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PROJECT TO DETERMINE THE PHYSICAL, CHEMICAL AND ORGANOLEPTIC PARAMETERS TO DIFFERENTIATE BETWEEN FINE AND BULK COCOA

PROJECT COMPLETION REPORT (PCR)

Note by the Secretariat:

The attached document is a summary of the Project Completion Report submitted by the Project Executing Agency (PEA), INIAP, Ecuador.

CFC/ICCO/INIAP/ Project on:

Project to determine the physical, chemical and organoleptic parameters to differentiate between fine and bulk cocoa

Authors: Freddy Amores (International Project Coordinator), David Butler, Gladys Ramos, Darin Sukha, Susana Espin, Alvaro Gomez, Alexis Zambrano, Neil Hollywood, Robert Van Loo and Edward Seguine

PROJECT COMPLETION REPORT

Prepared by INIAP

INSTITUTO NACIONAL AUTÓNOMO DE INVESTIGACIONES AGROPECUARIAS

QUEVEDO - ECUADOR

I. BASIC PROJECT DATA

PROJECT TITLE:	Project to Determine the Physical, Chemical and Organoleptic Parameters to Differentiate Between Fine and Bulk Cocoa
PROJECT NUMBER:	ICCO/ 06 (CFC)
PROJECT EXECUTING AGENCY:	Instituto Nacional Autónomo de Investigaciones Agropecuarias (INIAP), Quito, Ecuador
SUPERVISORY BODY:	The International Cocoa Organization (ICCO)
PROJECT DURATION:	31/01/01 (Starting date) 26/03/06 (Completion date)
PROJECT LOCATION:	Ecuador, Papua New Guinea, Trinidad & Tobago, Venezuela
PROJECT FINANCING PLAN:	Total Cost: .... US$ 1,666,570 *Of which:* CFC Grant .... US$ 839,223 Co-financing contributions.................. US$ 205,837 Counterpart Contributions.................... US$ 617,517
DATE OF REPORT:	August 2007
AUTHORS OF REPORT:	Freddy Amores, David Butler, Gladys Ramos, Darin Sukha, Susana Espin, Alvaro Gomez, Alexis Zambrano, Neil Hollywood, Robert van Loo and Edward Seguine.

II. BACKGROUND AND CONTEXT OF THE PROJECT

2.1 Summary of the project proposal

1. The definition of fine or flavour cocoa remains controversial as there is no single universally-accepted criterion that could be adopted as a basis for determining whether or not cocoa of a given origin is to be classified as fine or flavour cocoa. Relevant criteria include the genetic origin of planting material, morphological characteristics of the plant, flavour characteristics of cocoa beans produced, chemical characteristics of cocoa beans, colour of the cocoa beans and nibs, degree of fermentation, drying, acidity and off-flavours. Points are awarded or subtracted by the quality assessors, depending on the condition of the cocoa beans in relation to the above criteria. However, the measurement of these criteria does not reflect objectively the cocoa quality in terms of taste or flavour, causing chocolate manufacturers problems in standardizing their products. This difficulty is shared also by traders on the international market, who base their decisions mainly on the degree of fermentation and genetic origin of cocoa.

2. The main objective of this project was to develop the capacity of all involved in the cocoa sector to adequately differentiate between fine and bulk cocoa, thus improving the marketing position of fine or flavour cocoa. The specific objectives of the project were to establish physical, chemical and organoleptic parameters enabling the evaluation of cocoa quality in relation to genotype and environment, and to disseminate selected parameters, methodologies, standards and instruments to be used in the evaluation of cocoa quality.

3. Three main outputs were expected from this project: reliable information on the physical, chemical and organoleptic characteristics which differentiate fine from bulk cocoa; the methodology to measure and compare the main parameters that define the quality of fine cocoa; and finally, standards and instruments to evaluate the quality of fine cocoa. In an internationally coordinated effort involving Ecuador, Trinidad & Tobago, Venezuela and Papua New Guinea, cocoa genotypes were selected, from which samples were taken. Subsequently, physical, chemical and sensorial analyses were conducted. Finally, results were collated and analyzed to arrive at conclusions to establish the differences between fine and bulk cocoa. Once this was achieved, useful quality standards for grading cocoa could be developed.

4. To implement this project on a sound scientific basis, it was envisaged to make use of advanced and powerful technologies to supplement the classical methods of analysis. For this purpose, the project engaged the services of the Plant Research Institute (PRI) in Wageningen, Netherlands, to carry out a DNA profiling of the cocoa beans using the Sequence Tagged Microsatellite Site (STMS) approach and to conduct a visualization and quantification of quality compounds in cocoa beans using Spectral Image Analysis. It was anticipated that the results of these various methods would support each other and, in combination, strengthen the overall outcome of the project.

2.2. Commodity issues addressed by the project

5. The world cocoa market distinguishes between two broad categories of cocoa beans: "fine or flavour" cocoa beans, and "bulk" or "ordinary" cocoa beans. As a general concept, fine or

flavour cocoa beans are produced from Criollo or Trinitario cocoa-tree varieties, while bulk cocoa beans come from Forastero trees. There are, however, known exceptions to this generalization. Nacional trees in Ecuador, considered to be Forastero-type trees, produce fine or flavour cocoa. On the other hand, Cameroonian cocoa beans are produced from Trinitario-type trees and their cocoa powder has a distinct and sought-after red colour. However, these beans are classified as bulk cocoa beans.

6. The International Cocoa Agreement, 1993, recognized 17 countries as producers of fine or flavour cocoa. Of these, eight were classified as exclusive producers of fine or flavour cocoa (including Dominica, Grenada, Jamaica, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Suriname, and Trinidad & Tobago) and the others as part producers of fine or flavour cocoa. The latter included Ecuador (75%), Venezuela (50%), Costa Rica (25%) and Colombia (25%) from the Latin American and Caribbean region.

7. The share of fine or flavour cocoa in total world production of cocoa has fallen dramatically, from about 50% at the beginning of this century to just under 5% (160 thousand tonnes) per year at present. The collapse in the relative importance of the production of fine and flavour cocoa is explained essentially by the fact that virtually all major expansion in cocoa production over the past five decades was related to bulk cocoa.

8. The Latin American and Caribbean region supplies about 80% of the world fine or flavour cocoa, followed by Asia and Oceania (18%) and Africa (2%). Ecuador, the world's largest supplier of fine or flavour cocoa accounts for over half of the total world production of fine or flavour cocoa. Colombia, Indonesia, Venezuela and Papua New Guinea produce around 10 thousand tonnes each. Jamaica, Trinidad and Tobago, Costa Rica and Grenada, each producing between 1 and 3 thousand tons per year, and are also important growers of fine or flavour cocoa in the Latin American and Caribbean region.

9. The decline in consumption of fine or flavour cocoa over recent decades has been brought about by a general shift in consumer demand away from solid or filled products, containing other ingredients endowed with stronger flavours (such as nuts, fruits, cream, etc), thus reducing the dependence on the aromatic and flavour characteristics of fine or flavour cocoa. Nowadays, chocolate manufacturers use fine or flavour cocoa beans in traditional recipes, mainly for a limited number of expensive, up-market finished products. Only very recently has the demand for fine or flavour cocoa started to grow very rapidly.

10. The traditional cocoa-consuming countries of Western Europe (the Benelux, France, Germany, Italy, Switzerland and the United Kingdom) represent the largest consumer market for fine or flavour cocoa, while the United States of America and Japan are also notable users of this type of cocoa. Imports of fine or flavour cocoa beans range from between 5% to 20% of total imports in these countries, with the Benelux, Japan and Switzerland importing higher percentages. Most major chocolate manufacturers have premium quality chocolate products in their range, which require fine or flavour cocoa from specific origins in their recipes for the distinct taste or colour of their chocolate. It should be noted that countries in Latin America, including Colombia and Venezuela, have large domestic markets and hence could also be regarded as consumers of fine or flavour cocoa.

11. Compared to the international market for bulk cocoa, the market for fine or flavour cocoa is generally regarded as a relatively small, highly-specialized and separate market, with its own supply and demand characteristics. Specialist agents buy directly from fine or flavour origins for specific chocolate companies. The price received is determined by the supply-demand balance for that particular origin and type of cocoa, with the quality and flavour requirements of the consumer being the primary considerations. Short-term factors influence the offer and bids in this small market with few participants, and hence the price obtained is highly variable. Nevertheless, fine or flavour cocoa normally commands a premium over London terminal markets that in exceptional circumstances could be above US$ 800 per tonne. But there are indications that over the past 10 to 15 years, the levels of premiums for fine or flavour cocoa have generally declined, especially for cocoa originating from the Latin American and Caribbean region. Consequently, farmers´ perceptions that the current internal market system does not recognize and/or reward the added value derived from adequately fermented beans have been exacerbated. These factors, couple to the recent general depression of prices, could be attributed to a combination of poorer husbandry, including fermentation and drying, as well as contributing to the mixing of fine and flavour cocoa beans with bulk cocoa beans. The fortunes of fine or flavour cocoa only changed very recently, as demonstrated by premiums which reached record levels during the past two years.

12. The lack of information on whether a certain batch of cocoa qualifies as fine or flavour creates problems. There are no problems where large traders or overseas manufacturers buy directly from plantations or large farms. They know exactly what they are buying and how the cocoa has been treated or handled. The problems occur where cocoa is collected from large numbers of smallholders by small traders or agents of traders. Once the cocoa is collected, it is a mix of cocoa from different places; post-harvest treatments may have been dissimilar, as well as the genotypes in certain batches. At that point, it is very difficult to assess the quality of the cocoa by visual inspection, cut test, smell or a simple organoleptic test. On the other hand, the buyers for export or the manufacturers run the risk of paying too much for a quality that is perhaps disappointing. This situation hampers efficient price formation and trade, and the "margins" that have to be calculated for that by the trade and industry are most probably to the disadvantage of the smallholders. It is this issue of inefficiency in the trade that was directly tackled under the project.

13. On current trends there is little prospect for a substantial increase in the supply of fine or flavour cocoas over the medium term. On the other hand, lower cocoa-bean prices have stimulated the demand for chocolate worldwide and recent years have seen an increase in the consumption of solid chocolate, especially in the main cocoa consuming countries of Western Europe. This has resulted in a relative shortage of supply of fine or flavour cocoa. Unless this supply deficit in fine or flavour cocoa is corrected, there is a danger that chocolate manufacturers may have to consider changes in their recipes, in favour of more readily available cocoas, which could have disastrous consequences for some cocoa growing countries.

14. A particular concern to chocolate manufacturing companies is the decline in quality of the cocoa beans on arrival at destination, due mainly to the imperfect post-harvesting procedures. The fine or flavour characteristics of the bean (from Criollo, Nacional and Trinitario varieties of cocoa trees) is not being questioned, but it is the apparent practice of shippers of mixing different qualities of beans that leads to the rejection of cocoa shipments and to a consequent decline in the

reputation of, and the premiums for, cocoa originating from a particular country. It appears that when cocoa bean prices are favourable, fine or flavour cocoa of good and uniform quality is exported. Low prices appear to provide little incentive to exporters to maintain quality and other inferior cocoa beans are mixed with the fine or flavour cocoa to obtain higher returns.

III. PROJECT OBJECTIVES, COMPONENTS AND EXPECTED OUTPUTS

3.1. General Objective

15. The central objective of the project was to provide universally accepted criteria to differentiate between fine/flavour and bulk cocoas. More specifically, the project aimed at assessing the characteristics of fine/flavour and bulk cocoas through a series of scientific evaluations of physical, chemical and organoleptic parameters and providing methodologies, standards and instruments for universal use in differentiating fine/flavour from bulk cocoa. The results of the project were expected to contribute to improving the competitive position of fine/flavour cocoa as a distinctive product and, once established, fine/flavour cocoa should be able to retain and/or increase the premium which it typically commanded on the market.

3.2. Project components and outputs

Component I: Fermentation and drying trials

Objective: To obtain physical quality parameters to be used in conjunction with other parameters to differentiate between fine and bulk cocoa. To obtain feedback from chocolate manufacturers on samples of dried beans with different fermentation regimes.

Output: A range of qualitative parameters which are characteristic of fine and bulk cocoas, as derived from the samples analyzed in the fermentation and drying trials. Preferences will be established from a variety of chocolate manufacturers as to their favourite fermentation regime for different cocoa genotypes.

Component II: Chemical assessment of quality parameters

Objective: To obtain chemical quality parameters of representative samples of fine and bulk cocoa, which will be used in conjunction with other parameters to differentiate between fine and bulk cocoa.

Output: A range of chemical parameters which are characteristic of fine and bulk cocoa.

Component III: Cocoa liquor preparation and chemical analysis

Objective: To establish a correlation between the flavours obtained from the cocoa liquors prepared and the different roasting temperatures.

Output: Chemical constituents related to beans at different roasting temperatures.

Component IV: Organoleptic assessment of sensory characteristics.

Objective: To obtain more parameters to differentiate fine and bulk cocoa through an organoleptic assessment of the representative samples of fine or flavour and bulk cocoa liquor samples tested by a properly trained sensory evaluation panel, in order to minimize subjectivity.

Output: Organoleptic Parameters and sensory characteristics specific to fine and bulk cocoas.

Component V: DNA profiling and spectral image analysis

Objective: To obtain molecular markers and other quality compounds specific to fine and bulk cocoa using DNA Profiling and Spectral Image Analysis.

Output: Molecular markers and spectral characteristics specific to fine and bulk cocoa.

Component VI: Analysis and interpretation of results

Objective: To produce a set of objective criteria that would be used to differentiate between fine and bulk cocoas.

Output: A set of criteria and instruments to be used in the differentiation of fine and bulk cocoa.

IV. PROJECT BENEFICIARIES AND ESTIMATED BENEFITS

16. All operators involved in the cocoa sector from cocoa smallholders through to consumers, including traders, exporters, processors, manufacturers and local economies in cocoa producing countries stood to benefit from the successful implementation of this project. The benefits from the project were expected to emanate from the improved transparency and efficiency in the cocoa trade; a more reliable and consistent quality for manufacturers, improving the quality of products and lowering costs of production; clear guidance for plant breeding to obtain varieties with certain desirable characteristics; and a better price for the farmer delivering consistently high quality fine flavour cocoa.

17. Almost all fine flavour cocoa is farmed on a small scale. Smallholders' farmers would gain from improved plant breeding and husbandry support services, facilitating their efforts to focus production more effectively to agreed specifications for the target market. Smallholders would be the main beneficiaries of this project as they were expected to receive a higher price for their fine or flavour cocoa, providing them with added incentives to improve husbandry and productivity. A higher production of fine quality cocoa should translate into more foreign-exchange earnings for the producing countries concerned, contributing to strengthening the cocoa sector economy and making more resources available to finance development programmes.

V. PROJECT STRUCTURE AND FINANCING PLAN

5.1 Project structure

18. The International Cocoa Organization (ICCO) as the sponsoring International Commodity Board (ICB) and in its capacity as Supervisory Body (SB) for the project, closely supervised the project and examined all information submitted by the Project Executing Agency (PEA), in this case the *Instituto Nacional Autónomo de Investigaciones Agropecuarias* (INIAP). This included an assessment of whether actions undertaken, expenditures incurred and results achieved by the project conformed to project specifications, as well as continuous assessments of the continued relevance of project activities and prospects for its successful completion.

5.2. Project financing

19. The total project costs were estimated at US$ 1,662,570, of which the grant requested from the Common Fund for Commodities amounted to US$ 839,223. It was expected that co-financiers would contribute the equivalent of US$ 205,837, while the participating countries would also make counterpart contributions available equivalent to US$ 617,510.

VI. PROJECT COORDINATION AND IMPLEMENTATION

20. INIAP as the PEA acted as the international project coordinator through one of the members of its scientific staff, regularly communicating with national coordinators of the other participating countries as well as with other organizations involved in the project. Regular reporting to ICCO and CFC project officials assigned to the project for supervising and monitoring was maintained. The coordinator provided advice and information to harmonize the decision making process. Decisions on administrative, financial, scientific and technical matters were communicated to project members and organizations involved to contribute to an efficient project execution.

21. INIAP established Memoranda of Understanding (MOU) with all collaborating Institutions and an Agreement with the Plant Research Institute (PRI) at the University of Wageningen in The Netherlands, a provider of research services (DNA and NIRS analysis and interpretation). Another task of INIAP was the distribution of the funds received from CFC.

22. The project started in February 2001 and was due to be completed in January 2004. However, two budget-neutral extensions were granted by CFC to complete certain project activities that had fallen behind and to organize the Closing Project Workshop in April 2006. During the Closing Workshop, the main project achievements as well as constraints and intended solutions were analyzed. The presentations given, working documents, posters and other documents produced at this workshop were distributed to all partners in a form of a CD-Rom as well as in a five-hundred page document. Hard copies and CDs of this document were handed over to ICCO and ANECACAO later on in September 2006.

23. The Project was implemented in close collaboration with the Cocoa Research Unit (CRU) in Trinidad and Tobago, the *Instituto Nacional de Investigaciones Agropecuarias* (INIA) in

Venezuela, the Cocoa and Coconut research Institute (CCRI) in Papua New Guinea and Plant Research International (PRI) at the University of Wageningen in the Netherlands. The Guittard Chocolate company also provided a valuable contribution to the project in terms of training to its members on sensorial analysis techniques, providing reference samples and contributing feedback on fine cocoa samples received from countries participating in the project.

24. At the start of the project, an initial workshop took place in Trinidad & Tobago to discuss and adopt working procedures and decide on genotypes from which samples would be taken. The meeting was also useful to review methodologies to assess physical, chemical and organoleptic traits of fine cocoa. The meeting was attended by the international project coordinators, the national technical project coordinators and other members of the research team from participating countries, project consultants, as well as representatives from ICCO and CFC and Plant Research International (PRI).

VII. SUMMARY OF PROJECT ACTIVITIES AND RESULTS

Component I: Fermentation and drying trials

25. Fermentation and drying protocols predominant in each participating country were used and all samples were sun-dried. Temperature and pH were monitored during fermentation and shell percentage, bean index and colour were measured. All samples were subjected to cut tests to evaluate the levels of bean fermentation.

26. Results showed that the pH of the cotyledon and of the shell converged at four days fermentation for Ecuador samples, six days fermentation for Trinidad & Tobago samples, three days fermentation for Venezuela Criollo samples and seven days fermentation for Papua New Guinea samples. Maximum temperature during fermentation ranged from 45 to 52 ºC. Monitoring of pH and temperature during fermentation, combined with the results of the cut test proved to be very useful in determining the optimal fermentation point in all PPCs.

27. **It was concluded that all of the parameters measured, with the exception of colour in the case of white Criollo cocoa from Venezuela, proved useful in determining criteria to achieve good quality cocoa, but did not help in differentiating fine from bulk cocoa**.

Components II and III: Chemical Assessment of Quality Parameters and Cocoa Liquor Preparation and Chemical Analysis

28. The fermentation index, acidity indices (physical, titratable and volatile acidity), butterfat content, melting point, polyphenols, purines and sugars were measured to characterize beans. Pyrazines and other associated aroma compounds were also measured for the same purpose.

29. Results showed that the fermentation index proved to be a good parameter to determine the optimal number of days of fermentation. Acidity tended to be higher in the Trinidad & Tobago bean samples than the Ecuador and Venezuela samples. Polyphenol content at the end of fermentation was typically 50% less than in fresh beans samples. Higher polyphenol concentration was detected in the cacao Nacional from Ecuador compared to local clones from

the other member countries. Ghana samples tended to show higher butterfat content than samples considered to be fine cocoa. Melting point temperatures ranged between 32 and 33.5ºC. Purines, particularly the theobromine and caffeine percentages were 20 to 25% less in fermented beans than in non-fermented beans; however, the theobromine/caffeine ratio proved to be stable across different fermentation times for the same genotype or origin. This was true not only for the beans but also for the liquors prepared from these beans. Due to this stability there is a clear potential for this ratio to be used to discriminate commercial cocoa origins, thus facilitating separation between fine and bulk cocoas. The ratio fructose/glucose also appears to have some promise in discriminating between cocoa origins, although further research is needed to confirm this finding. Finally, pyrazines and other volatile compounds proved to be generally useful in comparing and differentiating samples from countries producing fine cocoa with Ghana reference samples. The main component analysis showed that aromatic profiles can turn into powerful tools to set apart different cocoa origins, differentiating not only fine from bulk cocoa groups, but also producing differences within fine cocoa origins. The ability of the aromatic profiles to segregate insufficiently fermented cocoa beans from those well fermented as shown by some of Ecuador's findings in this project, suggests that future research in this direction would be of value.

30. **The main conclusion is that the theobromine/caffeine ratio proved to clearly differentiate fine from bulk cocoa. However it cannot differentiate beans of good and poor quality so would not assist in predicting expected flavour profiles. On the other hand, aromatic (volatile compounds) profiles hold promise to differentiate both origin and the quality due to post harvest processing. Further research to develop this potential is strongly recommended.**

Component IV: Organoleptic assessment of sensory characteristics.

31. The development of this component generated knowledge that allowed a clear separation between fine cocoa and the Ghana reference. Additionally, the methodology proved to be useful in differentiating between fine cocoa samples from different origins. **This confirmed that in general fine cocoas from different origins have distinct flavour profiles, thus eliminating market competition among them because they each occupy distinct niches in the market. This situation provides a strong incentive for future collaborative research among fine cocoa producing countries to advance the development of the fine cocoa market.**

32. This collaborative research could be based on shared initiatives to continue characterizing fine cocoa origins not only between countries but also within countries (to provide identities for the beans produced by traditional cocoa growing areas) as well as exploring new sources of unique sensory profiles which could be of further interest for cocoa breeders and the chocolate industry, particularly those specializing in manufacturing gourmet products. Such sources may be found in the upper Amazon region where there are wild cocoa trees producing white, semi-white and/or pale beans. Some of these are available in cocoa germplasm banks in Ecuador and could be used to advance in this type of research. After all, Latin American and the Caribbean region are the main source of cocoa genetic variability, a strong factor in determining flavour.

33. The project identified a spectrum of unique sensorial attributes for the samples from each of the PPC. There is growing evidence that further knowledge of this phenomenon would lead to better commercial exploitation of unique flavour profiles by the supply chain and the industry.

Through the project, typical flavour attributes from each country have been characterized. These include floral attributes exhibited by the cacao Nacional from Ecuador, the nutty sensorial notes typical of the Criollo cocoa beans from Venezuela, the distinct fruity and acid sensorial notes emerging from roasting well fermented beans from Trinidad & Tobago and Papua New Guinea. A strong floral note was also detected in certain bean samples produced by Trinidad & Tobago and finally a new malta/caramel sensorial note was identified for Criollo cacao beans from Venezuela which was not recognised before the project was implemented.

34. **Another outcome from the project is the appearance of evidence which suggests the strong influence of the environment on the flavour profiles of the same genotypes grown and processed in different countries.** This environment-induced variability can stimulate future commercial opportunities to be exploited using similar approaches in other crops. This research would lead us to a better understanding of how different aspects of the environment affect cocoa flavour profiles across seasons, years and places.

35. More knowledge and better understanding will allow better management of environmental factors that affect fermentation and influence sensorial quality. This, in turn, would be effective in producing and controlling the quality of cocoa with unique and well characterized flavour profiles. A preliminary research plan to achieve this goal has already been formulated by project participants and this will form the basis of a proposal to seek support for such a study. To address similar issues, Ecuador has just initiated field actions in the frame of a local project aimed at achieving the knowledge necessary to better characterize flavour profiles in at least two of the main cocoa producing areas of the country. The objective is to contribute in building flavour identities with the view to achieve "origin" cocoa.

36. **It was also confirmed by the project that sensory panels are a valuable tool to identify flavour defects in fine cocoa samples. These panels could be the basis of plans to develop schemes of cocoa quality control with certification.** This is a necessary step to make significant changes to the present scenario which is plagued by claims of low quality for certain fine cocoa commercial origins. Complementary, flavour assessment proved to be a valuable tool to guide decision making to improve post harvest processing.

37. **Finally, the implementation of the project's organoleptic component resulted in the development of human capacity in the area of sensorial testing skills in the research teams in each PPC. These skills are already being used to provide not only research services but also testing services for operators of the local cocoa supply chain. INIAP in Ecuador, CRU in Trinidad and INIA in Venezuela are becoming increasingly active in this task.**

Component V: DNA profiling and spectral image analysis

38. The agreed number of STMS (Sequence Tagged Microsatellite Site) markers were developed and applied by PRI to distinguish the cocoa genotypes used in the project. Some genotypes in local clone collections proved to be identical or genetically very similar. A draft scientific paper (unpublished) was written and discussed with the partners at the Project Workshop in June 2005. A dendrogram based on a cluster analysis of the data showed clustering of different types of bulk (Forastero) and flavour (Nacional, Criollo or Trinitario) genotypes. The marker technology can be used to identify individual genotypes, however, distinguishing

individuals within the Criollo group from Venezuela proved difficult, probably due to their narrow genetic background.

39. **The set of the molecular markers chosen may only be used for identification/distinction of genotypes and offer no guarantee for high flavour quality. This is partly because environmental and management effects can change flavour, and also because within some genetically related groups both good and poor flavour qualities exist. It is possible to identify the genotypes of pollinators in a cocoa plantation by examining various beans from the same mother tree. This could give an indication of the total genetic make-up of the population of trees in a plantation, but for routine use the analysis would be too expensive to determine whether a certain batch of beans can be traced back to a certain plantation.**

40. However, using the set of molecular markers, it would be possible to determine if a certain batch contains a mixture of different types of cocoa (for example Nacional and CCN 51 in Ecuador). Certification identity of fine cocoa batches would be possible using molecular markers.

41. The initial results of the UV excitation/emission spectra resulted in a good correlation between the time of fermentation and flavour assessments by the Trinidad sensory panel. Correlations were poor with the Ecuador flavour assessment, and project partners considered that the flavour results for the Trinidad samples were more reliable. PRI used bean samples from Ecuador that were produced early in the project when the sensory panel was inexperienced and the flavour results were less reliable. Training in sensory assessment requires considerable experience and it takes time to achieve robust and reliable results.

42. At the workshop in June 2005, PRI demonstrated to the project partners that the NIRS analysis was very powerful in discriminating different fermentation times. For the Trinidad samples several good prediction models were found for different flavour attributes. For the Venezuela samples it was possible to create a prediction model for separating the Criollo from the other genotypes and a prediction model for the new malt/caramel flavour that was defined as characteristic for the Criollo types. For Ecuador samples, fermentation time could be well predicted by the NIRS analysis, but it proved that further analysis of the flavour data in relation to NIRS would be necessary since the quality of the flavour data improved with time for the Ecuador sensory panel. Relationships with flavour were better for bean samples from later years than for the bean samples tasted in the earlier years. **For all samples, good prediction models were found with NIRS for the theobromine/caffeine ratio. This is a good example where basic differences between Ghana, Nacional, Trinitario and Criollo genotypes could be distinguished by NIRS**.

43. These prediction models are preliminary indicators of the potential of NIRS. They are perceived to be calibration models for which validation was only possible on a limited scale due to the relatively small number of flavour assessment results. PRI received the agreed number of bean samples for NIRS analysis; however, the project strategy of using the different fermentation durations for repeated sensory assessment could not be fully implemented. To produce reliable statistically results, the Trinidad sensory panel selected fully fermented samples for assessment. Time did not permit flavour assessment of the numerous samples with different fermentation

times. This reduced the number of samples that could be used to correlate with NIRS data. Nevertheless, **the NIRS and UV-excitation/emission analyses have demonstrated the feasibility of developing prediction models for flavour that would be a technique using fast, physical measurements on raw cocoa. To further develop and validate these methods a much larger number of samples are required to build on this promising start and it would be valuable for each of the participating countries to acquire a NIRS capability and built up a large database.**

Component VI: Analysis and interpretation of results

44. Analysis of the knowledge accumulated in the preceding components and the discussions held during meetings in Trinidad and Tobago in June 2005 and during the final project workshop in Ecuador in April 2006 led to a number of conclusions regarding the instruments available to differentiate between fine or flavour and bulk cocoa.

45. Organoleptic assessments together with the theobromine/caffeine ratio emerged as the most promising components for a quality control technology system in cocoa, particularly to separate fine or flavour and bulk cocoa. Herbal floral was the typical ancillary note of the *Nacional* genotypes in Ecuador. Fruity ancillary notes are sensorial traits associated to the Trinidad & Tobago and Papua New Guinea origins. Nutty and caramel/malt notes are flavour traits closely associated to Venezuelan *Criollo* genotypes.

46. All the samples of fine or flavour cocoa from the four countries participating in the project fell within the range of 2-6 for the theobromine/caffeine ratio. The Ghana samples studied in the project fell clearly out of this range. Preliminary information on other West African cocoas such as from Ivory Coast provided by Trinidad & Tobago, confirmed this assertion. Theobromine and caffeine are parameters that can be subjected to a quick measurement in beans (unroasted or roasted) and cocoa liquor. Roasting does not affect the stability of this ratio. Its predictability through NIRS proved stable and remained consistent with earlier findings by Nestlé and CIRAD. The next step is the validation of these findings and their incorporation into local quality control systems combined with DNA and NIRS information within each country.

VIII. PROJECT BENEFITS

47. The project produced knowledge to reinforce the scientific basis that sustained the concept that fine and bulk cocoas had specific attributes influencing the way these products were used. This information is an important input for economic and commercial decisions made by the different stakeholders (producers, exporters, traders and manufacturers). Future dissemination will accentuate its use and favour more informed decisions reducing uncertainty in the market, one of the problems affecting the positioning of fine or flavour cocoas.

48. On the other hand, the project has opened up new avenues for the validation of tools to measure and evaluate the differences between fine and bulk cocoas, particularly using the flavour. Evidence of the critical role of the environment on the development of fine and flavour cocoas has also set the stage for future research to establish the factors and better understand the phenomenon of environment-induced flavour-variability. A follow up research project to work in

both directions is being formulated for consideration by ICCO. The ultimate goal will be the management and use of this variability as a resource to create economic value in the cocoa industry.

49. Finally, the project has created opportunities for several important technology transfer activities related to post-harvest management and sensorial evaluation of cocoa in participating countries.

50. The project has enabled the establishment of an international collaborative network to further advance physical, chemical and organoleptic research as well as technology transfer initiatives, mainly among Venezuela, Trinidad & Tobago, Ecuador and the USA. This collaborative network may contribute to a more effective and coordinated use of limited resources and knowledge in research on fine or flavour cocoa. This knowledge is a scarce resource in the development of research, technology transfer and in setting up of integral cocoa quality systems in the region.

51. The project produced a spectrum of flavour attributes unique to each fine or flavour cocoa producing country, demonstrating that the countries concerned did not compete with each other in the international market. This was not an expected output but strongly justifies further investigation of the variability of local genetic resources to explore possibilities of new and unique flavour profiles with a potential for commercial development.

52. The project produced growing evidence that further knowledge of fine cocoa flavours and factors that control this phenomenon could lead to a better understanding, control and commercial exploitation of this cocoa as a natural resource.

VIII. PROBLEMS AND LESSONS LEARNED

53. Throughout the duration of the project, a series of problems were encountered that impacted on its efficient implementation. Three of these constraints have had a particular impact on the project:

54. Firstly, the International Project Coordinator lacked the experience required to conduct such a multi-country and multi-linguistic project. His heavy commitments on several other fronts at local and international levels affected the adequate and timely discharge of his duties on administrative, financial, technical and scientific matters. It is clear now that the complexity and scope of this type of projects demand the appointment of a full time coordinator such as the one available in the Germplasm projects. Nevertheless, the experience gained by all scientists and project participants remains an invaluable asset for future use.

55. Secondly, the low proficiency in English from some scientists in Ecuador and Venezuela also constituted a problem that hindered the project. This was a limiting factor in the communication flow and exchange of information with the Trinidad & Tobago and Papua New Guinea researchers as well as other organizations and people involved in the project.

56. Thirdly, the poor communications between PNG and the other countries, at times, delayed the decision-making process, in particular when it came to substitute certain clones for others. This issue is likely to affect other projects in which PNG is involved.

57. Finally, a banking crisis in Ecuador just as the project was gaining momentum caused the project funds to be "frozen" in the bank holding the project account. The initial financial arrangements were that funds would transit into INIAP's accounts before being transferred into the bank accounts of the other institutions. This situation delayed some activities and put considerable pressure on the project coordinator to solve the resulting financial crisis and made efforts to release the funds as well as requesting additional funds form local sources (ANECACAO) and CFC very difficult. Local project operations practically stopped until new funds were received.

IX. CONCLUSIONS AND RECOMMENDATIONS

9.1. Conclusions

58. The project produced mixed results. On the one hand, it has generated a body of knowledge that can, separately or in combination, be used to distinguish between fine or flavour and bulk cocoa. For instance, the theobromine/caffeine ratio proved to have consistently good discriminating power to segregate fine or flavour from bulk cocoa. This was widely evident with bean samples from all project participating countries at any site. This ratio held a good potential to be predicted by Near Infra-Red Spectrometry (NIRS) and its validation should be an important component of any follow-up project. The project also showed that basic differences in the theobromine/caffeine ratio between Ghana, Nacional, Trinitario and Criollo can be picked up by NIRS and that NIRS was also very powerful in discriminating between different fermentation times. Some good prediction models based on NIRS were found for different taste/flavours attributes but floral and fruity flavours were difficult to predict.

59. On the other hand, certain criteria were not so conclusive in discriminating between fine and bulk cocoa. For instance, pyrazines and other volatile compounds making up the aromatic flavour of cocoa proved relatively promising as parameters to segregate fine or flavour and bulk cocoa in Ecuador, Venezuela and PNG. However, the findings strongly call for further studies to develop any discriminating potential these could have. In the same way, molecular markers may only be used for identification of or distinction between genotypes and gives no guarantee for high flavour quality because environmental and management effects can change flavour.

60. PH levels during fermentation combined with temperature and cut test results can only be utilized in a combined approach to determine the optimal fermentation point. Except for Venezuela's white Criollo beans, the colour of the beans is a trait that has poor potential as a discriminating parameter between fine and bulk cocoa.

61. Acidity related parameters as well as the fermentation index, organic acids content, polyphenol content, purine concentration and sugar related parameters were all significantly affected by the degree of fermentation, while butterfat percentage and butterfat melting point were not. Consequently these held no potential to differentiate fine or flavour from bulk cocoa samples.

62. The project concluded that there were clear organoleptic differences between samples considered to be fine or flavour cocoas and the reference for bulk cocoa from Ghana. In addition, the diverse range of flavours that emerged from the different country clones assessed provided strong evidence that "fine or flavour" producers did not compete with each other in this specialised market segment but rather that each producer occupies a unique flavour niche within the market, due to the combination of genotype and local environmental conditions.

63. This project was the first to analyse the potential of ultraviolet fluorescent spectrometry for the characterization of ground cocoa beans. In addition, good single linear regressions or bilinear models were found relating emission levels to various taste traits and purines. The number of samples analysed was low but the models would justify further development of the use of UV fluorescence emission/excitation spectrometry for assessing quality traits of cocoa beans.

64. Finally, after appropriate validation exercises, a combination of DNA marker analysis for genotype identification and fast spectral (NIRS or UV) analysis of samples could be used to establish quality control systems aimed at improved fine or flavour cocoa quality.

9.2. Recommendations

65. It is recommended that the project results be used for initiatives that would contribute to the development and strengthening of the fine or flavour supply chain and market. In this respect, it can be considered to formulate a follow-up project proposal as an output of the collaborative work carried out in this project. Such a proposal would seek to validate the methodology aiming at evaluating and differentiating fine or flavour cocoa origins from bulk cocoa, particularly based on the approach achieved in the NIRS analysis.

66. Good linear models were found in the project relating emission levels to various taste traits and purines (theobromine / caffeine ratio). It is worth continuing this line of research to develop the promising potential of the UV fluorescent methodology as a tool to discriminate between fine and bulk cocoas.

67. Such a proposal could also include a component to study in more detail environment-induced variability of flavour for a better understanding of the factors and mechanisms of action influencing this phenomenon. An improved understanding of this phenomenon might facilitate the management of the flavour variability as an economic resource to be exploited in the fine and flavour cocoa market.

68. Finally, it is important to capitalize on the investment made in this project by continuing to disseminate the knowledge and technology transfer processes acquired during project implementation. One way of achieving this could be the design and implementation of formal cocoa quality control systems in the participating countries and beyond.