphytes including lichens, bryophytes (liverworts and mosses), pteridophytes (ferns) and bromeliads may directly damage cocoa and aggravate disease through prolonged surface wetness and increased humidity and by trapping spores washed down through the canopy.

Copper fungicides are purely protectant (contact) in action, killing germinating spores before the germ tube has chance to penetrate the pod surface. Pods remain protected provided fungicide is deposited before inoculums arrive and residue is maintained at fungitoxic levels.

Prophylactic Control of *Phytophthora* Pod Rot

Control of *Phytophthora* pod rot by targeted sprays of copper fungicide with minimal run-off and deposit erosion requires:

- Sprays timed with dry-weather windows
- Targeting of flower cushions and pods at all stages of development
- Selection of the most appropriate nozzles for lever operated knapsack sprayers
- Fungicide formulations with high tenacity and resistance to weathering
- Reduction in application frequency without compromising protection

Spraying before the rains arrive or during prolonged dry spells should pre-empt sporulation and give enough time for deposits to dry and harden. Fixed copper fungicides are naturally tenacious and smaller particles adhere more strongly to surfaces through their increasing mass to surface area ratios. For instance, Agro-grade cuprous oxide manufactured by Nordox AS is micronised to a mean particle diameter of 1.2 µm. Field studies showed how this benefits dispersion and suspension in the spray tank, resistance to weathering (wind, water and growth movements), fungicide efficacy and disease control[5].

Cocoa pods are borne down the entire canopy profile from high branches to the lower trunk (bole) just centimetres above soil level. Pods at all stages of development including cherelles are susceptible to *Phytophthora* infection. Lever operated knapsack sprayers are the preferred choice and canopy height should be managed at 3–4 m so that high-positioned pods can be sprayed without having to fit an extension lance[1].

Laboratory and field research conducted by IPARC (International Pesticide Application Research Consortium) showed more efficient and effective spray deposition on pods using narrow cone nozzles. These deliver relatively low flow rates with small droplet size spectra to achieve a high deposit per unit emitted, compared with the variable cone nozzles invariably supplied with lever operated knapsack sprayers. Higher dose transfer efficiency thus achieved is particularly important in achieving high performance from contact-acting fungicides like cuprous oxide.

Tenacity and resistance to weathering is important but deposits should not be static. A key strength of fixed copper fungicides is their sparingly soluble property affording local redistribution of copper ions in water films over the same pod. And, washed by rain, down through the canopy in drips, splashes and rivulets to protect susceptible new pods produced between spray applications[6].

Cocoa grown in Nigeria, Cameroon and wetter parts of Côte d'Ivoire has traditionally received 10–12 applications per year, while cocoa in the wettest areas of Papua New Guinea is sprayed on a weekly basis. Across Brazil's huge Bahia State pod loss correlates to variations in rainfall. Areas with most rainfall and highest disease pressure regularly recorded 100% pod infection and required frequent application to secure worthwhile yield.

Brazilian scientists concerned over cost and logistics of frequent spraying consolidated spray programmes into fewer applications at higher doses, so amount of cuprous oxide applied per year stayed the same. Success was ascribed to high redistributive capacities of cuprous oxide deposits over extended periods of time. High concentration application produced a correspondingly thicker deposit with 'laminal' liberation, whereby the inner mass of cuprous oxide deposit is protected against weathering, thus providing extended fungicidal activity and pod protection[2]. Attempts to significantly increase individual application dosage, while reducing the number of applications, are made easier by the relatively recent development of 'high copper' cuprous oxide formulations (WP and WG) that contain 75% copper.

Phytophthora Stem Canker Control

Neglected cocoa is prone to *Phytophthora* stem canker which is potentially more serious than *Phytophthora* pod rot, because infections can girdle main branches and the trunk (bole) to kill the tree. Stem canker is a serious problem in Southeast Asia and Oceania caused by *P. palmivora* and in parts of West Africa by *P. megakarya* as well. Cankers may occur at the collar or just below soil level or at much higher positions on scaffold branches, because inoculums may originate in the soil (*P. megakarya*) or from infected pods high in the tree.

Control requires excision of cankerous tissue and treatment with canker paint. All diseased bark and wood and a peripheral 3-cm band of healthy bark is removed. The cleaned area is treated with paint containing cuprous oxide and adjuvant (sticker and surfactant) and then sealed with a layer of petrolatum grease. Cocoa farmers in Southeast Asia achieve good results using Nordox cuprous oxide fungicide paint with oils and polymers added to increase tenacity, longevity and penetration into the wood. The same procedure is used to control *Erythricium salmonicolor* (*Corticium salmonicolor*), an equally damaging bark and wood infecting Basidiomycete fungus causing pink disease in cocoa[7].

Control of Epiphytes

Algae and lichen on leaves inhibit photosynthesis and gaseous exchange. Larger epiphytes increase the risk of wind damage and branch breakage. Bushy moss growth may inhibit development of cauliflorus (truncate) cocoa flowers borne in flower cushions directly on the bark of the trunk and main branches. Epiphytes retain water and inhibit air circulation to aggravate *Phytophthora*. Brazilian research showed epiphytes can harbour *Phytophthora* spores.

Cuprous oxide controls algae, lichens, bryophytes, ferns and bromeliads. Routine application (3–4 per year) of fixed copper fungicide (including cuprous oxide) for control of *Phytophthora* pod rot kept cocoa trees in Trinidad epiphyte free. Cuprous oxide also kills molluscs (slugs and snails) which can damage nursery seedlings.

The chemistry currently used to control *Phytophthora* in cocoa has uniquely long pedigree because copper fungicides are virtually the only ones 'left standing'. Almost all other fungicides with a comparable vintage have long since been withdrawn, and most newer ones have failed to establish widely in cocoa due to

Careful cleaning of the bark infection is just as important as the canker paint treatment. This stem canker in Vietnam has been scraped off to expose stained wood beneath. The stained wood may still harbour infection and will therefore be removed before applying cuprous oxide canker paint to protect and seal the wound (Nordox AS)

high cost, residue problems or other factors such as fungicide resistance.

Lest we forget, definitive cocoa research stretches back equally far as the study of epiphytes in cocoa and their relationship to incidence of *Phytophthora* shows. C. A. Thorold, a cocoa pathologist and well known author active over 50 years ago, studied epiphytes on cocoa in Nigeria in relation to incidence of *Phytophthora*. Thorold was already referring readers to much earlier work carried out in 1927 by H. A. Dade in Ghana and 1910 by J. B. Rorer in Trinidad.

[1]Bateman, R. (2008) Pesticide use in cocoa: a guide for training, administrative and research staff. 1st Edition, June 2008. ICCO/IPARC, London/Ascot, UK, 56 pp.

[2]Pereira J.L. (1985) Chemical control of *Phytophthora* pod rot of cocoa in Brazil. *Cocoa Growers Bulletin* **36**, 23–38.

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[4]Akinnifesi, T, Asubiojo, O.I & Amusan, A.A. (2006) Effects of fungicide residues on the physico-chemical characteristics of soils of a major cocoa-producing area of Nigeria. *Science of the Total Environment* **366**: 876–879.

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[6]Mabbett, T.H. (1986) The biology and application needs of *Phytophthora* pod rot of cocoa. *Cocoa Growers Bulletin* **37**, 24–33.

[7]Mabbett, T.H. (2007) Canker control: a life saver for trees. *Far Eastern Agriculture* November/December 2007. pp. 12–15.

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Cocoa Swollen Shoot Virus in Ghana

In Ghana, cocoa production occurs in the forest areas of the country where rainfall is 1000–1500 mm per year. Although most cocoa production is carried out by peasant farmers on plots of land less than 3 ha, a small number of farmers appear to dominate the trade. In 2007, cocoa exports constituted 28% of foreign exchange earnings and 57% of overall agricultural exports of the country. Cocoa therefore plays an important role in the economic development of Ghana by generating government revenues and household incomes[1].

Besides being a major foreign exchange earner, cocoa serves as the raw material for numerous consumer products such as chocolates and beverages and has even made its way into the pharmaceutical industry in recent times. To the peasant farmer, it is an important perennial tree crop which generates income for the upkeep and education of the family which may run through the extended family. In many instances the prestige enjoyed by a cocoa farmer in society is attributed to his acreage and the income he earns from his farming activities.

Disease Problems of Cocoa

Among the diseases affecting cocoa, viral pathogens are known to play a significant role, with at least three distinct groups of viruses recognised to infect cocoa in Ghana. Cocoa swollen shoot virus (CSSV) is by far the most economically important and has been and will continue for many years to be a major problem for the cocoa industry of Ghana. The financial impact of cocoa production losses attributed to CSSV has been enormous; even where overall losses do not appear to be great, local areas or economies have been severely affected. This has seriously affected cocoa production in certain areas of the country with resultant hardship to farmers[2].

Viruses cause disease not only by feeding on the cells or useful substances needed for the upkeep of their hosts but in the process may secrete toxins or other substances into them. This in turn upsets the metabolism of cells and leads to the development of abnormal conditions that affect the functions and life of the organism. In the course of this, they take up space leading to the disruption of normal processes, which affects the performance of their hosts.

Discovery of CSSV

Records indicate that CSSV disease was first discovered by W. F. Steven at Effiduase in the New Juaben district in the Eastern Region of Ghana in 1936. Stories have been told in Ghana especially among the Akans-speaking people that CSSV was present in the forest regions of Ghana before the introduction of cocoa from its centre of origin in the Amazon basin. CSSV was isolated from several naturally occurring forest trees including *Adansonia digitata* (baobab), *Ceiba pentandra* (kapok), *Cola chlamydantha*, *Cola gigantea* var. *glabrescens* and *Sterculia tragacantha*. Most of these indigenous forest trees appeared to have higher natural resistance to CSSV than cocoa – a non-indigenous tree. Some of these alternative hosts were symptomless carriers while others exhibited mild chlorotic symptoms.

Transmission of CSSV by Mealybugs

Several views have been expressed on the transmission of the virus but it is firmly documented that at least 14 species of mealybugs of the family Pseudococcidae within the superfamily Coccoidea are responsible. Both sexes of nymphs and the adult females of the mealybug are known to spread the disease between adjacent trees by crawling through the canopy from infected to healthy trees or by being carried by attendant ants (*Crematogaster* and *Camponotus* spp.). CSSV is also known to be transmitted mechanically, which has been shown by brushing partially purified virus onto cocoa beans. International spread of CSSV is usually caused by the movement of infected cocoa pods as seed materials, and infected budwood as cutting materials. Transmission of the virus can be minimised by implementation of simple quarantine procedures such as the removal of seeds from pods before they are moved any distance.

Symptoms of CSSV

There are many strains of CSSV with symptoms of the disease manifested in different shades of colours. The non virulent strains predominate and cause various types of leaf chlorosis, root necrosis, root and stem swelling, and dieback which is typical on Amelonado cocoa trees in Ghana[3].

Swollen shoot virus strain 1A, also known as New Juaben, produces swellings on the branches and roots (Fig 1). The symptoms caused by this strain on newly flushed leaves of Amelonado cocoa trees are red vein banding, followed by clearing or chlorosis alongside the veins (Fig. 2). The pods of cocoa trees are not spared as infected pods become mottled, smoother than normal, rounded and usually contain only half the normal weight of beans.

Other strains of CSSV do not produce swellings and most do not produce any pod symptoms. However, all of them give rise to leaf symptoms, which vary in detail enabling the strains to be distinguished.

Fig. 1. The swollen shoot symptom that gave the disease its name, here caused by the strain New Juaben, is in fact rarely seen (H. C. Evans)

Fig. 2. CSSV-symptomatic cocoa leaf with chlorotic areas along the veins (A. K. Quainoo)

Classification of CSSV

CSSV belongs to the family Caulimoviridae and genus Badnavirus with many distinct variants. The badnaviruses are further classified as belonging to the family Pararetroviridae now Badnaviridae. The CSSV viral particles are bacilliform in shape with the genome consisting of double-stranded DNA. CSSV is reported to exhibit latent infection which presents the greatest problem because the latent period is very variable and ranges from a few weeks to more than two years, and is further influenced by the health, age and size of the tree.

Eliminating CSSV

Various attempts at controlling CSSV in the past included: biological control of the mealybug vector, chemotherapy and heat therapy of planting materials, removal of wild hosts, breeding for CSSV resistance, destruction of visibly infected cocoa trees termed 'zero tolerance', and the use of a mild strain to confer cross-protection. These have yielded at best partial success, and this has made the management of CSSV very complicated and difficult.

Tissue culture techniques using somatic embryogenesis have been applied to a number of perennial tree crops to eliminate viruses. The field of plant tissue culture is based on the premise that plants can be separated into their component parts (organs, tissues or cells), which can be manipulated *in vitro* (in test tubes) and then grown back into complete plants. Somatic embryogenesis from stigma and style cultures of *Citrus* (orange trees) was used to eliminate citrus psorosis virus from *Citrus* species. Somatic embryogenesis was also effective in eliminating fan leaf viruses and leaf roll-associated viruses from grapevines.

The technique was equally effective in eliminating CSSV from infected cocoa trees producing disease-free embryos and plantlets. The effectiveness of somatic embryogenesis as a technique in eliminating CSSV was further demonstrated by plantlets generated from the infected trees testing CSSV negative by capillary electrophoresis two years after weaning in the glasshouse[4].

Detection of CSSV in Components of Cocoa Pods and Pollen Grains

Since 1940, contradictory views have been expressed on whether or not CSSV was transmitted through cocoa seeds. Recently, research carried out on cocoa seeds and seedlings using polymerase chain reaction (PCR) and real-time PCR techniques indicated that CSSV DNA could be found in every component of the cocoa seed and was also present in seedlings from pods harvested from CSSV-infected Amelonado cocoa trees. The presence of CSSV in pollen grains from CSSV-infected Amelonado cocoa trees suggested that the virus may be transmitted through the gametes which may serve as a possible route to embryo invasion for CSSV[5].

The PCR assay allows the detection and quantification of viral load in all parts of the cocoa seed and cocoa materials, and may have a significant role to play in germplasm conservation and distribution. This makes it ideal for the selection of disease-free cocoa trees for breeding programmes and the development of genetic transformation.

With the eventual elimination of CSSV through somatic embryogenesis, detection and quantification of the virus through PCR assays has presented opportunities and questions for researchers and policy makers to develop the commodity further. The outcome should result in an improvement of the crop performance and income of the cocoa farmer and the economy of the country in general. The technology should not be restricted only to cocoa but applied to other commodities such as shea nut through the design of appropriate primers.

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Gates in African Cocoa

The announcement in February this year of a major programme in West African cocoa, funded by the Bill & Melinda Gates Foundation and the cocoa industry, demonstrates commitment to making cocoa farming economically and ecologically sustainable in order to secure the future of the sector. The initiative is part of a 5-year programme to boost incomes of West/Central African cocoa and cashew farmers through improved training and access to markets. Funding of US$48 million from the Bill & Melinda Gates Foundation is being matched by a further $42 million in cash and kind from private industry.

The West Africa Cocoa Livelihoods Program will be managed by WCF (World Cocoa Foundation) and implemented by a consortium of partners: the German development organisation GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit), the IITA (International Institute of Tropical Agriculture) Sustainable Tree Crops Program (STCP), the non-profit organisations ACDI/VOCA and Technoserve, and SOCODEVI (a network of Canadian cooperatives). The governments of the participating African countries are full partners and will support the programme's implementation.

Financial and in-kind contributions for the cocoa programme come from the Hershey Co., Kraft Foods, and Mars, Inc.; cocoa processors Archer Daniels Midland Co., Barry Callebaut, Blommer Chocolate Co., and Cargill; and supply chain managers and allied industries Armajaro, Ecom-Agrocacao, Olam International Ltd., and Starbucks Coffee Co.

Farmer associations will play a significant role in leading training and knowledge sharing. Activities will focus on improving farmer knowledge and productivity, cocoa quality, crop diversification and supply chain efficiencies. The project, which is part of the Foundation's Agricultural Development Initiative, will reach approximately 200,000 smallholder cocoa farming households in Cameroon, Côte d'Ivoire, Ghana, Liberia and Nigeria and aims to help farmers double their incomes.

According to WCF, implementation plans and site selection are being finalised, with activities expected to begin in late 2009 and early 2010. Once underway, the programme will train farmers in better production techniques, quality improvement and business skills; professionalise farmer organisations to better meet member needs; and improve farmer access to agricultural inputs and improved-quality seedlings. The project will also improve farmers' access to market information and opportunities for diversification into alternative food and cash crops to maximise farmer income and security.

Web: www.gatesfoundation.org / www.worldcocoafoundation.org

Assessing How Genotype Performance Varies With Environment

Characterisation of genetic resources underlies breeding and crop improvement programmes. However, in carrying out such evaluations, consideration is also needed as to how different genotypes interact with their growth environment. This is particularly pertinent for cocoa for two reasons. Firstly, as a tropical species, cocoa is sensitive to small changes temperature, light, humidity and water stress. Secondly, in regions where cocoa is cultivated there is often greater variation in these environmental parameters than in the Amazon basin (the centre of origin of cocoa). For example, in Bahia, Brazil night temperatures during the winter can be significantly lower than many other cocoa-growing regions (see Fig. 1 for a comparison of two contrasting growing regions/seasons). Furthermore, in West Africa, the Caribbean and parts of South America there is a distinct dry season in which the crop may become stressed. As a result of climate change, it is predicted that dry periods in West Africa are likely to

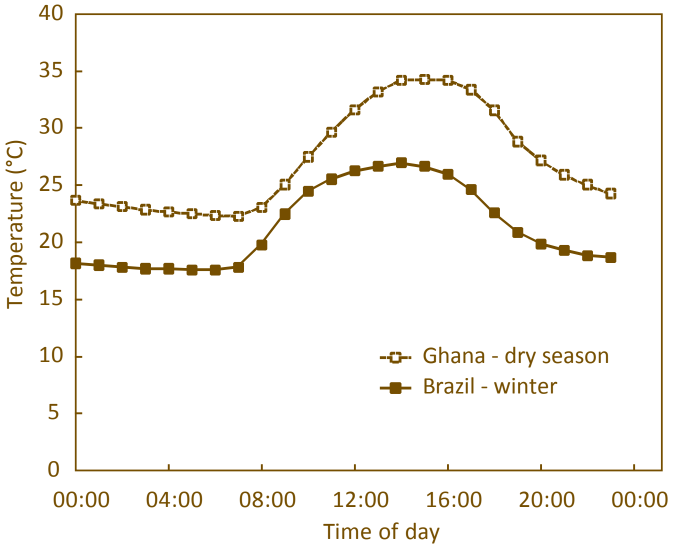

Fig. 1. The daily pattern of air temperature in Ghana (Kumasi District) during the dry season compared with Brazil (Itabuna, Bahia) during the winter season

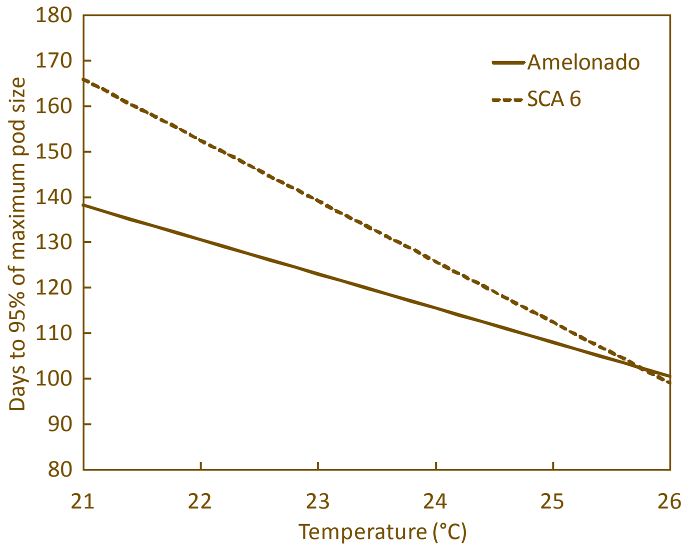

Fig. 2. Simulated response of cocoa pod development time in relation to temperature for two contrasting cocoa clones

become more pronounced. Crop husbandry techniques will also affect environmental stresses. Most notably, the amount and type of overhead shade used will not only impact on the amount of solar radiation received by the plant but also on temperature, relative humidity and soil water.

Experimental Approaches

A number of experiments at the University of Reading in the UK have considered the impacts of different environmental stresses on cocoa and have examined particular genotype and environment interactions. In particular, a Cocoa Research UK-funded experiment over a three and a half year period considered the impact of different temperature regimes on contrasting cocoa genotypes (varying in origin and morphology). For this, a semi-controlled environment greenhouse was utilised in which the diurnal and seasonal temperature profiles of three cocoa-growing regions were simulated; these being principle cocoa-growing areas in Brazil, Ghana and Malaysia. Such an approach has the advantage of being able to separate out particular environmental parameters and thus to ascertain a link between cause and effect.

Early data from this experiment demonstrated that whilst growth rates were consistently higher in the 'Malaysia' simulated environment, the magnitude of the response to the different temperatures regimes varied between clones[1]. Thus the stress brought about by the cooler conditions, particularly in the 'Brazil' simulated environment, impacted more on some genotypes than others. Such differential responses to temperature of genotypes could also be seen in the reproductive phase[2]. For example pods reached maturity more quickly at higher temperatures, with resulting smaller pods, but some genotypes were more sensitive to temperature than others (see Fig. 2 for a comparison of two contrasting clones). Temperature also had an impact on quality parameters (bean size and lipid quantity); for example, the optimum temperature for maximising bean lipid content varied between two particular genotypes.

Another approach, also making use of semi-controlled glasshouse conditions to mimic Malaysian and Brazilian temperature conditions, identified changes in the methylation status of seedling and clonal populations. This highlights the influence of the environment in determining the genomic architecture of a plant and modifying how the plant behaves. By identifying genes modified in this way we can select gene pathways influenced by changes in the environment and so be guided to traits that are important for a plant's response to its environment. This has implications for the selection and breeding of cocoa varieties that are well adapted to their local environment, and that are able to respond adequately to future changes in environmental conditions.

From Greenhouse to Field

Some of our current activities, including collaborations with CRIG (Cocoa Research Institute of Ghana) and CRIN (Cocoa Research Institute of Nigeria), are considering how different clones respond to light and water stress in both greenhouse and field conditions.

Further afield, researchers worldwide have been engaged in the CFC/ICCO/Bioversity[*] Project on 'Productivity and Quality Improvement: a Participatory Approach' (a collaborative project involving 15 institutions)[3]. This includes an international clonal trial where the same clones have been grown in ten different locations and will aid cocoa researchers considerably in establishing the stability, or otherwise, of a wide range of traits to different growing environments.

[*] CFC: Common Fund for Commodities; ICCO: International Cocoa Organization; Bioversity: Bioversity International, formerly IPGRI.

Adapting to a Varied and Changing Environment

Cocoa growers may adapt to the varied and changing environment in which cocoa is cultivated using two broad strategies: modification of husbandry techniques and developing varieties that are more tolerant to environmental stresses. Whilst the number of genotypes studied to date is limited, evidence is mounting that different cocoa genotypes respond differently to abiotic stresses. The potential therefore exists for better matching of planting material with local growing conditions. This will become more important as climate change results in more severe stresses in particular regions.

[1]Daymond, A. & Hadley, P. (2008) Differential effects of temperature on fruit development and bean quality of contrasting genotypes of cacao. *Annals of Applied Biology* **153**, 175–185.

[2]Daymond, A.J. & Hadley, P. (2004). The effects of temperature and light integral on early vegetative growth and chlorophyll fluorescence of four contrasting genotypes of cacao (*Theobroma cacao*). *Annals of Applied Biology* **145**, 257–262.

[3]Eskes, A.B. (2001) Collaborative activities on cocoa germplasm utilization and conservation supported by the CFC/ICCO/IPGRI project. 13th International Cocoa Research Conference, Kota Kinabalu, Malaysia.

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Farmers and ACIAR project team at a clonal trial site in South Sulawesi, Indonesia (Philip Keane)

Australia Aids Better Breeding in Indonesia

In April this year, ACIAR (Australian Centre for International Agricultural Research) announced a partnership between Australian and Indonesian research and extension agencies and Mars, Inc. to encourage Indonesian smallholder cocoa growers to replant with improved varieties and adopt better crop management. Cocoa production in Indonesia, which boomed following its expansion since the early 1980s in new regions such as Sulawesi, has come to the end of its 'honeymoon' period and is now cut by up to 50% owing to pests and diseases, ageing trees and falling soil fertility. Many of the cocoa trees in Sulawesi originate from seed brought from Malaysia without quality screening. A concerted programme of varietal improvement and more advanced farm management is needed to ensure the industry overcomes the production constraints that have built up.

The cocoa improvement programme is part of the Smallholder Agribusiness Development Initiative in eastern Indonesia, under the Australian Indonesia Partnership. The Initiative is helping smallholder farmers move from being opportunistic and subsistence-orientated towards being profitable and productive smallholder agricultural businesses.

Building on earlier research (see *GRO-Cocoa* No. 10, pp.5–8), researchers from La Trobe University, The University of Sydney and Mars Symbioscience have been working with farmers to select resistant varieties of cocoa and test them in farmers' fields across South and South-East Sulawesi. Material from selected trees is grafted onto substandard trees or onto seedlings for in-filling gaps. Farmers are being encouraged to compare the performance of the selected genotypes with their standard trees. According to La Trobe University's Phil Keane, "This is the main idea we are promoting: farmer experimentation 'try-it-and-see'. This helps farmers consider themselves as businessmen and as 'scientists', and helps to dispel the perception that they are merely 'peasant' farmers." He adds, "We are trying to do the same with improved management and pest and disease-control methods: try them on 20 trees and compare the results with neighbouring trees." The involvement of field technical advisors of Mars, Inc. has been crucial in extending these ideas to a wider range of farmers and showing that the farmers respond well to propagating and testing their own 'best trees' and testing ideas for improved management.

Web: www.aciar.gov.au/cocoa

ICRC Satellite Meetings

Specialist meetings following the 16th International Cocoa Research Conference (ICRC: 16–21 November 2009) will also take place at the Hyatt Hotel in Bali, Indonesia. Registration for the workshops is being administered jointly, with the fee (US$ 100) to be paid at the registration desk on 22 November 2009.

Sixth INGENIC Workshop

The Sixth INGENIC (International Group for Genetic Improvement of Cocoa) Workshop will be on 22–24 November. With the theme, 'Current developments in cocoa genetics and breeding', it will be dedicated to presentations and discussions on issues of recent interest in cocoa genetic improvement and on collaborative activities. Workshop topics include: Molecular studies, including sequencing of the cocoa genome; Breeding for flavour quality; Resistance to the cocoa pod borer; and Ongoing and new collaborative regional or international activities.

The organisers have invited introductory presentations for each of these topics, which will be followed by plenary discussion sessions. The deadline for submitting titles of presentations (see below) is 30 June. Full presentations will be posted in pdf format on the INGENIC website and conclusions of the discussions will be published in the *INGENIC Newsletter*. To pre-register for the workshop, send name, affiliation and email address to the INGENIC Secretariat before 31 July.

Enquiries/submissions to: Dr Michelle End, INGENIC Secretary.
Email: michelle.end@cocoaresearch.org.uk
Tel/Fax: +44 1256 851082

INCOPED Sixth International Seminar

The INCOPED (International Working Group for Cocoa Pests and Diseases) Sixth International Seminar will be held on 23–25 November. With the theme 'Sharing crop protection technologies for sustainable cocoa production', the seminar will focus on synthesising, sharing and disseminating the latest technological packages in cocoa pest and disease management to increase cocoa production on a sustainable basis. Given the devastating impact of losses from pests and diseases on small farmers' livelihoods, the organisers particularly encourage submissions (which will be given in English only) that provide practical recommendations for cocoa farmers. NOTE: The deadline for abstract submission has been extended to 31 AUGUST.

Enquiries/submissions to: Mr Soekadar Wiryadiputra (National Coordinator, INCOPED).
Email: soekadar@yahoo.com
Fax: +62 331 757131

With copy to: Mr Andrews Y. Akrofi (Chairman, INCOPED), P.O. Box 8, Akim Tafo, Ghana.
Email: andrewsakrofi@yahoo.com

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