SIXTH INGENIC WORKSHOP
22 to 24 November 2009 – Hyatt Hotel, Bali

THEME: Current Developments in Cocoa Genetics and Breeding.

INGENIC held its Sixth International Workshop to coincide with the 16th International Cocoa Research Conference (ICRC) held 16th-21st November 2009 in Bali, Indonesia. As agreed at the 5th INGENIC meeting in Costa Rica, October 2006, the theme of the meeting was "Current Developments in Cocoa Genetics and Breeding" to allow INGENIC members flexibility in reporting on their research and ideas for future collaborations. It had also been agreed to structure the meeting to allow plenty of time for discussion, with a limited number of introductory papers rather than a full programme of technical papers, in order to avoid any duplication with the main conference. The main themes were regional breeding initiatives, follow-on activities from the CFC/ICCO/Bioversity projects, CacaoNet and breeding for quality attributes. In addition, the INGENIC Molecular Biology group met on the 22nd November for detailed discussions on various topics including genetic characterization studies, biotechnology, and the utilization of molecular biology techniques in studying pests and diseases. The presentations made during the meetings are available on the INGENIC website and key findings and discussions points are highlighted below.

Ninety-three delegates from cocoa research institutes, universities, NGOs and the cocoa industry from around the world registered jointly for the INGENIC and INCOPED[1] workshops. A Reception, sponsored by the Cocoa Research Association Ltd (CRA Ltd)[2], was held on Sunday evening and in his welcoming address, Tony Lass MBE, (Chairman, CRA Ltd*.)* was pleased to reaffirm the UK chocolate industry's continuing support for cocoa genetic resources initiatives and research on pests and diseases following the handover of the cocoa research programme of BCCCA to CRA Ltd. which took place in September 2008.

Earlier that day the INGENIC molecular biology group had met to discuss current issues in genomics and biotechnology. Dr. Peter Aikpokpodion had kindly agreed to chair the meeting since Dr. Mark Guiltinan, Chairman of the Mol. Biol group, was not able to attend the conference though he was able to participate in the meeting via a Skype internet link.

A Joint Opening Ceremony was held for INGENIC and INCOPED Workshops and speeches were made by Dr. Herdradja Natawijaya, Directorate of Estate Crops Protection at the Department of Agriculture, Indonesia, Mr. Sona Ebai, Secretary General of COPAL, Mr. Andrews Akrofi, Chairman of INCOPED and Dr. Dario Ahnert, Acting Chairman of INGENIC.

Before his speech, Dr. Ahnert led a minute's silence to reflect on the sad loss of Dr. Paulin, Dr. N'Goran and Dr. Iwaro, colleagues and friends who had all made a tremendous contribution to the cocoa genetics and breeding effort. He also expressed on a message of best wishes for a successful meeting from Bertus Eskes, Chairman of INGENIC, who had been unable to attend the Workshop due to ill health. Dr. Ahnert commented that the INGENIC Board had very much missed Dr. Eskes' active contribution over the past months, but was pleased to report that Dr. Eskes was now getting back to work. All those present joined him in wishing Dr. Eskes a full and rapid recovery.

As ever, INGENIC is very grateful for the financial and in-kind support received from the many institutions and individuals which enable INGENIC to function and to hold this Workshop including BCCCA/CRA Ltd., Bioversity, Bundesverband der Deutschen Susswarenindustrie, CEPLAC, CIRAD, COPAL, CRIG, CRU, ICCRI, Mars, MCB, PennState University, UESC, and USDA.

Special thanks goes to Michelle End for her leadership and hard work on the organization of this meeting. We would also like to thank all those who have helped in the organization of this event, especially to Mr. Agung Susilo and our colleagues from ICCRI, Indonesia.

[1] The International Permanent Working Group for Cocoa Pests and Diseases

[2] CRA Ltd, a UK based organization managing scientific cocoa research on behalf of Cadbury, Mars and Kraft Foods and members of NYSE Liffe

SESSION 1: Challenges Facing Cocoa Farmers and Regional Breeding Initiatives

One of the Recommendations from the 4th INGENIC Workshop, held in Accra, Ghana, 2003, was that "Similarities between cocoa producing countries in the same region (America, Africa and Asia) justify regional approaches to cocoa breeding". Representatives from each region had been invited to give presentations on local current constraints for cocoa production and progress made in establishing regional breeding activities.

South-East Asia/Pacific Region

Dr. Kelvin Lamin (MCB) gave an introduction on the challenges facing cocoa farmers in South-East Asia on behalf of the INGENIC Asia-Pacific Regional Cocoa Breeding Group (APRCBG) which comprises researchers from CCI (PNG), CPCRI (India), ICCRI (Indonesia), MCB (Malaysia), NLU (Vietnam), USM (Philippines) and Mars. Farms in the region tend to be small and are generally run by ageing farmers and their families, though the younger generations are often deserting the farms for life in the cities. Even though smallholder farmers in SE Asia can attain relatively high yields of up to a tonne of dry cocoa/ha/yr, yields are often declining due to the ageing trees and lack of new planting materials, depleted soils and shortage of good, inexpensive fertilizers. Pests such as Cocoa Pod Borer (CPB, *Conopomorpha cramerella*) and diseases such as Vascular Streak Dieback (VSD, *Oncobasidium theobromae*) and Black Pod (*Phytophthora palmivora*) cause heavy losses and widespread training on rational efficient and safe utilization in pesticides and resistant planting materials are urgently needed. Activities are being undertaken to help the farmers learn how to improve all aspects of the management of their farms, to help them access credit and also to support the development of farmers' organizations such as clubs and cooperatives.

Dr. Smilja Lambert (Mars) outlined the history of the APRCBG which had started in 2004 and had been formalized as the INGENIC Asia/Pacific Working Group in 2008. Annual meetings are very important in stimulating the spirit of collaboration and have resulted in very useful exchanges of information and genetic materials. Thanks to Mars support, these meetings have been held to coincide with other regional cocoa events thus allowing breeders to participate in important cocoa meetings which otherwise they would not have been able to attend. Each collaborating institution has agreed to produce seed from three hybrid crosses involving their best clones, or six clones in NLU Vietnam's case, so that at least 200 trees of each hybrid can be established in each participating institute. To date, over 9000 hybrid seeds and budwood from six clones, have been exchanged and further exchanges are anticipated in the coming months once administrative procedures have been completed. Field trials, supported by funding from WCF, are coming into bearing and will be evaluated using agreed standard methodology. Key learnings from the initiative have been that it is necessary to address legislative and administrative issues concerning the exchange of germplasm, including Material Transfer Agreements and quarantine requirements, at the earliest stage to avoid losses of material due to delays caused by problems in the paperwork. The next phase of the project will involve the introduction of materials that have resistance to Witches' Broom and Frosty Pod (Monilia) diseases and also the evaluation of potentially very valuable parental types for productivity and quality attributes with the emphasis on flavour.

Dr. Lambert also described a second collaborative activity to assess pod husk hardness which is likely to be a key factor in resistance to Cocoa Pod Borer. Each institute is using a hand-held penetrometer and standardised methodology to assess hardness. Though it has been found that hardness is not always well correlated with field resistance, and data on hardness for the same clone differs between institutions, the technique is reasonably consistent at each site and can be used for local evaluation and ranking of clones.

Dr. Jeffrie Marfu (CCI) described how his institute was screening for CPB tolerance in an effort to develop new clones to distribute to farmers following the discovery of CPB in PNG in 2006. Data from pod hardness assessments was combined with data from physical assessments for CPB damage and % infestation, along with other traits such as VSD resistance, to select potential material for further trialling in heavily infested areas. No material with complete

resistance/tolerance had been identified as yet and it was likely that any new materials would need to be grown under an integrated pest management system with frequent harvesting being a key component, to reduce infestation levels.
Mr. Agung Susilo (ICCRI) described his work on pod wall factors which influenced CPB resistance./tolerance. Clones with high densities of trichomes, for example, often had lower CPB infestation levels. He was also gathering data on the deposition patterns of tannin granules and lignin in the walls in the developing pod. It seemed that clones which had higher levels of tannin granules and lignin appearing earlier in pod development were often those which had less CPB infestation.
There followed some interesting discussions particularly relating to CPB, its several morphotypes in Papua New Guinea and the possibilities for producing hybrids with other *Theobroma* spp. to introduce pod wall characteristics which might reduce CPB infestation levels. There are collections of many of the other *Theobroma* spp. for example in Brazil which might be a useful resource for collaborative work. Participants were interested in ways to ensure that the material they were developing would incorporate genes for resistance to diseases such as Witches' Broom and Frosty Pod which were not endemic in the region but which posed a potential threat, given the ever increasing levels of intercontinental travel. The importance of intermediate and post-entry quarantine was noted in this respect, both in moving new germplasm into the country for use in breeding programmes and also for transferring selected types for evaluation in countries/regions where the diseases are already widespread.

South America
Dr. Adonias de Castro Virgens Filho (CEPEC/CEPLAC) gave a presentation on the challenges facing cocoa farming in the Americas on behalf of his colleagues at CEPLAC/CEPEC and other institutes in the region [weblink to .pdf]. Some of the factors identified were heavy losses due to fungal diseases such as Witches' Broom, Frosty Pod, Ceratocystis and Black Pod, and the low adoption rates by farmers of technologies to control them due to the difficulties in implementing cost efficient phytosanitation and spraying in ageing plantings, lack of resistant planting materials and lack of access to credit. Even where farmers had been provided with new planting materials with resistance to Witches' Broom derived from Scavina ancestry, for example, it had been found that this resistance was breaking down as the disease evolved and resistance could only be maintained if resistance was based on genes from several genetic sources and completed by other techniques including biocontrol, chemical control and effective phytosanitation. Frosty Pod (Moniliasis) was causing serious losses in many areas of the Andean and Central American countries and was a major threat to cocoa production in neighbouring areas due to its long-lived and resilient spores which are produced in great abundance. Collaborative efforts are underway to develop and distribute resistant types using molecular markers to complement traditional selection methods with a view to combining resistance to both Frosty Pod and Witches Broom with other favourable characteristics, including traditional flavour attributes where appropriate. Efforts were underway too to develop effective control strategies for Ceratocystis, particularly by developing resistant rootstocks, Phytophthora Black Pod and various insect pests which would incorporate genetic, biocontrol, chemical and cultural control elements.
It is also recognised that agronomic factors such as pruning to achieve the appropriate tree architecture and shade management are essential to efficient production and that different production systems, for example no shade, agroforestry etc., will require different types of planting materials. Care must be taken in the selection of rootstocks, and in planting at the appropriate densities for the clone or variety's vigour, with complementary mixtures of types to ensure effective pollination.
Appropriate renumeration for quality was also considered as a major challenge since at present farmers' investments in improving quality were not being rewarded. Further work on post-harvest practices, and trained sensory panels were required to support this area of research.

Dr. Dario Ahnert (UESC) gave a presentation on Regional Cocoa Breeding Initiatives in the Americas. The American Cacao Breeding Program (ACPB) was proposed during a regional meeting held at CATIE in 2005 and attracted interest from institutes in most of the cocoa

producing countries in the region. There are a number of on-going activities which have regional interest including population improvement programmes for Frosty Pod (CATIE Costa Rica), Witches Broom (INIAP Ecuador, CRU Trinidad, and CEPLAC Brazil) and Black Pod (CRU Trinidad and CEPLAC Brazil) and other activities such as the CFC Regional Variety Trial and CFC/USDA QTL trial which already involve collaboration between the institutes. However, progress in implementing the ACBP has been hindered by a lack of coordination and training, difficulties associated with the exchange of germplasm from both a legal and technical point of view, and problems in establishing standardised methods for selection. Since only a very limited amount of germplasm with resistance to the main diseases is available, priority activities will be to collect, exchange and evaluate germplasm, and to initiate collaborative breeding activities to combine disease resistance characteristics with other desirable characters such as an open canopy architecture. Dr. Pires and colleagues from CEPLAC had drafted a proposal for a collaborative project on preventative breeding for Moniliophthora and Phytophthora species, which could form part of the ACBP, and were inviting institutions from within their region, and from West Africa and Asia-Pacific, to develop the idea further. The objectives of such a project would centre around the exchange and evaluation of germplasm, and its use in recurrent selection programmes assisted by molecular marker technology, which would result in the continued release of high yielding improved varieties to farmers in all regions which had durable disease resistance combined with good quality characteristics.
In the ensuing discussions, the importance of germplasm exchange was emphasised, particularly to broaden the range of sources of resistance available for incorporation into breeding lines. CEPLAC indicated that Brazil might be willing to exchange progenies as part of a collaborative activity though current legislation would preclude exchange of primary germplasm. The Mayaguez collection was mentioned as a source of freely available germplasm, much of which had been characterised for its Phytophthora reaction and flavour characteristics. The importance of flavour profiling as a consideration during the breeding process was emphasised since certain clones, including CCN51, have been selected on the basis of their high yield but have rather poor flavour. Mars reiterated their offer to flavour profile breeding materials for free to help ensure that materials released to farmers have suitable flavour attributes.

West Africa

Dr. Yaw Adu-Ampomah (COCOBOD) introduced Dr. Peter Aikpokpodion (CRIN) who gave a presentation on the challenges facing cocoa farmers in West Africa and regional breeding activities on behalf of the Cocoa Breeders Working Group (ACB). Dr. Aikpokpodion had acted as Chair of ACB until he had handed over to Dr. Desiré Opoku (CNRA) at the end of his two year term earlier in the year.
Cocoa farms in the region are usually low yielding, often due to the ageing trees of old or unselected seedling varieties, and also to heavy losses due to the prevailing pests and diseases, notably Black Pod, mirids and Cocoa Swollen Shoot Virus (CSSV). Farmers themselves tend to be old and the low farm incomes are no incentive for the younger generations to stay in cocoa farming. Local environmental changes and global climate change are likely to be contributing to prolonged drought conditions causing crop losses and poor establishment of new plantings. In addition, market requirements are changing, for example with the introduction of more stringent legislation for pesticide residues and other quality attributes. Farmers need planting materials which are high yielding and begin bearing at an early stage, are pest/disease resistant and of shorter stature so that they can be more easily managed. Materials are needed which are suitable for rehabilitating or re-planting existing farms, new plantings and new systems such as agroforestry. Moreover, efficient seed gardens and/or clonal gardens are needed to generate the planting materials in sufficient quantities to make them accessible to the farmers that require them.
The ACB evolved from the CFC/ICCO/Bioversity project in 2003 and received support from USDA and Mars through a project to improve breeding using molecular approaches in 2007. It has subsequently become a thematic sub-group in the Sustainable Tree Crops Program receiving support form a number of donors including USAID and WCF. The core members are CNRA Cote d'Ivoire, CRIG Ghana, CRIN Nigeria and IRAD Cameroon though membership is being extended to research institutions in other cocoa producing countries in the region. Current activities include

a range of clonal and hybrid trial, including a regional progeny trial to test new clones from previously under-utilised populations alongside local control crosses and common clones. A Marker Assisted Selection programme for Black Pod rot resistance has been set up in Ghana and Nigeria and individuals with the allelic configuration for resistance to Witches Broom disease and/Black Pod have been identified from the five families under evaluation. QTLs for Black Pod resistance and CSSV resistance are being sought within a segregating population of over 250 plants in Cote d'Ivoire and Ghana. New germplasm introductions and evaluations have been planned so that each institute concentrates on a few accession groups and then pools the results so that interesting materials can be identified more efficiently. The ACB has resulted in a considerable exchange of technical expertise, for example training in budding techniques or DNA extraction methodology, and also in the exchange of seeds and budwood. Future plans include the development of decentralised seed/budwood gardens to accelerate the distribution of new planting materials, farmer-participatory assessment of the hybrid trials planted during the CFC project and the development of demonstration plots to help train farmers in the grafting procedures needed to regenerate their farms. The group has been meeting annually and will next meet in Abidjan in 2010.
The participants shared Dr. Aikpokpodion's perspective on the value of collaboration to all participating institutes, and the benefits it brought especially to those countries which have less available support for research. The efforts to introduce clonal cocoa cultivation to West Africa, through the identification of suitable clones and through farmer training, would be a valuable move towards the modernisation of cocoa farming in the region.

SESSION 2: International Collaborative Activities

Cooperative activities following on from CFC I and II projects

For the past ten years cocoa breeding and genetic resources efforts have benefitted from support from the Common Fund for Commodities (CFC) and co-funding organizations in the CFC/ICCO/Bioversity projects "Cocoa Germplasm Utilization and Conservation, a Global Approach" (1998-2003) and "Cocoa Productivity and Quality Improvement, a Participatory Approach" (2004-2010). These projects, with a total budget of close to US$20 million, have involved 14 partner institutes and have done much to stimulate the breeding effort and build a spirit of cooperation between the scientists involved. On behalf of Dr. Bertus Eskes, who has acted as coordinator for both projects but was unable to participate in the Workshop, Dr. Stephan Weise (Bioversity) had compiled a presentation to stimulate discussion on possible follow-up activities which would maintain the momentum, and ensure outputs were maximised, once the project comes to an end in 2010, based on responses from project participants to the following questions which had been circulated in advance of the meeting.
1. What are the key benefits your institution HAS gained from the CFC project's cooperative activities?
2. What areas need CONTINUED attention through an international collaborative effort?
3. What NEW areas need an international collaborative effort looking forward?
Respondents had identified many benefits from the collaborative activities, including the establishment of International Clone Trials and Regional Variety Trials aiming at sharing and evaluating germplasm under different growing environments and pest/disease pressures. The adoption of a farmers' participatory approach to breeding, to capture their knowledge and carry out on-farm trials to ensure suitability of the material, was also identified. Other key benefits were the improved availability of germplasm with known characteristics, including pre-bred material with superior disease resistance, which was being distributed following quarantine, and the sensory profiling/organoleptic evaluation of samples. All those involved had benefited not only from the scientific outputs of the project, but also in terms of the human capacity building and unprecedented levels of co-operation between research institutes in cocoa producing countries, regional and international institutions, and the private sector.

Many respondents considered that there was much to be gained by continuing the on-farm, international and regional trials since some of these were only just coming into bearing and all of

them were likely to generate useful data over the coming years. A coordinated approach to data collection and evaluation for these trials between the project partners would ensure that maximum knowledge and progress in breeding would be gained. There was also interest in continuing the pre-breeding and breeding work being undertaken at the international cocoa genebanks and in making more of the germplasm available through quarantine with accompanying information on its characteristics and performance.

In response to the question of new areas for collaborative activities, the need for more well-trained breeders and the creation and/or continued support for regional breeding activities were highlighted. Linkage with CacaoNet as a framework for continued collaboration was put forward with support for the international collections as part of the global strategy for the conservation and use of cacao genetic resources. Collaboration in areas such as genetic profiling to assist genebank management, breeding for quality attributes and for varieties to withstand climate change was also recommended. Furthermore, it was suggested that collaborative studies on the optimal management of selected clones would be beneficial to establish how new varieties could best be planted, pruned and fertilized for example as part of an integrated crop management system.

In the following discussion, participants re-iterated their concern that the outputs from the CFC projects would only be fully realized if the trials set up during the projects could be continued and fully evaluated. Unless financial support could be secured from external sources, there was the danger that institutes in some countries would not have the resources to maintain the trials and valuable results could be lost if the trials were abandoned, data remained uncollated or could not be fully analysed. This was a particular concern for the on-farm trials. Results to date would be presented during the Final Workshop for the project scheduled for June 2010 and it was suggested that Bioversity should have an important role in making an assessment of the trials and recommending priorities for continuation, ideally in time for that meeting.

The current CFC projects had indicated some interesting effects of the environment on cocoa quality, responses to pests and diseases and yield but further work was needed in this area. Prof. Hadley suggested that new international clone trials would be very valuable in assessing the adaptability of elite selections to climate change but noted that the trials would have to be re-structured to ensure that they could generate the necessary data. Dr. Lambert commented that a number of the institutes she worked with in the SE Asia Regional Breeding Group had not been able to participate in the CFC funded projects since their countries were not members of ICCO. However, these institutes, and possibly others in non-ICCO member countries, were interested in participating in these international projects if a suitable mechanism could be found.

Dr. Weise thanked participants for their contributions both to his questionnaire and to the discussions in the meeting. He looked forward to sharing this information with Dr. Eskes since it would make a very useful contribution to the preparations for the Final Workshop in 2010.

CacaoNet

Many of the Workshop participants had been present when Dr. Jan Engels had given his key note presentation on CacaoNet - the Global Cacao Genetic Resources Network at the main 16th ICRC in which he had described the importance of a coordinated approach to genetic resources conservation and CacaoNet's progress in developing a Global Conservation Strategy. At the INGENIC Workshop, Dr. Michelle End gave a presentation on how INGENIC's members had contributed to this process to date with a view to encouraging both individuals and institutions to take an even more active role in the further development of the CacaoNet Strategy document.

As agreed at the INGENIC discussion meeting held during the 15th ICRC, INGENIC had surveyed its members' opinions on conservation strategy in April 2007 and prepared a report on the responses received for the CacaoNet Steering Committee in May 2007 which was circulated to the INGENIC mailing list for comment. The Survey had covered questions such as what type of

material could be usefully included in a global public domain collection and how and where it could be conserved. Although there were differences in the way respondents referred to the types of collection, many respondents distinguished between a collection designed for long-term conservation, which could be referred to as a "Base" collection, and a dynamic collection of accessions which are of more immediate value to breeders, which could be referred to as an "Active" collection. It would be most important to include a good representation of the overall genetic diversity available in the Base collection whereas the priorities for the Active collection would vary by region depending on the local needs of breeders and farmers. There was support for the concept of a "virtual" global genebank, which would consist of accessions physically held in different genebanks around the world but which would be managed as if they formed part of one collection. The cost of maintaining large genebanks was recognised and the value of both molecular and traditional techniques to eliminate unnecessary duplication and misidentification was noted. Many of the respondents indicated that though they appreciated the value of techniques such as cryopreservation, especially as a means of safety duplication, it was important that information was available on the characteristics and performance of the material in order for it to be effectively utilised. Support was also expressed for precautionary and pre-breeding, and continuing need for quarantine facilities to ensure that clean germplasm could be disseminated to interested parties.

The detailed responses received were used as background material for an Expert Consultation on the Establishment and Composition of Global Strategic Cacao Collections which was initiated by a four day meeting held at the University of Reading in March 2008. Representatives of many of the larger genebanks and organisations interested in cacao germplasm, including INGENIC, participated in the meeting, or contributed to the report which is available on the CacaoNet website http://www.cacaonet.org/). The Consultation covered many aspects including detailed discussions on how genetic fingerprinting data, and other characterisation data, could be used to select accessions for the Global Strategic Base Collection with the aim of representing 95% of the genetic diversity within each of the genetic groups identified by Motomayor's 2008 study, and within any new groups which might be discovered by future collecting expeditions. The methods to conserve such a collection, including safety duplication, and strategies to ensure that genebanks holding the accessions could receive financial and/or managerial support where required, were discussed. The Global Strategic Active Collection was envisaged to be composed of material with combinations of characteristics which are of more immediate value to breeders and as such, the priorities would be sharing characterisation/evaluation data and the material itself for evaluation in different growing regions rather than ensuring the safety duplication and long-term security of accessions (since its genetic make-up could be reconstructed from material in the GSBC if that should become necessary). The Consultation also covered the information management systems that would be needed to manage a virtual collection and how they could function alongside existing national and international databases.
At the Consultation meeting, Bioversity had described how the development of conservation strategy documents for other crops, such as potatoes and bananas, had been very important in relation to obtaining funding from the Global Crop Diversity Trust (GCDT) and other donors. Unfortunately cacao is not one of the GCDT's priority crops, and thus unlikely to receive funding from it in the immediate future. However, GCDT may offer a route to manage funds designated for cacao conservation, and it had been agreed that there would be many advantages in developing a crop strategy for cacao along the lines of those prepared for other GCDT priority crops.

Dr. End went on to outline the structure of CacaoNet's Conservation Strategy Document which is currently under development and thanked all those who had already contributed their knowledge through the survey and consultation process and those individuals who had offered to take an active role in drafting the individual sections. She urged INGENIC's members to regularly check the CacaoNet Conservation Strategy webpage (http://www.cacaonet.org/) and continue to provide their input as revisions to each draft section are posted with a view to ensuring that the final document accurately represents the current status of the world's cacao germplasm and provides a clearly defined strategy for its optimum conservation and utilisation.

There followed some discussions on technical issues relating to the structuring of the Base Collection and how this could take molecular data and geographic data in to account. The benefits of coordination that CacaoNet's efforts could bring to cacao conservation were widely appreciated but there was much interest too in strengthening the coordination of pre-breeding and breeding activities and the possible roles of CacaoNet, Bioversity and INGENIC in this, especially following the completion of the CFC germplasm project.

SESSION 3: Breeding for Quality Attributes

The vast majority of cocoa beans are used by the confectionery industry, so it is essential that farmers can produce beans that are of a suitable quality to make chocolate. However, the term "quality" can have different meanings to different people and many aspects of quality are affected by environmental and post-harvest factors. Moreover, the vast majority of farmers are unable to assess key aspects of the quality of their cocoa, such as fat content and flavour, since they do not have access to the necessary analytical/processing equipment. Therefore it is essential that they are provided with suitable planting materials, and have the knowledge to treat them appropriately, to ensure they can produce a high quality cocoa that will meet the requirements of manufacturers and consumers.

Introduction from an Industry Perspective

Dr. Martin Gilmour (Mars) gave an introduction to "quality" from a chocolate manufacturer's perspective, emphasising that this encompasses physical, food safety and product related criteria. Training materials, such as those prepared as part of the Sustainable Tree Crops Programme (STCP), are available to help farmers to adopt good agricultural practices when they use agrochemicals, harvest, ferment and dry their cocoa to address current quality and food safety issues such as pesticide residues, free fatty acids (FFA), Poly Aromatic Hydrocarbons (PAH) and mycotoxin (eg OTA) contamination. He emphasised that if farmers have access to pest/disease resistant planting materials this can also have a positive effect on quality as well as yield, for example by reducing pesticide usage and therefore residues, and reducing the level of pod damage which is often associated with secondary microbial infections leading to mouldy off-flavours, FFA and OTA. Dr. Gilmour described how different types of beans are used by the chocolate industry; from the single estate/variety cocoas which may require specialised fermentation conditions but can often be sold for the highest premiums, through the bulk cocoas, fermented to achieve a good cocoa flavour, which are used in large quantities for milk chocolates, to the less expensive unfermented cocoas which are used for cocoa butter production. Thus, it is important that breeders have clear objectives in terms of the market for the types of cocoa they are developing and an awareness of the farmers' traditional practices in their country/region since for example, it has proved very difficult to get farmers in Sulawesi to adopt fermentation techniques despite many training initiatives. Dr. Gilmour outlined some aspects that the industry would like to be considered in breeding programmes, including yield, bean size/fat content, flavour (traditional, or fine for specialty products), and pest/disease resistance. He also emphasised the industry's continuing willingness to be involved in breeding programmes from the earliest stages, including offering flavour/fat analysis, to ensure that the improved planting materials eventually supplied to farmers will meet the requirements of industry and the consumer.

Quality Aspects under Genetic Control and Environmental Effects

Dr. Emile Cros, an expert in quality analysis from CIRAD, had been invited by INGENIC with funding from USDA/Bioversity to participate in this Workshop to share his experiences of factors influencing quality, including genetic, environmental and post-harvest effects. He discussed how different actors in the cocoa chain, from farmer to consumer, have different concepts of "quality" and how to assess it, though the price factor is included by all. Dr. Cros highlighted some results from research projects where the genetic and environmental effects on quality aspects such as

flavour profile and biochemical composition were investigated. He warned that the genotype x environment effect on flavour was particularly difficult to analyse since in some cases, SCA 6 for example, the clone's characteristic flavour was apparent even when grown in contrasting environments, whereas in other cases the flavour varied considerably according to the country where the material was grown. Some biochemical characteristics, such as the ratio of theobromine to caffeine, are strongly related to genetic background and are relatively stable across different growing environments. Whereas other characteristics, such as epicatechin levels, are strongly influenced by post-harvest treatment. An analysis of combinations of these factors can thus be used to give an insight into the genetic and geographical origins of samples. Research is also underway to identify genetic markers for quality factors which could be used for example to distinguish Trinitario/Criollo types. Dr. Cros went on to discuss the complex effects of fermentation, drying and roasting on flavour development. He concluded that post-harvest processing allows the expression of the potential of quality, and this potential depends on genotype. In the third part of his presentation, Dr. Cros discussed approaches to flavour profiling and the compounds associated with each of the main components of flavour.

Breeding for Flavor Quality

Dr. Darin Sukha (CRU, Trinidad) presented some findings from his PhD thesis on "terroir" effects on cocoa quality in which he had investigated the effects of processing location, growing environment and genetic effects on flavour profile. Even within a relatively small country such as Trinidad, processing location effects and some growing environmental effects were observed. Moreover he found a strong clonal effect; a pronounced floral note was detected consistently in cocoa liquors produced from one of the commercial clones tested wherever it was grown/processed. Similar environmental x genotype effects were noted in a study of cocoa produced from the same clones grown in four different countries (Ecuador, Papua New Guinea, Trinidad and Venezuela). All the cocoa samples were processed into liquors using a standard protocol and tasted by a trained panel in Trinidad. Some flavour characteristics were found to be closely associated with the country of origin, for example the Ecuadorian samples had floral notes whereas Venezuelan samples had caramel/malt flavours whichever clone was tested. However, some clonal characteristics, such as SCA's floral flavour, was consistent wherever the clone was grown. Dr. Sukha concluded that these studies provide a scientific basis for the "terroir" effect and niche marketing of fine/flavour cocoas from different origins/estates. Moreover trained personal and facilities are available in Trinidad, and elsewhere, to carry out this type of analysis not only for the industry but also as a contribution to breeding programmes,

Breeding for Cocoa Quality Attributes in Papua New Guinea

Dr. Peter Epaina described the cocoa breeding programme underway in PNG which aims to produce new varieties with improved quality characteristics as well as yield, disease resistance and agronomic characteristics, which will improve growers' profitability. Quality assessments, including flavour attributes and fat content, are made for most breeding materials and base germplasm. He concluded by emphasising that breeding for specific quality parameters can be done and that his institute is open to collaboration for work in this area.

Discussion

The presentations were followed by a lively discussion. Dr. Phillips (CATIE) asked what emphasis should be placed on breeding for high levels of polyphenols since this seemed to be an area of consumer interest. Dr. Gilmour agreed that there was considerable research on the health benefits of polyphenols in cocoa and that it might be worth considering screening germplasm for this characteristic. Dr. Cros commented that Forastero types, with a short (two day) fermentation, had higher levels and that the fine flavour types are generally low in polyphenols. Dr. Lambert added that it is well known that levels of polyphenols decrease during fermentation, but some clones lose their polyphenols at different rates to others. Dr. Rohsius was interested in the factors contributing to the terroir effect, and suggested that environment during pod maturation, pulp and fresh cotyledon composition as well as the processing conditions could all be involved. Dr. Sukha agreed that further research in this area would be useful in elucidating these factors. Dr. Padi

asked how breeders could make progress in breeding for quality factors given the strong environmental/post-harvest effects. Dr. Sukha suggested that multi-locational trials, with standardized post-harvest processing conditions, would be important in this respect. In Trinidad, for example, new varieties were assessed in different areas for five years before they were released. Dr. Gilmour re-iterated the industry's interest in offering flavour/quality analysis to those involved in breeding new varieties but commented that there is a real need for more sensory analysis facilities within producing countries not only to support breeding work, but also to improve quality control and help raise farmer awareness of the importance of good post-harvest practices. Dr Ahnert commented that he had found that farmers had a much greater appreciation of the impact of their post-harvest practices if they could taste the final product. For example, he had made liquors from beans dried in smoky driers, and once the farmers had tasted them they appreciated how their drying practices could impact on flavour.

The discussion turned to genetic effects on flavour and it was noted that although no pollen parent effect was found in Dr. Sukha's work, nor a strong effect noted in previous research by Clapperton and Lockwood, there was a need for further research in this area. Dr. Motamayor reported that the SE Asia Regional WG was developing a proposal to study combining ability for flavour with a view to elucidating aspects of flavour inheritance and Dr. Ahnert was interested in the possibility of incorporating a complementary study into the breeding proposal under development for the Americas region mentioned in Session 1.

There was also some discussion on how to raise farmers' awareness of quality issues and how the supply chain could be reformed, perhaps through the introduction of traceability/certification, to ensure that farmers could be rewarded for producing higher quality cocoa. It was also agreed that there needed to be better mechanisms to raise awareness and address food safety issues such as heavy metals and pesticide residues.

It was agreed that it would be useful to increase opportunities for researchers, the industry and other stakeholders to interact over quality issues and Dr. Cros expressed his intention to create an International Group for Quality aspects, including food safety/regulatory and flavour quality aspects, along the lines of the other "IN" groups.

SESSION 4 Other Papers

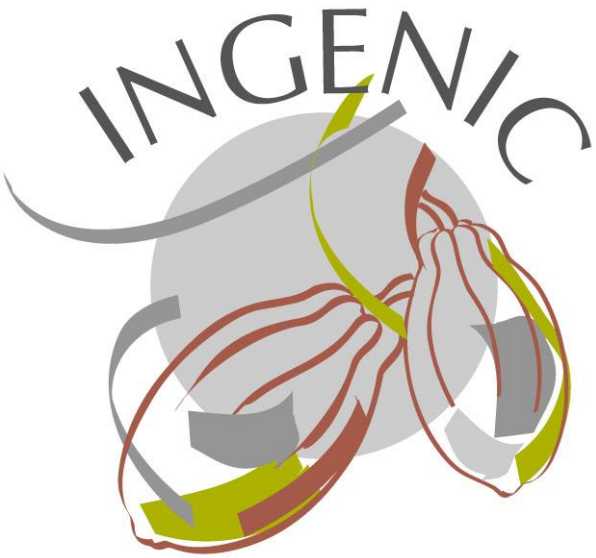
Adaptability of improved varieties with changing environmental conditions

Dr. Surendra Surujdeo-Maharaj (CRU) presented his case study of a possible breakdown in the resistance of SCA 6 to Black Pod in Trinidad. Much collaborative international research has been undertaken following the finding that there is no significant genotype x isolate interaction for *Phytophthora* reaction and SCA 6 has been widely used as a resistant control. There is considerable diversity in the aggressiveness of *Phytophthora* and CRU had been using a moderately aggressive isolate for its research, However, it had become necessary to select a new isolate, when the original isolate lost its ability to sporulate. The new isolate was collected from the same location as the original but it was found that although the expected "resistant" reaction was found when using SCA 6 for leaf tests, no difference could be detected between the reaction of the susceptible control ICS 1 and SCA 6 in pod tests. Dr. Surujdeo-Maharaj put forward two hypotheses to explain this; either the original strain was much less aggressive than the new one and this could have allowed SCA 6 to escape such a severe reaction or that a new strain of *P. palmivora* has been found which can overcome the resistance on pods of SCA 6 but not on leaves. The implications of the latter scenario would be that the leaf test could no longer be used as a predictor of pod resistance in early screening tests. It was suggested there could be a new collaborative project in which all countries involved in Black Pod resistance breeding/pre-breeding should periodically examine their isolates over time to evaluate the host-pathogen reaction, particularly in the CFC international clones available at each collection, so that their findings could be compared.

In the ensuing discussion, Dr. Aikpokpodion and Dr. Lamin commented that their research teams had found similar variation in isolate-host reaction. A number of researchers had also experienced problems in repeatability and environmental effects, and a tendency for isolates to become less aggressive once in culture. There was agreement that it was very important to take into account

the geographical distribution of isolates, their prevalence and persistence, in determining which isolates to use in this type of screening work.

This INGENIC Workshop had provided a very useful opportunity for breeders, food scientists and industry members to share their experiences and hold the discussions which hopefully will lead to further collaborative work and accelerate progress towards the improved varieties which are such an important part of a sustainable cocoa economy.



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Published by INGENIC 2012

With thanks to

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Foundation of the German Cocoa and Chocolate Industry

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