



**International
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Research**

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BOOKLET OF ABSTRACTS



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SESSION 1

COCOA CULTIVATION: INNOVATIVE APPROCHES AND PRACTICES FOR SUSTAINABLE PRODUCTION



ORAL PRESENTATIONS



Unwrapping the Chocolate Transcriptome: The Gene Expression Atlas of the Tropical Crop *Theobroma cacao*

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ABSTRACT

Theobroma cacao has emerged as a model tropical tree crop for genomic studies. A number of important tools have been developed for cacao science including: multiple high resolution genome assemblies, RNA expression data, metabolomics datasets, etc. To complement this work, we have developed a transcriptome map of 22 representative cacao tissues across multiple developmental stages, including orthotropic and plagiotropic, as well as across a diurnal and drought treatment time course, and response to pathogen infection. All treatments contain replicates ranging from three to five. Transcriptomes were mapped to high-resolution de novo assembled and annotated SCA6 and CCN51 reference genomes. 74% of the SCA6 and CCN51 genes were supported by functional annotations. Expression matrices are available for all datasets. In addition, an interactive digital atlas of these transcriptomes has been generated through electronic fluorescent pictographs (eFPs) to allow for easy visualization and comparison of expression data which is housed at the University of Toronto BAR server. The *Theobroma cacao* gene atlas provides an important resource in the exploration and study of the cacao genome and gene families to better understand this under studied crop. In this presentation, I will present an overview of the Atlas, the BAR eFP visualization tool, and describe the results obtained using the atlas to explore differential gene expression in different stages of embryo development as well as in different cacao clones. We also explored expression of lipid biosynthesis gene families in various tissues, focusing on cacao embryos, to pinpoint the paralogs that are integral for cocoa butter development. The Cacao Gene Atlas Consortium included the following contributors, from Penn State University: Sarah Prewitt, Akiva Shalit-Kaneh, Eric Wafula, Mark Guiltinan, Siela Maximova, Claude Depamphilis, Benjamin Knollenburg, Noah Winters, and Evelyn Kulesza; and from The University of Toronto BAR: Nicholas Provart and Asher Pasha.

Keywords: Transcriptome atlas, Visualization atlas, Lipid biosynthesis

The « BarCo » project: for the promotion of barrier crops to curb the expansion of the Cocoa swollen shoot virus in Côte d'Ivoire

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ABSTRACT

The Cocoa swollen shoot virus disease (CSSVD) is considered as a threat in Côte d'Ivoire since the early 2000s, when serious outbreaks were reported in the Central-West region. Today the disease has reached most of the production areas, becoming a major threat for cocoa industry. Control measures currently implemented by cocoa sector are the destruction of infected cocoa trees and their closest neighbors. This strategy has proven alone ineffective, as new disease outbreaks have often been reported in the young cocoa plots. Among plant diversification strategies proposed by research, the use of barrier crops has proven effective in protecting young or mature plots from CSSV in Togo and Ghana. This strategy is based on the hypothesis that cocoa monocultures on vast and continuous areas, which were promoted in a recent past, are conducive to CSSV expansion. The virus is transmitted from an infected cocoa tree to a healthy one by mealybugs, which do not meet any obstacle to their dispersion in large monocultures. The BarCo project “Towards the use of barrier crops and biological control of vector mealybugs to curb the spread of the Cocoa Swollen Shoot Virus (CSSV) in Côte d'Ivoire” was implemented from June 2018 to December 2020, with the objective to test and promote barrier crops as a strategy to reduce the progression of CSSV in affected production areas, especially the region of Soubré (South West of Côte d'Ivoire). A living lab approach was adopted, where members of two farmer cooperatives were involved in all stages of the project. A set of fourteen 0.25 ha cocoa plots surrounded by 10 m large hedges of coffee (*Coffea robusta*) or acacia (*Acacia auriculiformis*), or without hedges (control plots), was implemented within large CSSVD outbreaks in mature cacao plots. About 330 farmers were trained on CSSVD symptoms, vector mealybugs and good planting practices and a technical sheet was distributed in 1400

copies. A survey of 300 cocoa farmers revealed a high level of comprehension and willingness to adopt the technology. However, other barrier crops were preferred by farmers, in the forefront of which oil palm, cashew and bitter cola (*Garcinia cola*). Sixteen-month observations revealed that CSSVD symptoms were not detected in the plots, whereas populations of at least four mealybug species were early recorded on young cocoa trees and coffee. The effectiveness of barrier crops in controlling the CSSVD is presented and discussed.

Keywords: Plant diversification, Planting pattern, Vector mealybugs

Genetic bases of fruity and flora aroma of the Nacional cocoa variety

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ABSTRACT

Cocoa is classified into two types of products: so-called standard cocoa, which has a pronounced cocoa taste and so-called fine aromatic cocoa, which is characterised by floral and fruity notes. The production of fine aromatic cocoa therefore represents about 5% of world production. Some Latin American countries produce almost exclusively fine cocoa, which is a significant source of income for them. One of the characteristics of Nacional cocoa, the emblematic cocoa of Ecuador, is its aromatic ARRIBA flavour. This aroma is mainly composed of floral and fruity notes whose genetic and biochemical origin is not well-known. This research objective is to study the genetic and biochemical determinism of the floral aroma of modern Nacional cocoa variety from Ecuador. Genome-Wide Association Study (GWAS) was conducted on a population of 152 genotypes of cocoa trees belonging to the population variety of modern Nacional. Genome-Wide Association Study was conducted by combining SSR and SNP genotyping, assaying biochemical compounds, and sensory evaluations from various tastings. A large number of association zones have been identified. A total of 60 association zones were characterised in relation to sensory taste notes (fruity (22) and floral (38)). And a total of 895 association zones were identified with volatile compounds, 480 with fruity characteristic and 355 with floral characteristic. In a second step, a search for candidate genes in these association zones was undertaken, which made it possible to find genes potentially involved in the biosynthesis pathway of the biochemical compound identified in associations. 556 candidate genes involved in the biosynthetic pathways of volatile compounds identified in association areas were detected. Five main metabolic pathways were identified as involved in the fruity traits of the Nacional population: the protein degradation pathway, the sugar degradation pathway, the fatty acid degradation pathway, the monoterpene pathway,

and the L-phenylalanine pathway against two for the floral traits (the monoterpene biosynthesis pathway and the L-phenylalanine degradation pathway).

Keywords: GWAS analysis, aroma compounds, candidate genes

Past domestication of *T. cacao* in Central and Latin America revealed by paleogenomics and analysis of methylxanthines

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ABSTRACT

Understanding the diversity of a species and its history, in order to better exploit it, is a challenge that breeders often face when creating new varieties adapted to the current environment. Many questions still remain about the first phases of cocoa domestication in Central and Latin America. Using a multidisciplinary approach, associating archaeologists with genomics and biochemistry scientists, we tried to retrace the history of the past domestication of cocoa trees, and their migrations in South America and Central America. Plant paleogenomics is a new field of research, that traces the evolution of cultivated plants in response to human domestication and natural selection since very ancient times. It is based on the analysis of ancient DNA (aDNA) from archaeological remains and can provide direct access to plant varieties consumed several thousand years ago. The oldest traces of cocoa consumption date back 5,500 years and have been identified in the southern Ecuadorian Amazon. New studies, reported in this paper, have been carried out from more than 300 archaeological samples collected mainly all along the Pacific coast of Ecuador and Colombia as well as in Central America and from diverse civilizations, the oldest of which dates back to more than 5000 years before our era. Analyzes have revealed traces of ancient cocoa DNA and methylxanthines (theobromine, theophylline and caffeine) in the ceramic residues of many pre-Columbian cultures. They show a wide use of cocoa throughout the Latin America continent and at very varied times which can go back more than 5000 years. The genetic origin of varieties consumed several thousand years ago could have sometimes been identified by comparison with a large collection of modern genetic resources representing the diversity of the *T. cacao* species. These results provide new keys to unraveling the past domestication of *T. cacao* in Latin and Central America.

Keywords: past domestication, paleogenomics, methylxanthine

Development of new cacao elite cultivars for the sustainability and competitiveness of the supply chain in Colombia.

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ABSTRACT

Cocoa crop plays an important role in Colombian rural development. In addition, it has been identified as a potential substitute for illicit crops, which also provides sustenance to 65,000 Colombian families. According to the ICCO, 95% of the cocoa grain produced in Colombia is fine and aromatic, a distinction granted only to 8% of the bean produced worldwide. However, yields in Colombia do not exceed 500 kg.ha/year, when they should be above 1,200 kg.ha/year. These low yields are due to the fact that a large percentage of cocoa producers in Colombia have hybrid materials and aged. This prior condition indicates that its potential is still limited, that is why a new strategy will increase the income of cocoa farmers in which new cocoa genotypes with high productivity, tolerance to diseases and high quality must be developed. The latter will guarantee the supply of this raw material for the chocolate industry. Aiming to support cocoa field in Colombia, la Compañía Nacional de Chocolates, a leading company in the chocolate industry for more than 100 years of existence, has had a permanent commitment especially with the families dedicated to this crop. The Agricultural Development area was established 1958, since the it has had a specialized team of professionals that has strengthened the cocoa-chocolate value chain in the various components in which is worked. This includes training through technical advice and training in our experimental farms. Plant material as a donation has been delivered which has promoted productive programs and partnerships. It also has included social accompaniment and agribusiness programs that has generated new knowledge and technologies through basic and applied research. Finally, its marketing has been done through the integral relationship with farmers ensuring direct access to the market and promoting good agricultural practices in cultivation. In this sense, a cocoa genetic improvement

program was established in which two new cocoa genotypes were obtained from field trials achieving commercial registration. Some characteristics were achieved like excellent sensory quality, high yield, self-compatibility, moderate resistance to the main diseases of the crop in Colombia. In this way, Compañía Nacional de Chocolates is consolidated as the first private company to develop cultivars endorsed in the National registry of commercial cultivars of Instituto Colombiano Americano ICA getting CNCH 12 and CNCH 13 cultivars, and therefore strengthening the genetic diversity of the country.

Keywords: Genetic improvement, Genotypes, *Moniliophthora roreri*

Processes for Knowledge Transfer and Related Efficiencies: A case of the CocoaSoils Program

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ABSTRACT

The CocoaSoils-Sustainable intensification of cocoa production through the development and dissemination of Integrated Soil Fertility Management (ISFM) options program seeks to promote a sustainable cocoa supply sector with increased productivity of cocoa farms (30%), efficient use of agricultural inputs and improved rural livelihoods (90,000 smallholder farmers with increased yields and incomes) while avoiding deforestation and child labour. The program seeks to develop and disseminate ISFM options for cocoa, filling an important knowledge gap towards increasing cocoa productivity. The aim is to ensure that both existing and newly developed cocoa ISFM related research products are used (integrated in their Extension networks) by private and public stakeholder partners, who will also ensure that recommendations generated through the research products are used by target households. To achieve these, the project developed a training manual with existing ISFM content for extension officers and a handbook for farmers after engaging cocoa experts and stakeholders in Cameroon, Cote d'ivoire, Ghana and Nigeria. The content of the manual and handbook include cocoa productivity, avoided deforestation, pruning, soil nutrient management, integrated pests and diseases management practices, shade management, soil conservation, organic matter and inorganic fertilizer application. In all, 484 extension officers (57 in Cameroon, 179 in Cote d'ivoire, 119 in Ghana and 129 in Nigeria) working with 10 licenced cocoa buying companies have been trained in the aforementioned topics across the four countries. In order to reach out to the smallholder farmers with the content of the manual, an extension agent led dissemination and digital dissemination techniques were adopted. Trained extension agents under the program integrated the content of the manual in their existing respective company dissemination approaches and carried out step down trainings for farmers of which a designed dissemination tool is used to report on such events. This process resulted in an efficient dissemination process of the content of the manual. In all, 32472 farmers (1347 in Cameroon, 2485

in Cote d’Ivoire, 2728 in Ghana and 25912 in Nigeria) were trained by extension agents on the content of the manual. Through digital platforms using Interactive Voice Response (IVR) and Short Message Service (SMS), the program supported its partners with dissemination of the content of the manual to 30781 farmers (4423 in Cameroon, 9220 in Cote d’Ivoire, 12476 in Ghana and 4662 in Nigeria). So far, the program has trained over 63253 cocoa farmers across Cameroon, Cote d’Ivoire, Ghana and Nigeria.

Keywords: cocoa production, extension, digital platform

How many years of evaluation are needed to select new productive cocoa clones?

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ABSTRACT

In perennial plants, the selection of new genotypes requires several years of evaluation to get a good estimate of the genetic value of the trees. The cocoa tree, which is cultivated for its seeds, produces continuously throughout the entire duration of exploitation of the plots, which can last up to 30 years. The genetic value of the trees' productivity over the entire harvesting period is therefore difficult to assess. In particular, how many years are needed to estimate the genetic value of the trees' productive capacity? To answer this question, the analysis of a trial comparing 42 clones in a statistical design with 4 blocks, located in Costa Rica, is proposed. The individual production of the 1187 trees in this trial was evaluated over 18 consecutive years. The first year of production is not a good predictor of cumulative production over 18 years with a genetic correlation of 0.68. It is necessary to have an accumulation of 4 years for the genetic correlation with the 18-year accumulation to be higher than 0.85, and an accumulation of 7 years for the genetic correlation with the 18-year accumulation to be higher than 0.90. Longitudinal data analysis allows for a better understanding of the links between production of the successive years. In this trial, the seventh year is a year of high production followed by a slight decrease in the eighth year. To determine an evaluation period that allows a good estimate of genetic value should therefore be based on the study of production kinetics. Indeed, it seems necessary to continue the evaluation of tree production until a high annual production that reveals the productive capacity of the genotypes. Studies on production kinetics also make it possible to envisage genetic improvement for better sustainability of cocoa trees to be proposed in appropriate cropping systems.

Keywords: production kinetics, selection strategy, sustainability

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DEXiCacao: a new tool to assess the overall sustainability of cocoa-based cropping systems

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ABSTRACT

In the West African cocoa belt, sustainability is a key issue for cocoa cropping systems, which production paradigm needs to be changed as the latter heavily contributed to deforestation and soil degradation. Agroforestry systems are recognized as appropriate cocoa management strategies since they can provide multiple ecosystem services, enhance agronomic productivity and improve the living standard of growers. To promote context-specific agroforestry systems and to increase the potential of adoption of agroforestry practices, it is necessary to assess and compare their overall sustainability. However, the assessment of the sustainability of cocoa-based agroforestry systems is a complex challenge because of the coexistence of conflicting objectives and the multidimensionality of their performances. In such an assessment, the environmental, economic and social aspects need to be simultaneously considered to evaluate potential synergies and trade-offs both in actual (ex-post analysis) and potential systems (ex-ante analysis). In the Cocoa4Future DeSIRA project, an innovative multicriteria model named DEXiCacao based on the DEXi framework is currently developed to assess the overall sustainability of cocoa agroforestry systems in a qualitative and comprehensive way. The DEXi framework consists of building an attribute tree organized to characterize a complex problem. The herein study presents the methodological development of the DEXiCacao model dedicated to cocoa agroforestry systems in Cote d'Ivoire. Its development is based on expert knowledge, literature review and agricultural surveys to (i) identify a set of assessment criteria, (ii) their aggregation modalities and (iii) to define thresholds of classes for each criteria. Different multi-disciplinary groups of scientists were mobilized in botany, agronomy, entomology, forestry, pedology and rural socio-economy. Using this framework, we were able to develop basics indicators and aggregated indicators designed to compare and assess the context-specific suitability

of a given cocoa agroforestry system among the three dimensions of sustainability. In the Cocoa4Future European project, DEXiCacao will be used to assess the sustainability of 150 cocoa cropping systems. This will help selecting the most promising cocoa-based agroforestry in each given context. DEXiCacao will also be used as a dashboard to determine strengths and weaknesses of the evaluated systems and therefore to identify potential improvements.

Keywords: Sustainability, Multicriteria assessment, Cocoa agroforestry

How to achieve a living income for different types of cocoa and coffee farming families?

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ABSTRACT

Many companies, governments, NGOs and industry platforms have stated the ambition that smallholder tree-crop commodity producers and their families should earn a living income. The aim of the paper is to give the reader tangible insights on what factors drive earning a living income and will conclude on how different types of cocoa and coffee producing households can best be supported and who could play which role. To do so, this paper dives into household survey data from 3-5 countries, collected in 2021, to show how many families earn a living income and what the living income gap is for different types of families. It then proceeds to assess the potential for different types of families to achieve a living income from on- and off-farm income sources in four ways: 1. Machine learning to conclude on which variables are key predictors of why families are (not) earning a living income 2. Econometric clustering analyses to categorize farmers in various groups 3. Categorize farmers in different groups based on pre-defined thresholds, derived from the literature and expert consultation 4. Comparing the results of the three analyses and combine with information from the literature to come to conclusions. A generic picture that emerges is that 75% of farmers are not earning a living income, with a living income gap of at least 2000 USD per year. About 40% of these families do not have the potential to earn a living income with what they currently do (mainly commodity production with some diversification). This is because they sell very low volumes because of low farm size or low yields because of extremely limited ability to invest. Because of this they need a different type of support, such as support in off-farm income generating activities including wage labour. Especially for this group different types of stakeholders should collaborate to ensure that they can achieve a living income from a food system approach. This also counts for less than half of the farmers has some potential to earn a living income from either commodity

production, on-farm diversification or both, depending on their characteristics (e.g. farm size). A maximum of 20% of the households has the potential to achieve a living income with commodity production. Their income gap is relatively small and they have the ability to invest and the farm size that allows for volume improvement or for diversification.

Keywords: Living income, Cocoa, Food system

Innovative data collection in collaborative cocoa fertilizer trials

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ABSTRACT

There is a large knowledge gap regarding soil fertility and mineral nutrition needs of the cocoa tree, as well as on how to manage impacts of climate change on cocoa production, the role of agroforestry in avoiding deforestation, and ensuring a living income for cocoa farmers. CocoaSoils is a public-private partnership between cocoa and fertiliser companies, CGIAR centres and other public research institutes which aims to contribute to tackling these important issues. To accomplish this, CocoaSoils has implemented an innovative approach to collect data that enables partners to store, structure, analyse data and generate recommendations based on findable datasets. We set up two types of trials: Core Trials which are long-term nutrient response experiments, and Satellite Trials which are farmer-managed sites in existing plantations. The trials are managed according to a set of protocols that were developed in close collaboration with the consortium partners, leveraging their expertise and know-how. To monitor trials and collect all the relevant data in a practical, fool-proof, consistent and scalable way, the project implemented a system of barcode identification at the tree, plot, and trial levels, coupled with open-source software Open Data Kit (ODK) ecosystem. Protocols were translated into XLSForm (an Excel-based form specification) forms, allowing technicians to collect data in the field using the ODK collect on their mobile devices. Collected information is immediately coupled to a digital data infrastructure workflow for storing and further analyses. For better data harmonisation, we designed a cocoa ontology. And, to enable partners to visualise and download data systematically, a user-friendly data-sharing portal was created. The development of the above-mentioned strategies is an innovative and unique approach in the cocoa sector. We changed the traditional way to collect data, where information can get easily lost and traceability is very challenging. With the trial results, we will generate a set of integrated soil fertility management recommendations and a decision support system for intensifying cocoa production through judicious use of agricultural inputs. We also aim to transfer the

lessons learned to the cocoa research community to improve data collection and processing and standardize data repositories.

Keywords: ODK, XLSForm, cocoa ontology

Multi-locational nutrient response trials for the development of cocoa fertilizer recommendations

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ABSTRACT

Limiting the expansion of agricultural land and avoiding deforestation will increasingly require (re)planting of new cocoa farms under sub-optimal soil fertility conditions. Ensuring proper establishment and achieving profitable and sustainable bean yields under such conditions requires appropriate use of inputs. Currently, the use of mineral fertilizers is uncommon in many established cocoa farms and nutrient recommendations vary considerably from country to country. At the same time, there is a lack of knowledge on the optimal composition and rates of nutrients that need to be supplied throughout the different stages of cocoa development to maximise production and profitability at minimal environmental cost. In view of this, the collaborative research project CocoaSoils has established a network of eleven large reference trials across six countries, at locations representative of the world's main cocoa growing areas, with the aim of determining multivariate responses to varying levels of nitrogen (N), phosphorus (P), and potassium (K). A system for unified experimental design, implementation and data collection was created to maximise opportunities for cross-trial comparisons. A robust experimental design was developed that allows for the estimation of joint N, P, K response surfaces under the assumption that single nutrient responses are constrained by co-limitation of the remaining nutrients. By assuming a specific nutrient response function, it is possible to estimate key parameters that can be used to calculate important measures such as maximum and minimum agronomic efficiency, available soil nutrients, economically optimal rates and water limited yields. We use computer simulations to show the potential for and limitations of such estimations and present a first analysis of data on vegetative growth from one of the core trials as practical proof of principle of our design and analytical methods. We show that useful inference of multi-dimensional

nutrient responses is possible, with estimations obtained for all parameters, albeit with considerable uncertainty. Analysis of the first empirical data showed that the experimental design was successful in accounting for within-field heterogeneity but without effects of nutrient application being apparent at this early stage. To our knowledge, the size and scope of this set of multi-nutrient response trials is unique in cocoa and offers unprecedented potential for research and development of improved fertilizer recommendations. We trust that the developed procedures and forthcoming data and insights will benefit the cocoa growing industry at large and will aid farmers in determining the most profitable levels and composition of fertilizer.

Keywords: Plant nutrition, Agronomy, Experimental design

Transcriptomic response of cocoa (*Theobroma cacao* L.) genotypes to water-deficit stress: Implications for drought tolerance

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ABSTRACT

Water-deficit stress severely affects the productivity of cocoa worldwide. Cocoa undergoes a rainless period of ~ 6 months in southern Indian states of Kerala and Karnataka. Area expansion in non-traditional regions warrants development of water-deficit-tolerant genotypes. In this study, we present the molecular response of cocoa genotypes (VTLC22 and VTLC15) subjected to water-deficit stress based on the transcriptome sequence features. Biochemical and physiological investigations such as stomatal resistance, leaf water potential, lipid peroxidation and total phenolics reveal that VTLC-15 is relatively resistant to drought. RNA-sequencing (RNA-seq) has demonstrated its potential to investigate the molecular biology of complex responses of organisms and to identify suitable biomarkers associated with a biological trait. The total RNA extracted from the leaves of both the control and treated (water-deficit stress) cocoa genotypes viz., VTLC22 and VTLC15 were sequenced using next generation sequencing (NGS) Illumina platform. The clean reads, after processing the raw transcriptome sequences, were mapped to the Cacao Genome Database (CGD), which harbours 43,653 transcripts for genome assembly and annotation of one of most cultivated cacao type Matina 1-6 cultivar. Analysis of differentially expressed transcripts revealed that, 486 cocoa water-deficit stress responsive transcripts are specific to VTLC15 whereas 505 water-deficit stress responsive transcripts belonged to VTLC22. Among this 303 transcripts were shared by both the genotypes. The differential gene expression pattern in the cocoa genotypes was further corroborated by the variations in the enrichment of KEGG metabolic pathways suggesting differential molecular responses of the genotypes to water deficit stress. Water-deficit stress activates multiple metabolic pathways involved in chalcone synthase, genes involved in cell number regulator, aspartate amino transferases, MYB-related protein among others suggesting the molecular

interplay of diverse metabolic pathways. Furthermore, conserved pre-miRNA sequences were found to be expressed between the genotypes suggesting the role of non-coding RNAs in response to water-deficit stress in cocoa. Implications of these results, in the context of cultivation of cocoa in India, are also discussed.

Keywords: biomarkers, metabolic pathways, stress-responsive transcripts

Preventive Development and Testing of Clones Resistant to Frosty Pod Rot in Brazil

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ABSTRACT

Aiming to preventively develop varieties resistant to frosty pod rot (*Moniliophthora roreri*), absent in major Brazilian cacao regions, in last 10 years most known sources of resistance were introduced in Brazil from Ecuador, Costa Rica, Peru and Trinidad & Tobago. Around 32 thousand progeny plants were produced by crossing those sources with local and imported clones using factorial mating designs. After screening for witches' broom in the nursery, around 12 thousand plants, progenies of those sources, were established in progeny trials at the Cacao Research Center (CEPEC), in Bahia, Brazil. From those trials, 233 plants were selected (SCP=Selections from CePec) and cloned in 11 clonal trials on farmer fields. The clonal trials were established under randomized complete block designs, with 2 or 3 blocks per farm, and 5 to 15 trees per plot. In all trials, two high yielding control clones were involved (CCN-51 and PS-13.19), as well as clones already recommended to farmers in countries where the disease is already endemic, totaling 8500 cloned experimental trees. Trials were established with farmers' help, under different soils, climate and managements (agroforestry, full-sun, Cabruca, Erythrina). Quarterly, individual trees are evaluated for the number of small (0-7cm), intermediate (7-15), adult (>15 cm) and mature pods, besides the number of infected pods by witches' broom and black pod rot and number of vegetative brooms. Besides that, a sample of at least six pods were collected from each clone and trial to measure other yield components (number of beans per pod, dry seed weight, and pod husk percentage). Best linear unbiased prediction (BLUP) of clonal values were estimated, considering all pedigree information, using data collected in 2020 and 2021 in those trials. Based on that information, clones SCP-17054, 17016, 17110, 17190, 17073, 16049, 17039, 16064, 17031 and 17207 presented the highest yields; being superior to those of the control clones. Clones released to farmers in other countries, where moniliasis is prevalent and tested in those trials, had a poor performance up to now, emphasizing the need of local testing and adaptation. On average, the clones tested had 43.9 g of dry beans/pod, 1.3 g per dry bean and 75.19% of husk. One hundred of those clones are finishing the quarantine period in Brazil, to be sent to Ecuador and Costa Rica, aiming testing them for frosty pod rot resistance under high disease severity, together with other recommended and advanced selections from Cepec's program.

Keywords: Cacao, Preventive Breeding, Moniliasis

Standardization of Living income benchmarking and knowledge gaps in farmer income assessment in cocoa farming. How to proceed?

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ABSTRACT

Stakeholders in the cocoa sector have adopted living income as a key sustainability indicator. Calculating the living income benchmark requires fast, cheap and standardized data collection. We developed such a method (van de Ven et al., 2020) and have provided a calculation model (WUR-LICT - WUR-Living Income Calculation Tool at <https://models.pps.wur.nl/models>) to allow others to use it. We have calculated living income for cocoa farmers in Côte d'Ivoire and Ghana across multiple datasets (van Vliet et al., 2021) finding that (30–58%) earned a gross income below the World Bank extreme poverty line and the majority (73–90%) did not earn a Living Income. Households with less income per person per day generally achieved lower cocoa yields, consisted of more household members, had a smaller land size available, and relied more on cocoa income than households with higher incomes. Our study highlighted two knowledge gaps. Firstly, for cocoa related income, the effect of different management practices on increasing yield could not be properly accounted for due to a lack of information on the costs of labour and other inputs for their implementation. Currently this is investigated through a common set of well-designed multilocational trials in the sector-wide collaborative CocoaSoils program, testing a “step wise” approach consisting of a sequence and/or combination of practices for maximum yield effect. Secondly, the identification and quantification of income from off-farm and alternative on-farm activities of all household members of cocoa farms was missing from most surveys. This is needed to calculate household income and to identify opportunities to close the living income gap. Segmentation of households based on different absolute and relative resource endowments such as total (or cocoa) farm size and labor to land ratio respectively, may provide further insight in potential pathways towards achieving living income. Farmer support could then be invested in a more targeted way. Currently many companies are individually collecting data and proceeding towards farmer segmentation, whereas it is highly unlikely that within the same geographical

region, they will find different farm types. Furthermore, the utility and interpretability of future household surveys would be drastically improved if definitions and variables addressed were standardized. To develop such common methodology, pooling resources such as in the CocoaSoils program, followed by learning from joint outcomes, would benefit the sector as a whole. Van de Ven, et al 2020. <https://doi.org/10.1007/s12571-020-01099-8> van Vliet, et al. 2021. <https://doi.org/10.3389/fsufs.2021.732831>

Keywords: living Income, standardization, knowledge gaps

Drone-based estimation of trees biophysical parameters in complex cocoa-based agroforestry systems

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ABSTRACT

In cocoa-based agroforestry systems, the biophysical parameters of upper canopy trees, such as height, crown area, crown forms and vegetation indices such as the normalized difference vegetation index (NDVI) are important tree attributes used to assess and monitor the ecosystems services provided by tree associated to cocoa tree. However, exhaustive field measurements of tree biophysical parameters with conventional field methods are laborious, time-consuming and require a significant workforce. The use of uncrewed aerial vehicle (UAV) in agriculture have proved useful in estimating crop biophysical parameters. UAV-based images provides low-cost flexible data acquisition with few weather constraints and high spatial resolution. However, to date, there has been limited application of drone surveys in cocoa-based agroforestry systems. The purpose of this study was to evaluate the use of economical high-resolution multispectral UAV images to assess tree biophysical parameters in cocoa-based agroforestry systems. The study was carried out in 12 cocoa-based agroforestry systems presenting various tree density and complexity. The studied fields are located in the centre-west of Côte d'Ivoire. The UAV flights were performed at an altitude of 80 m using a DJI multispectral Phantom 4 Pro quadcopter. The images were processed using the structure from motion technique in Pix4DMapper software and produced multispectral orthomosaic aerial images, digital surface model, and point clouds. By subtracting the digital surface model and the digital elevation models, tree heights were mapped while the crown areas were extracted from the orthomosaic. NDVI were calculated using the red and near-infrared spectral bands of orthomosaic data. To assess the accuracy of the UAV measurement, correlations and root mean square error were used to compare UAV extracted height and crown area with ground measured data. A very strong

correlation was found between individual tree height derived from UAV's canopy height model and field-measured tree height ($R^2 = 0.8$). The difference between the field measurements and the UAV measurements were dependent on the tree height and crown class. This study thus highlighted that an inexpensive UAV system can measure the biophysical and structural characteristics parameters of most trees in cocoa-based agroforestry systems with accuracy comparable to those of the expensive field inventories.

Keywords: canopy structure, UAV, Digital Surface Model

Several enemies at the same time: interaction between two cocoa pod diseases and a cocoa pod borer and their impact in Peruvian agroforestry systems

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ABSTRACT

Farmers frequently need to deal with several pests simultaneously, at farm, plot and even plant level. Diseases can affect the same plant, yet their incidence and severity can vary, resulting in plants with different injury profiles within the same plot. Despite this co-occurrence, pests are often studied and treated separately as they can be caused by distant taxa including fungi, nematodes and insects. The impact of these pests on the plant is modulated by the interactions among them, which can enhance or hamper the incidence and severity of each other. These pest interactions are affected by several factors including, the sequence of arrival of each disease on the plant, the phenology of the plant, influencing resource availability, and abiotic factors such as temperature, humidity and proximity to attacked plants. Comprehensive analyses including all these factors are needed to better understand the temporal dynamics of injury profiles, their effect on resource production and to help design sustainable management strategies. For two years, the incidence of three cocoa pests: American cocoa pod borer - *Carmenta foraseminis*, black pod disease - *Phytophthora palmivora* and frosty pod rot disease - *Moniliophthora roreri*, was monitored each fifteen days in the Peruvian Amazon region of San Martin. A total of 400 cocoa trees, distributed in 10 plots belonging to 5 communities were monitored. 58% of the produced pods show signs of at least one of these three pests. By including the different pests' temporal dynamics, different combinations of

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conditions facilitating or limiting pest incidence were explored. Based on these findings, ideas to design appropriate management strategies are discussed.

Keywords: multipest, injury profile, pest interaction

The CocoaSoils nutrient offtake model: preliminary results from on-farm trials

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ABSTRACT

Current nutrient recommendations in cocoa vary per country and often do not include N. To improve recommendations, partners in the CocoaSoils consortium (www.cocoasoils.org) have set up large-scale fertiliser trials (Core Trials) and small on-farm trials (Satellite Trials) across the tropics. We developed a nutrient offtake model to determine fertiliser rates and tested selected treatments in farmers' fields to answer the following questions: 1) Can farmer yields be improved by additional nutrient applications as recommended by the offtake model? 2) What are the differences between countries in terms of yields and responses to treatments? 3) Are the offtake model recommendations cost effective? With the offtake model we calculated the offtake in vegetative biomass and beans and converted these to nutrient recommendations. In 389 Satellite Trials, we compared farmer practices (control, T1), Good Agricultural Practices without additional nutrient applications (T2), GAP + national fertiliser recommendations (T3) and GAP + offtake model recommendations (T4). We monitored yields and calculated return on investment (ROI: USD earned per USD invested) for T3 and T4, assuming the following prices (in USD kg⁻¹): dry cocoa beans 1.58; nitrogen 1.3; phosphorus 4.1; potassium 1.3. Preliminary yield results from the Satellite Trials suggest that yields in T4 plots were consistently higher (around 2150 kg dry beans ha⁻¹ year⁻¹) than yields in T3 plots (around 1920 kg ha⁻¹ yr⁻¹) in all countries but Nigeria. Yield patterns in Ghana, Cote d'Ivoire and Cameroon were similar; yields from Nigeria were substantially lower. Response patterns were similar in the main and light season. Adding nutrients according to the offtake model predictions was cost effective but ROIs were highly variable (1-5 USD USD⁻¹). Estimated offtake quantities fall well within the range of recommendations listed by Van Vliet and Giller (2017); estimated N requirements

are similar to other crops. There was a clear positive effect of T4 over T3 on yield. From the data we cannot tell which nutrient was responsible for the response: was it mostly the N, or the K, or a combination? The Core Trials will provide the answers to these questions when they enter the productive phase. In terms of costs, ROI may become negative when fertiliser prices increase or cocoa prices decrease, especially in Nigeria.

Keywords: Nutrient offtake, Yield, Return on investment

Evaluating long term soil organic matter dynamics of cocoa farms in indonesia

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ABSTRACT

In Sulawesi (Indonesia), cocoa yields are suboptimal, and inadequate management practices have led to detrimental soil degradation. One critical component of soil fertility is soil organic matter (SOM), but the dynamics of SOM in cocoa farms are poorly understood. This study aimed to improve our understanding of SOM dynamics on cocoa farms and propose a SOM management strategy for cocoa cultivation in Sulawesi. A meta-analysis showed that the mean organic carbon (C) stock of 15–35-year cocoa system (including shade trees and soil to 10 cm depth) was about 85 Mg ha⁻¹. For this age range, the mean C stocks for aboveground cocoa, shade trees, litter, and roots were about 10, 40, 1, and 11 Mg ha⁻¹, respectively. The mean soil C stock (0–10 cm) was about 24 Mg ha⁻¹, but taken deeper, soil C stocks can be substantial and may exceed plant C. Furthermore, large differences observed within the same age classes suggest that modified designs and practices can increase C storage for a particular pedoclimatic context. A chronosequence study across 13 Sulawesian cocoa farms indicated a substantial decline in SOM contents, stocks, and SOM per unit clay during the early years after planting. These findings suggest that, after plot clearing, the high temperatures and precipitation found in Sulawesi can result in rapid SOM mineralization. Hence farm practices, such as improved organic additions, should target this sensitive period. A modeling experiment provided a framework to predict SOM variations on cocoa farms. The AMG soil model combined (Clivot et al., 2019) with a growth curve describing cocoa biomass from the chronosequence dataset. The simulations also indicated that SOM could deplete rapidly after planting, and the long-term trend can either be a decline or a build-up that could even exceed planting levels. Future research could include further calibration of model parameters, improved modeling of pruning and shade trees in residue deposition, and including the response of crop growth to environmental parameters. The above results highlight that Sulawesian cocoa farms are particularly at risk of SOM losses in the initial years after planting. This is a critical period during which organic additions could support cocoa productivity and provide other

environmental benefits. Recommendations for SOM management and future research are proposed to limit soil degradation and improve the C balance of cocoa farms.

Keywords: Cocoa, Carbon, Modeling

Development of immunoassays to detect Cocoa Swollen Shoot Virus

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ABSTRACT

The global chocolate market is expected to grow from USD 138.5 billion in 2020 and reach USD 200.4 billion by 2028, growing at a CAGR of 4.8% period 2021-2028. Cacao Swollen Shoot Virus disease (CSSV) has been identified as the main disease threat to productivity. Previously developed immunoassays using conventional techniques to detect CSSV in infected leaves have not proved to be sensitive enough, due to the high background interaction with plant material. Current laboratory tests available to confirm CSSV infection involve detection of CSSV v DNA using polymerase chain reaction (PCR) technology (Dzahini-Obiatey, 2010 and Oro et al., 2012) this can currently only be performed in a laboratory environment by specialist staff. In addition detection of DNA for diagnosis of infection is complicated by the recent identification of integrated CSSV sequences into the host genome (Muller et al., 2021). In this paper we describe the development of immunoassays to detect CSSV infection in infected and non-symptomatic leaves from infected trees. One form of the immunoassay is as a biosensor in the form of a paper based cassette where the presence or absence of infection is detected through a fluorescent readout. This biosensor would be applicable for use in in-field monitoring. The results of the evaluation of *Theobroma cacao* leaves from plants infected with New Juaben (Envirotron, UWE, UK) and field samples from sites in West Africa will be presented.

Keywords: Cacao Swollen Shoot Virus, Biosensor, Immunoassay

An Overview of The Potential of Regenerative Agriculture in Cocoa Production

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ABSTRACT

Regenerative agriculture (RA) has been suggested as a pathway to address the challenges of accelerated climate change, alarming rates of biodiversity loss, forest and soil degradation, and poor crop productivity. While RA is very broad both in its definition and practice, it is necessary to identify specific practices for cocoa production to devise a sustainable entry point and development pathway in West Africa. RA considers the entire ecosystem from soil and plant health, farm biodiversity, environmental sustainability to farmer livelihoods. Moreover, RA prioritizes soil health characterized by five principles: minimizing soil disturbances, soil coverage, increasing plant diversity, keeping living roots in the soil, and integration of livestock in the farm. The specific practices associated with RA are extended and more diversified crop rotations, less tillage, cover crops, reduced use of synthetic fertilizers, grazing management for livestock. Considering the existing cocoa-based systems in Africa, and the concepts and potential benefits of RA, the underlying questions are: is there a sustainable entry point for RA, and how could RA work in perennial production systems such as cocoa? Additionally, beyond agroforestry, could RA be a system to consider to ensure resilience, high productivity, and sustainability? Is there any contribution of RA to the profitability of perennial crops such as cocoa? This article uses a systematic review to assess the possibility of employing RA in cocoa production systems in West Africa, with a case study from Ghana. Results show that cocoa farmers regularly practice agroforestry, crop diversification, apply organic amendments, and some focus on climate-smart practices. A survey conducted in 2019 revealed that only about 32% of the sampled farmers in Ghana are using organic amendments. Thus, farmers are practising RA in various forms but in many cases, not to the expected level of intensity. Among the most limiting is capital, technical and scientific guidance. In many cases, crop productivity, environmental conservation, and improved farmer livelihoods are interrelated and this relationship needs to be considered holistically. We propose the following practices as a possible strategy to integrate RA in cocoa-based systems:

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intensified soil organic management (including biochar, composting, and mulching) to stimulate agroecological processes, integrated pest management, agroforestry, and climate-smart cocoa production. Also, the training of farmers and other practitioners will fuel the interest of smallholder farmers and facilitate knowledge transfer as well as an exchange of best practices and practical experiences.

Keywords: Regenerative Agriculture, Sustainable cocoa production, Climate change adaptation

Digital tools and Ontology: A Collaborative Pathway For Managing & Sharing Cocoa Data

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ABSTRACT

Despite the fact that cocoa is a significant global commodity, and its production includes millions of smallholder farmers, there is a scarcity of high-quality data on cocoa-agronomy-livelihood interaction. Historically, many experimental datasets ended up in separate repositories in various formats, often with missing headings and contextual information, due to a lack of appropriate infrastructure, comprehensive standardization, harmonisation, and support. Hence creating barriers in sharing and re-using such data and making impossible comprehensive analysis of cocoa agronomy and better decision making. To overcome this research barrier, we present an integrated digital data collection workflow based on the findable, accessible, interoperable, and reusable (FAIR) principle, which includes field data acquisition, data curation, semantic interoperability, data publication, metadata management, data discovery and search, and visualizations tailored to specific user groups. This workflow is designed in Agile software development fashion and implemented using an open-source software ecosystem. The Open Data Kit (ODK) collect mobile app allows field workers to collect data more efficiently. We have developed cocoa ontologies that enable us to standardize, harmonize cocoa agronomic data for future sharing and collaboration. The workflow has been implemented in 6 countries Cote d'Ivoire, Ghana, Nigeria, Cameroon, Indonesia and Ecuador and supports multiple partners (including government extension systems, the private sector, NGOs, farmer organizations and community-based extension workers) in managing and sharing data. The developed workflow and technologies could be applied to other perennial crops, such as coffee. In the future, an important step will be to educate the community about digital data collection in general, and the Cocoa Ontology in particular, so that it can be promoted more broadly, making uniform data sharing easier. Finally, ongoing updates to incorporate expanding vocabulary and classes are critical to ensuring a long-term ontology that is sustainable.

Keywords: mobile devices, Ontology, smallholder farmers

A novel method for estimating pest and diseases related yield loss in cacao pods in the Peruvian Amazonia.

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ABSTRACT

Cacao pest and diseases (P&Ds) infect and affect their hosts in specific ways, which adds complexity to study their global impact on production. Commonly, incidence is used as an indicator to evaluate P&Ds, however, it does not provide any information on yield loss, whether we look at it as an economic loss, or just as a loss in quantity or quality. Therefore, incidence is not enough, from an agronomic point of view, to evaluate the impact and the damage that P&Ds have over production. By focusing on three specific P&Ds within the P&D complex that affect the cocoa pod in the Peruvian Amazonia (Black Pod disease, Frosty Pod Rot and the “Mazorquero”, local name for the American cocoa pod borer), we aim to produce a simple model that will allow us to estimate more accurately the P&Ds incidence related yield loss and help us simulate different scenarios to calculate economic loss. To evaluate the amount of damage caused by these P&Ds, 120 cocoa pods of the CCN-51 Cocoa variety were opened (each one infected with either one or a combination of the P&Ds outlined above), then the seeds were counted and classified in healthy (unaffected), usable (affected by disease but still usable) and damaged (unusable due to disease) to establish a pod damage index (PDI) for each disease or disease combination. Furthermore, we established injury profiles (IPs) at tree level (which correspond to the PDIs and their possible combinations) which allow us to have an estimation of the yield loss per tree. Through an existing database on incidence for these P&Ds, we established four PDIs and 15 tree's IPs. A model was designed relating incidence and the tree's IPs to estimate the yield losses. Our results show that the Black Pod

and the Mazorquero, as well as their combination, tend to cause the least amount of damaged seeds, while the Frosty Pod Rot tends to cause the most damage. Black Pod and Mazorquero tend to have similar impact, showing mixed results between healthy and usable seeds, while their combination has a bigger impact with more usable than healthy seeds. The model will allow us to identify the situations that reduce significantly the impact of P&D , and could have useful applications in P&Ds research in regulation and cocoa plantation management. Indeed, the resultant model allowed the simulation of different scenarios predicting the economic loss through the use of incidence data.

Keywords: Pest and Diseases, Incidence, Yield Loss

The role of litter decomposition in nutrient cycling in cocoa

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ABSTRACT

Litterfall and litter decomposition are key aspects of nutrient cycling in tree crop systems. They largely determine nutrient flows from vegetation to soil, especially in low-input systems, which are mostly managed by smallholders. Insights in litter volumes and decomposition rates may help to understand nutrient constraints on crop productivity in low-input systems and to adjust fertilizer recommendations. Several knowledge gaps impair our understanding of soil nutrient replenishment through litter decomposition in cocoa (*Theobroma cacao* L.). The aim of this study was to uncover spatiotemporal variability of litterfall, and to assess the role of macrofauna in litter decomposition and nutrient release. Litterfall was measured fortnightly at two distances from the tree. In total, thirty trees were monitored, located on three different fields in low-shade cocoa agroforestry systems of Southwestern Nigeria. From January 2020 to January 2021, litter decomposition rates were determined with litter placed in 2 mm mesh bags without macrofauna access, and in open frames on the ground which were covered with a 2 mm mesh on the top with macrofauna access. Variation in litterfall was analysed using a linear mixed-effects model with distance, year, and month, as fixed factors and sites, plots-within-sites, and trees-within-plots as random factors. Changes in cocoa leaf litter mass were analysed for frames and bags separately with a first-order exponential decay model. Analysis of variance and t-test were run to detect significant differences. Annual litterfall ranged from 6.7 to 14.8 t ha⁻¹ y⁻¹ across sites and years. Total variation of monthly litterfall revealed minor inter-annual or within-site variation (intra-correlation class coefficients, ICC < 4%). Months and sites were responsible for 35.4% and 7.5% of total observed variation, respectively. Litter decomposition rates were significantly larger ($P < 0.01$) in frames than in bags, with relative decomposition rates of 2.0×10^{-3} day⁻¹ and 1.7×10^{-3} day⁻¹.

respectively. Subsequently, macrofauna access increases release from cocoa leaf litter with 27.4% ($P < 0.001$) and 68.2% (P90%) in one year, but not affected by macrofauna access (K loss was not significantly higher in frames (about 6%, $P > 0.05$). This study identified seasonality as the main component of spatiotemporal variability of litterfall. The importance of macrofauna in cocoa leaf litter decomposition and nutrient release was highlighted.

Keywords: nutrient cycling, decomposition; macrofauna, litterfall

A stepwise approach to achieve the best agronomic management practices and sustainable fertilizer use in West African cocoa production

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ABSTRACT

Smallholder farmers are constrained by limited resources resulting in sub-optimal management and inability to purchase fertilizer. On the other hand, the best returns to fertilizer applications are achieved when yield limiting factors such as pests and diseases are eliminated. The main question is, what is the most sustainable approach to achieve best agronomic management practices (BAMPs) and enable resource constrained farmers to apply needed nutrients in cocoa? We used an additive approach of four plots (T1-T4) representing increased intensities of management on about 389 cocoa plantations over two years (2020 and 2021) in Cameroon, Cote d'Ivoire, Ghana, and Nigeria. The T1 (control) was managed as usual by the participating farmer, T2 entailed applying all the best agronomic management practices except fertilizer application, T3 included all BAMPs as in T2, plus application of the nationally recommended fertilizer in each country. In T4, BAMPs were applied plus fertilizer based on the estimation by an off-take model, which calculates the nutrient requirements of the cocoa trees to grow roots, stems branches, leaves and pods, using nutrient uptake data and allometric relations from empirical measurements. Plot selection was constrained within acceptable limits of cocoa tree density of 950 to 1900 trees/ha and tree age of 8-22 years. Shade was considered as a continuous variable as most farms had little, but variable density of shade trees. Results showed that cocoa productivity was significantly different in the four plots (T1-T4) across all the four countries. Applying best agronomic practices including structural pruning (T2) gave no significant increase in yields (702 kg/ha) above that of the T1 control (670 kg/ha). Application of fertilizer (T3 and T4) resulted in the largest yield increase above current farmer practice, and T4 (offtake model) performed significantly better (902 kg/ha) than (T3), the national recommendation (816 kg/ha). A stepwise approach to integrate BAMPs and eventually fertilizer into

the cocoa farming systems as a strategy to support resource-constrained farmers is proposed. Although we cannot determine the effects of fertilizer on cocoa yields when GAP is not applied, a stepwise approach may help to overcome the high demand on labour and capital. The lack of significant difference in yield between T1 and T2 combined with the large bean yield response when fertilizer is applied (T3 and T4) strongly supports the need for judicious use of fertilizer (right quantity □ correct formulation) in cocoa production systems of West Africa.

Keywords: sustainable intensification, nutrient management, stepwise investments

Mapping candidate genes for resistance to Vascular-streak dieback disease of cocoa

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ABSTRACT

Vascular-Streak Dieback (VSD) disease of cacao, caused by the fungus *Ceratobasidium theobromae*, has devastating impacts on cacao production in southeast Asia and Oceania. This study aimed to identify genomic regions associated with resistance to VSD using a population derived from a cross between the cocoa genotypes S1 (VSD resistant) and CCN51 (VSD susceptible). QTL analysis was performed using a genetic linkage map constructed with 8,698 DArT markers and 1,470 SNP markers. Two QTL were detected, one on linkage group 8 and the other on linkage group 9. The QTL on linkage group 8 explained 15-16% of the phenotypic variation while the QTL on linkage group 9 explained 16-18% of the phenotypic variation. Five polymorphic microsatellite (SSR) markers were identified within the QTL regions. SSR markers showed clear polymorphism among the VSD resistant and susceptible lines in the two populations, S1 x CCN51 and CCN51 x M07. These results suggest that these markers could be closely associated with VSD resistance and therefore used in marker-assisted selection for cacao breeding programs in response to VSD disease. Further, genomes of the S1 and CCN51 genotypes were sequenced using paired end short reads. Both S1 and CCN51 whole genome sequencing generated 383 and 367 million clean reads, respectively, and 93% of the reads from both genomes mapped to the reference genome Matina 1-6. Alignment to the reference genome enabled the detection of 1.87 million polymorphic SNVs/Indels and 8,363 polymorphic structural variants (SVs) among the two genomes. The resequencing of the genomes of cacao genotypes S1 and CCN51 provides a valuable resource to narrow the search for candidate genes that underlie VSD resistance.

Keywords: QTL, resistance, markers

Breeding of cocoa (*Theobroma cacao* L.) genotypes tolerant/resistant to cocoa swollen shoot virus (CSSVs) in cocoa orchards infected by the disease in Côte d'Ivoire

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ABSTRACT

The cocoa swollen shoot disease (CSSD) has caused, since its recrudescence in 2003, high production losses in cocoa farms, thus affecting the sustainability of Ivorian cocoa production. In order to select tolerant or resistant cocoa trees to this disease, 320 farmer accessions of cocoa trees with good agronomic performance were collected from plots infected by the disease in Côte d'Ivoire. These genotypes were vegetatively propagated on Amelonado grafting, a cocoa variety known to be susceptible to the disease. Agronomic data collected during one year on the plants propagated in the greenhouse were mainly related to the presence or absence of CSSV symptoms on the graft and rootstock and the type of symptoms. The observed accessions were also subjected to molecular diagnosis by PCR and qPCR to search and quantify CSSV within them. Three phenotypic groups were identified in the greenhouse. The first group called "Potentially Tolerant Accessions" to CSSD (APT) is composed of 255 asymptomatic cocoa trees both in the field and in the greenhouse. The second group called "Potentially Sensitive Accessions" (APS) is composed of 49 symptomatic cocoa trees in the field and in the greenhouse and the third group (APT/APS) is composed of 16 asymptomatic cocoa trees in the field but symptomatic in the greenhouse. The results of molecular diagnosis showed that 53.33% of APTs, 71.42% of APSs and 50% of APT/APS were positive for molecular diagnosis by PCR. By qPCR, 42.29% of the trees in the APT group had near zero viral load. In addition, 34.82% of trees in the APT group were negative for CSSV by both techniques. These results show a tolerance/resistance of trees in the

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APT group to swollen shoot. Confirmation of the tolerance of APT group cocoa trees is envisaged in multilocation trials. The use of genotypes having confirmed their resistance or tolerance to the disease in the current recurrent and reciprocal selection scheme in Côte d'Ivoire is proposed and discussed.

Keywords: cocoa, tolerant, Swollen shoot

The Impact on Farmers of the Cocoa Living Income Differential

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ABSTRACT

The March 2018 Abidjan Declaration committed Côte d'Ivoire and Ghana to collaborate on cocoa market matters with the specific objective of raising farmgate prices. They subsequently announced that they would seek a \$400/ton differential over benchmark prices (16½% over the then prevailing market price). This differential has become known as the Living Income Differential (LID). This paper sets out to analyze the effectiveness of the LID and, to the extent that the LID objectives were not attained, why this was the case. The paper reports a detailed analysis of the US and EU import data: • European data show that, Ivorian and Ghanaian beans obtained differentials over the ICE benchmark that averaged \$50-\$100 per ton more in 2019-20 than in the five previous campaigns, and that these increases rose to \$350-\$400 per ton in 2020/21. • Nigerian beans obtained similar increases over benchmark prices in these two campaigns. The spillover also generalized to a lesser extent, to Cameroon. • These differences are not apparent in the US import data. Ivorian differentials in the US are completely in line with those in the previous five campaigns while Ghanaian differentials actually fell. The ICCO indicator price averaged over 2020/21 was virtually unchanged over the pre-LID 2018/19 average. Over the same two year period, official farmgate prices rose by 26% in Côte d'Ivoire and 39% in Ghana. These increases convert to 20% and 16% respectively when deflated by local CPI indices. The LID therefore does appear to have delivered real increases to farmers in 2020/21. Import data for 2021/22 are not yet available. Premiums paid in London over the ICE futures market for West African cocoa showed sharp rises at the start of the 2019/20 and 2020/21 campaigns but have collapsed to 2019 levels at the start of the 2021/22 campaign. These premium data corroborate the observed pattern in the differentials from the EU import data but indicate that the impact of the LID was probably confined to these two years. The analysis raises two important questions. The same companies export West African cocoa to the European and North American markets. Why, then, was the LID transmitted to consumers in the former but not the latter? Secondly, why has the LID apparently become ineffective in 2021/22? The paper will examine differences in market structure between Europe and the US to suggest tentative answers to these questions.

Keywords: LID, Differentials, Farmgate prices

How does labour availability influence pesticide use on cocoa farms?

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ABSTRACT

Pests and diseases represent a major challenge in cocoa production, which farmers commonly control using synthetic pesticides. Stricter residue regulations in cocoa importing countries and an increasing demand for sustainably produced cocoa generate pressure on chocolate manufacturers to source cocoa from production systems with little to no use of synthetic pesticides. Instead, alternative pest and disease management practices are promoted. The promoted practices, like manual weeding and phytosanitary measures, however, are often labour intensive. High prices for hired labour and an ageing cocoa farmer population due to youth migration to the cities limits labour availability on cocoa farms. So far, little knowledge exists about the relationship between labour availability and sustainable cocoa production. In this study, we thus aim to find answers to the question: How does an increase of labour availability contribute to reducing synthetic pesticide use among cocoa farmers? We hypothesise that the amount of available farm labour is positively associated with a reduction of pesticide use and an increase in alternative pest and disease management practices. We test our hypothesis using a natural experiment within a sample of Ugandan cocoa farmers. As a response to the COVID-19 pandemic, the Ugandan government imposed two national lockdowns, due to which urban workers and students returned to their rural homes, generating changes in available farm labour. We interviewed a sample of Ugandan cocoa farmers just before the outbreak of the COVID-19 pandemic and repeated farmer interviews in 2022. Comparing the 2019 and 2021 data, we will test the relationship between labour availability and pesticide use as well as alternative pest and disease management practices on farms as outcome variables. This is done using a difference-in-difference approach with entropy weights to estimate the causal effect of available labour on the outcome variables, controlling for multiple factors that could affect them like training participation and perceived pest and disease pressure. First insights into the data support our assumption that higher family labour

availability increased time investments in both food and cash crop management including cocoa, however detailed data analysis is pending to confirm a consequent reduction in synthetic pesticides. Our results will contribute to the knowledge about the relevance of labour for sustainable cocoa production and thus inform the development of future private and public sustainability initiatives.

Keywords: Labour availability, Pesticide use, Uganda

Impact of pruning intensities on cocoa tree productivity, pest (mirids) and disease (black pod disease) infestations on farmer field trials in Côte d'Ivoire

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ABSTRACT

The current study was carried out to evaluate short term effects of pruning intensities on fruit set, pod health and yield responses in mature trees of 10 to 15 years old. Two different pruning intensities (Removal of 20% removal of secondary branches and removal of 40% of secondary branches) were compared to unpruned trees (Control). We investigated also whether effects of pruning intensities vary across agroecological zones (transitional and humid forest zones). Five cooperatives distributed in two agroecological zones were selected (two in transitional zone and three in evergreen forest zone). Five trial sites were installed per cooperative each with the 3 pruning treatments (unpruned Control, 20% pruning and 40% pruning). Pruning treatments were applied the first time in April 2020 then renewed in April 2021. Various observations on yield parameters i.e., pod size, number of pods (healthy, mirid infected, black pod infected), number of beans per pod, fresh bean weight and dry bean weight were recorded for each plot at every harvest event (starting in December 2020) for both light and main crops. Experiment results revealed that during the first year of trial (20/21 crop season) both pruning intensities increased dry bean yield. However, the lighter pruning intensity (20% pruning) was more suitable in transitional zone as it showed higher yield (648.5 Kg/Ha) compared to heavy pruning (40% pruning and 591,2 Kg/Ha) and unpruned control (522Kg/Ha). In evergreen forest zone, heavy pruning showed higher yield (890,5 Kg/Ha) compared to light pruning (832,5 Kg/Ha) and unpruned control (742,4 Kg/Ha). During 21/22 main crop both pruning intensities delivered comparable yield results in the two agroecological zones (600 Kg/Ha) but were still higher than unpruned control (500Kg/Ha). Pruning decreased mirid (52% and -60% respectively for 20% and 40% pruning intensity) and black pod -Phytophthora (-43% and -45% respectively for 20% and 40% pruning intensity) infestations over crop seasons. Our results confirmed that pruning is a key lever for reducing mirid and black pod

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disease infestation and improving productivity which contributes to increasing farmer income. Our findings showed also that light pruning is suitable in transitional zones when starting the implementation. Finally, by improving pod health pruning could contribute to improvement of beans quality by reducing the level of free fatty acids that are favored by fermentation of poor-quality beans. The link between pruning and improvement of bean quality and potential for reducing FFA level is currently being investigated on our trial sites.

Keywords: cocoa tree pruning, mirids and black pod disease, yield

Effectiveness of Biostimulants as a sustainable solution for improving production of cocoa trees in Ecuador: enhancing flowering and fruit setting to improve final number of pods, weight and yield by tree.

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ABSTRACT

Ecuador is one of the largest cocoa producers in the world with 138 -238 miles tons of production per year. The 600,000 hectares dedicated to cocoa cultivation are managed by smallholders who do not have access to advanced technologies to optimize their yields and require new solutions such as biostimulants. Biostimulants could be compared to food supplements that stimulate and optimize plants metabolism and thus improve their growth and productive capacity. They are environmentally friendly solutions in line with sustainable development of agriculture. The objective of this experiment is to test the effectiveness of our biostimulants on cocoa production. For this, we carried out an experiment with Ángel Llerena Hidalgo, cocoa specialist from the Universidad Católica de Santiago de Guayaquil located in Cerecita, Guayas, Equator. Randomized blocks design was used to test separately a radicular biostimulant (5l/ha) applied 14 times during crop cycle, a foliar biostimulant (3L/ha) applied 3 times during growth peak stage, a biostimulant for optimizing flowering (3L/ha) applied just before flowering, during flowering and in the beginning of fruit setting. We included a last thesis that is a complete biostimulant management program including the 3 types of biostimulants. The biostimulants were chosen based on their mode of action which was investigated by transcriptomic and metabolomic studies previously performed in model crop. The results obtained showed that the plots treated with biostimulants produced significantly more flowers than control. The flower biostimulant gave the best results with 3 times more flowers than the non-treated trees. All treatments have a positive impact in the parameter's measures meaning number of pods, weight of pods, yield per tree, production in hectare and production in quintal. Once again, the best result is obtained after applying the flowering biostimulant with 47% increase of cocoa production per hectare. This study demonstrated that biostimulants application can be an efficient sustainable solution for improving productions of cocoa trees. Therefore, the simple practice of application of eco-friendly biostimulant would benefit small and marginal farmers of cocoa.

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Keywords: Biostimulant, Sustainability, Yield

Sustainable competitiveness of the cocoa sector in Ecuador: issues of integrated socio-ecological governance

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ABSTRACT

The macro-economic context of cocoa is characterised by a worldwide growth of chocolate consumption, a sectoral industrial concentration, and a renewal of socio-ecological challenges for the production development. To remain competitive, cocoa-producing countries must follow new environmental and social standards. These standards lead to a reduction of the ecological footprint of cocoa due to deforestation, to a reduction in the use of pesticides, and to higher compliance with international labour standards. They also lead, in the expansion of the International Sustainable Development Goals, to modifying the distribution of value in the sectors for farmers, or to protecting the territories of indigenous people. These norms structure the notion of “inclusive competitiveness” and its translation into public policies or action strategies for actors in the cocoa sector. This paper uses a methodological approach developed within the framework of the European Union (Avadí et al. 2021 - VCA4D) that analyses agricultural value chains by combining economic, environmental and social indicators. In Ecuador, this approach is documented by two surveys of 40 actors from the value chain (producers, cooperatives, exporters, industrialists), and 20 institutional actors (ministerial support services, donors, project and program managers, research, certification institutions, etc.). The interviews were carried out in two phases in 2020 and 2021, respectively. This approach also mobilises an in-depth analysis of international secondary databases on the functioning of markets (IICCO, FAO, COLEACP, IFOAM), and national databases on the Ecuadorian cocoa sector and production costs (ESPAC, SENA). The results explain why, with an unfavourable production cost differential, Ecuador has improved its competitiveness indicators since 1997. They reveal a break in the trajectory in 2015, which implies a renewed policy of qualitative differentiation of Ecuadorian cocoa to move away from a commodity specialisation. These results highlight the risks of sectoral integration governed by a globalised industry. Moreover, they show the potential for competitiveness that can

be mobilised by small producer organisations. Finally, they reveal how the increase in social-ecological impacts are more related to public institutions of governance of socio-organisational norms than to product certification. These results converge to document a globalised governance of investment regulation in the cocoa sector of developing countries. They clarify and debate the conditions for the development of cocoa production in the service of local populations by reducing the extensive exploitation of ecological resources.

Keywords: Value Chain, Ecuador, Inclusive competitiveness

Cocoa Pod Survivorship Curves to Improve Yield Forecasting Methods

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ABSTRACT

Forecasting cacao yields is key for both researchers and farmers since 1) it allows a reliable estimation of potential revenues, 2) helps farmers' organization to project operational funds to buy the quota of cacao beans to be traded and 3) aids manager to better schedule labor demand and operational costs in commercial farms. We measured, for over 18 months, and monitor the incidence of pests and diseases of +1000 pods from eight clones growing under timber-shaded cacao plantation in Turrialba, Costa Rica. The experimental plot was 12 years old and cacao density was 1300 plants/ha (2.5 x 3 m). Shade cover and tree density was 60% and 120 trees/ha, respectively. Agronomic management included pruning and fertilizer application twice a year. Assessed clones were PMCT-58, CC-137, CATIE-R1, CATIE-R4 and ICS-95 and CCN-51 were used as control. Similar experiments were established in Nicaragua, El Salvador, Guatemala, and Peru. Approximately 5-7 trees and 100-120 pods per clone of four categories (very small-0-7 cm, small-8-14 cm), medium-14-21 cm and large-21-28 cm) were tagged and measured (pod length and diameter (mm) every two weeks. Pods were selected and measured at two strata (below and above 1.5 m) and the length of the productive tissues (stem and main branches up to 2 m) of each tree was quantified. Competing risk and survival analysis, a data time-event type analysis frequently used in the study of diseases and processes of recovery, was used to build survivorship curves per cacao clones and pod size categories. Pods growth pattern followed the sigmoidal curve trend and growth rates varied according to clones and pod size category. Productive tissue length varied per clone and ranged from 4.5 to 11.7 m. The Kaplan-Meier approach confirmed that fruit position along the trunk is significant on the pod survival behavior. Across clones, pods reached maturity at 135-155 days, but several risks were faced by each pod size category: up to 35% of very small pods were affected by Cherelle wilt, 18% of small pods were

affected by frosty pod, between 8-10% of medium pods is affected by black pod and between 4-7% of large pods were damaged by squirrels. Based on findings, a discount factor according to pod size category is proposed to reliably forecast cacao yields.

Keywords: Shaded cacao, Yields, Forecast

Composted plant residue amendments in integration with *Trichoderma asperellum* suppresses above-ground diseases and improves the growth of cacao (*Theobroma cacao* L.)

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ABSTRACT

Cacao (*Theobroma cacao* L.) suffers severe losses due to infectious and non-infectious diseases. This work reports the potential of three formulations of composted plant residues in combination with *Trichoderma asperellum* to reduce these cacao diseases. All formula consisted of gliricidia and rice straw. In addition, the first compost contained empty stalks of oil palm fruit, the second contained billygoat weed, and the third compost had coconut husks. These three composts formula plus *T. asperellum* were applied through soil amendment. Then, their impact was evaluated on significant above-ground diseases, specifically vascular streak dieback (VSD) and *Phytophthora* pod rot (PPR), availability of NPK for the plant, and decreased Ni content in the plant. By comparing to the control, the efficacy of first, second, and third compost plus *T. asperellum* in controlling VSD was 73%, 68%, 72%, and PPR 65%, 51%, and 59%, respectively five months post-application in the first year. In the second year, the efficacy against the disease was higher than in the first year. It was 83%, 75%, and 58% for VSD and 69%, 61%, and 78% for PPR, respectively. Moreover, the treatments increased pod production and P content in the leaves, while N and K content rose just in treating the second and third compost plus *Trichoderma*. Ni content only decreased in the treatment of the first compost plus *Trichoderma*. These data showed that especially first compost in integration with *T. asperellum* treatment suppressed above ground diseases and increased cacao pod production. Therefore, disease management and cacao growth on a bigger scale could potentially use the *Trichoderma* integrated-composted plant residues

Keywords: Compost, Soil amendment, *Trichoderma*

Genetic origin of Venezuelan cacao (*Theobroma cacao* L.)

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ABSTRACT

Since the 17th century, Venezuelan cocoa has been recognized for its excellent sensory quality. Although it is true that such quality depends on many conditions such as edaphic, climatic, cultural management and postharvest management, the genetic component is one of the determining factors. In Venezuela, it is possible to find cacao trees in practically the entire national territory, both cultivated and in the wild; however, there are three areas of higher production in the east of the country, the west and the central-coastal region. The cocoa beans from these regions differ in both morphological and quality characteristics, although all are classified as fine aroma beans. In order to study the genetic origin of Venezuelan cocoa, a national study was carried out based on the morphological characterization of leaves, flowers, fruits and seeds and molecular using microsatellite markers. The study included trees conserved in 13 germplasm banks nationwide and in some Cocoa farms, representative of the genetic diversity of the different production areas of Venezuela. The results of both morphological and molecular characterization showed the occurrence of a wide genetic diversity. The comparison with reference clones characteristic of different genetic groups, demonstrated the presence of Criollo, Trinitario, Forastero low Amazonian genome as well as native trees of each locality, and their hybridizations. Forastero type cocoas from the upper Amazon were not significantly represented. On the other hand, Criollo type cocoa trees were found in all the Germplasm banks. A higher proportion of Criollo cocoa from the west of the country (37.3 %), its hybridizations (37.5 %), as well as a native group called Tuy (17.4 %) explain the particularities of Venezuelan cocoa and its expression in high quality sensory profiles. On the other hand, the composition of the genetic diversity varied among the different production regions, which makes possible products with different characteristics aimed at a wide range of chocolatiers with high demands on their raw material. The singularities found promote the continuity of the study of

cocoa in other parts of the country, its conservation and use in genetic improvement programs.

Keywords: Venezuelan Cocoa, genome, morphological characterization

Service delivery models in the west african cocoa sector: is a smart mix able to close the income gap for cocoa farmers in a responsible and sustainable manner?

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ABSTRACT

The search for innovative and sustainable interventions for closing the enduring income gap among cocoa farmers remains a top development priority for stakeholders. Access to climate-smart and socially responsible farm services is argued to be one way to minimize this inequality. However, evidence on which models (subsidized versus market-based and formal versus informal) work in Sub-Saharan Africa is lacking. The authors fill this gap by evaluating the performance of formalized market-based service delivery models promoted by Solidaridad in the West African cocoa sector. Longitudinal data on the intervention in Ghana and Cote d'Ivoire, which took cognizance of living income benchmarks for cocoa farmers in Ghana and Cote d'Ivoire as well as the impact of climate change on cocoa production is used for the evaluation. Preliminary results indicate that farmers who relied on formalized market-based service delivery models for cocoa production realized a similar but statistically significant increase in net income to those who did not. Additionally, the adoption of recommended agroforestry practices and the avoidance of children in labour service delivery were reported among cocoa farmers who sourced services from formalized market-based service delivery models. Based on these preliminary findings, could it imply that market-based service delivery models hold major potential for closing the income gap of cocoa farmers in a sustainable and responsible manner? The authors believe, based on the initial findings of the evaluation, that this is the case. It has been observed over the last five years, however, that the promotion of subsidized service delivery in the cocoa sector by the government discourages the formation of market-based service delivery models and slows down the scaling up of existing ones. For desired outcomes, there is the need to promote a smart mix of service delivery to smallholder cocoa farmers based on the co-benefits of the subsidized and formalized market-based models. Our results, therefore, provide an insightful basis to inform the policy discourse on what the smart mix should be.

Keywords: , ,

POSTER PRESENTATIONS



Genetics resources to study *Moniliophthora perniciosa*

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ABSTRACT

Moniliophthora perniciosa, the causal agent of witches' broom disease of cacao, is one of the main cacao pathogens in the tropical. Besides species of the Malvaceae family, the fungal has emerged in host species of the Solanaceae, Malpighiaceae, and Bignoniaceae families. This host range is still poorly understood. The genome sequencing of *M. perniciosa* strict sense isolates supports bioinformatics and comparative genomics approaches as important tools in studying the biology and evolution of *M. perniciosa*, herein focuses on genome size. The genomic sizes of six *M. perniciosa* isolates (representatives of wild nightshade, cultivated nightshade, and cocoa) were estimated from raw genomic sequencing data using KmerGenie v1.7051 software. This prediction showed a variation of the genomic size of 38.19 to 51.53Mb. In general, *M. perniciosa* from Solanaceous hosts showed a smaller genome size than isolates from cacao, except for one isolate from bell pepper that showed the biggest size. It was proven that there is cross-infection between cocoa isolates and cultivated nightshade through pathogenicity studies. However, those from wild nightshade are not pathogenic to cocoa. This variation in genome size may reflect the evolution in the pathogenicity of this fungus, through several mechanisms. In particular, organisms with bigger genomes tend to have more genes, more and longer introns, and more transposable elements than organisms with smaller genomes. Our findings indicate that genome size variation is an important adaptation during the evolution of *M. perniciosa*.

Keywords: Phytopathogen, *Theobroma cocoa*, Genomic size

Determination of hormone efficiency for propagation of cocoa (Theobroma cacao L.) by twigs in microtunnels

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ABSTRACT

In Peru, fine-aroma native cacao is disappearing, each year more producers prefer clones of high production hybrids such as CCN-51, causing unstoppable erosion and vulnerable genetic uniformity, being left behind and extinguishing completely, very important genes to maintain the diversity of the species. Therefore, it is required to have a fast and efficient propagation method that allows preserving the genetic characteristics of the material; and the twig rooting method is an interesting option. The aim of this study was the establishment of a vegetative propagation system through twigs of superior cocoa genotypes (IRC-3, BT, CJO-1, CCN-51, BJG, IRC-4, TSH-565), based on the use of auxins to promote root formation from selected branches, evaluating the effect of the hormone Naphthaleneacetic Acid (NAA) and Indolebutyric Acid (IBA). It was observed that with the use of the IBA, rooting was earlier than with the use of NAA; thus, for NAA, the clone IRC-03 (T19) formed roots at 42 days, while for the clone CCN-51 (T34) at 56 days. In the case of IBA, the clone IRC-03 (T24) presented root formation at 35 days, for clones CCN-51 (T40), BT(T32), CJO-1 (T15) root formation was achieved at 42 days. The results showed that vegetative propagation by twigs is a reliable and effective method for obtaining cocoa plants, and offers the possibility of conserving the characters of interest of the selected genotypes

Keywords: GENOTYPE, AUXINS, TWIGS

Optimization of somatic embryogenesis expression of high-value cocoa clones in the region of san martin - PERU

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ABSTRACT

Obtaining cocoa plants through the germination of sexual seeds, originates a high genetic variability in their population. On the other hand, plants obtained under asexual propagation techniques maintain the genetic characteristics of the plants from which they come. Somatic embryogenesis is a biotechnological technique that is considered an alternative in terms of mass production of cocoa plants with high genetic value. In order to evaluate the response to somatic embryogenesis, two types of explants (petals and staminoids) were studied in five cacao genotypes: Blanco Juan Guerra (BJG), Blanco Tarapoto (BT), CCN-51, TSH-565 and CJO-1, which were induced to form embryogenic calli, using two sequences of culture media for the processes of induction (PCG – Primary Callus Growth and INDI), expression (ED – Embryo Development and INDIEXP) and maturation of somatic embryos (PEC – Primary Embryo Growth and MM6). The results showed that the INDIEXP culture medium was more efficient in the expression of cocoa primary somatic embryos for the BJG (30 embryos) and CCN-51 (12 embryos) genotypes, at 51 days of culture. Regarding the PCG medium, it was shown to be more efficient for the BT (20 embryos) and TSH-565 (18 embryos) genotypes, expressing embryos at 78 days of culture; the CJO-1 genotype did not form somatic embryos. For the type of explant, all the embryos formed were from staminoids. Somatic embryos were observed in all their development stages: globular, heart, torpedo and cotyledonary, as well as cotyledons and roots. The formation of true leaves and roots occurred after 90 days of cultivation. Somatic embryogenesis currently represents an alternative to produce cocoa clones; however, the asynchrony for obtaining somatic embryos that showed the different cocoa genotypes is a variable to control in the production of new plants of high genetic value.

Keywords: *Theobroma cacao* L., somatic embryogenesis, staminoids

Molecular chaperone modulation in cocoa leads to plant resistance to *Moniliophthora perniciosa*

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ABSTRACT

Moniliophthora perniciosa, the causal agent of witches' broom disease, is one of the major cocoa pathogen that affect cocoa farming in South and Central America. The control of this phytopathogen is usually carried out by replacing plants with resistant genotypes accompanied by phytosanitary pruning. The identification of plant genes that are related to the plant's defense mechanism is important not only to unravel the molecular basis of plant-pathogen interaction but also to identify new strategies to combat the pathogen. Research often seeks to identify genes that code for PRs (pathogenesis related proteins), a set of novel proteins associated with host defense which impede the pathogen progress. PR proteins exist in plant cells intracellularly and also in the intercellular spaces, particularly in the cell walls of different tissues. In so, most PRs are secretory proteins and are translated and assembled in the lumen of the Endoplasmic Reticulum (ER). The Biding Protein (BiP) is a molecular chaperone located in the ER lumen that bind newly-synthesized proteins as they are translocated into the ER and maintains them in a state competent for subsequent folding and oligomerization. BiP is an abundant protein under all growth conditions, but its synthesis is markedly induced under conditions that lead to the accumulation of unfolded polypeptides in the ER as when plants are under pathogen attack. In this work we superexpressed BiP in tomato plants, a model plant susceptible to *M. perniciosa*. Ten transgenic lines, that presented different BiP levels on western blot analyses, were inoculated with *M. perniciosa* spores. After 45 days we observed that all control plants (not transformed) presented severe witch's broom disease symptom while transgenic lines symptom varied from severe to mild according to BiP level. In so we observed a positive correlation between BiP accumulation and *M. perniciosa* plant's tolerance. Our results suggests that BiP might have a protective activity against pathogen attack. It is possible that under accumulation of BiP in ER lumem,

secretory proteins, as PRs, are more promptly assembled giving the plant a molecular advance in responding to the pathogen infection. More research has to be developed in order to better understand the molecular basis of the induced resistance. However, our results brings the notion that it might be possible to develop new strategies to control the pathogen based on the induction of endogenous cacao BiP expression.

Keywords: Plant Defense, Witches' broom, BiP

Transcriptomic (RNA-seq) analysis of genes responsive to cadmium stress in *Theobroma cacao*

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ABSTRACT

Dietary exposure to the heavy metal Cadmium (Cd) can lead to several human health problems. Cd has been detected in cacao beans (*T. Cacao*) grown in South American countries, including Colombia at significant levels. Despite this, the mechanisms involved in uptake, transport, and accumulation of Cd in cacao are not known. To investigate this, cacao plants were grown in a hydroponic platform and exposed to 10 ppm Cd in the hydroponic media. Accumulation levels in leaves were measured as well as the effect on gene expression using transcriptome sequencing. The highest and lowest uptake was identified in genotypes PA-122 and TSH-660, respectively. Roots and leaves were sampled at 0 hours (moments before 10 ppm Cd exposure), leaves were sampled 24 hours and leaves and roots 48 hours after treatment. Libraries were then sequenced with an Illumina HiSeq X producing an average of 6 .882.143 reads per library, which were mapped to the Belize Criollo V2 genome. A large number of genes involved in signal transduction, ROS signaling, and metal ion transport were significantly up and down regulated. The present work will allow the identification of genes involved in cadmium uptake that can be further used to produce improved varieties with low cadmium absorption using genome editing techniques.

Keywords: Transcriptomic, Cadmium, Differential expression

Exploring the use of endophytes to improve grafting of T. cacao regional material with fine flavor potential

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ABSTRACT

The municipality of San Andrés de Tumaco (Nariño, Colombia) has the potential to produce fine flavor cocoa beans due to the quality of regional materials and the optimal agroclimatic conditions. However, the production of these regional materials faces several challenges due to their low grafting success (IMC-67 rootstock). One possible alternative to improve the propagation of these materials is to promote plant cell growth at the junction of a graft union using Plant Growth Promoting Bacteria (PGPB). Here we explore the potential of PGPB to improve grafting in commercial and regional materials. To do this, we first evaluated the diversity composition of the endophytic communities in seeds and seedlings of commercial and regional materials growth under sterile conditions. We evaluated different tissues (roots, cotyledons, and leaves) and used amplification and sequencing of 16S rRNA and ITS regions for bacteria and fungi. Second, we isolated T. cacao endophytic microorganisms and characterized the growth-promoting capabilities (PGP). Finally, we evaluated the effect of their inoculation on the grafting success of commercial and regional T. cacao materials. The results of the microbial diversity analysis using gene markers and isolates agreed with the identification of a common core of endophytic bacteria, mostly bacteria of the genera Pantoea, Bacillus, and Pseudomonas. Several of these isolates showed indole production and ACC deaminase activity, both important plant growth-promoting capabilities. From a set of around thirty-two isolates, the four with the highest activities were evaluated individually. Each isolate was inoculated at the junction of a graft union, controlling bacterial cell density. Grafting assays were conducted at the research center El Mira from AGROSAVIA (Tumaco, Nariño) in commercial and regional materials under field conditions (10 replicates per treatment). The results showed an increase in successful grafting from 50 to 80 %

(compared to the control) in regional and commercial materials, however the best inoculant was not always the same, and varied between materials suggesting a material-PGPB specific response. Thus, our results showed that bacterial endophytes promote grafting and therefore could be an alternative to improve the propagation of T. cacao materials and promote the social and economic transformation of the region.

Keywords: Grafting, Endophytes, PGPB

Participatory methodologies for sustainable technological innovation in cocoa systems: at the Colombian southwest region

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ABSTRACT

In Colombia, cocoa has positioned as a production system that stimulates territorial development processes in areas affected by violence, where a presence of illegal economies exists. It is a crop that enables productive reconversion by offering medium and long-term economic alternatives for farming family's livelihoods. In this context, the challenge of reconverting to cocoa involves not only the analysis of models, from a technological perspective, but also from the cultural understanding that these transformations imply. The Alliance Bioversity international-CIAT, ICCO Cooperation and the Red Adelco have made an inter-institutional articulation to implement the Rutas PDET program, which is part of a territorial stabilization process settled in the peace agreement for the termination of the armed conflict in Colombia. This program is funded by the European Fund for Peace and focuses on accompanying dairy and cocoa value chains in three departments of the country, through three main components: technological innovation, improvement of road infrastructure, and business development. This lecture focuses on the methodology used in the implementation of the technological innovation component, at the cocoa production system by showing the analysis carry on of the social, economic and environmental subsystems, and the transversal incorporation of a differential approach of generational and gender integration. This process involved contextualization actions, exchange of knowledge between farmers (farmer to farmer), co-design of territorial technological models and adaptation of models at the farm scale. This methodology seeks to accomplish sustainability of the SAF and the territorial stabilization model, based on the reconstruction of the social network.

Keywords: Participatory Methodologies, Technological Innovation, Social Network

Innovative co-designed agro-ecological transition pathways that vary according to the historical loops of cocoa production areas

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ABSTRACT

Côte d'Ivoire has been the world's largest cocoa producer for several decades. About 20% of the population earns an income that depends on cocoa production. Despite this substantial economic weight, cocoa farmers are facing numerous agronomic difficulties in their plots: an upsurge in phytosanitary problems such as swollen shoot or mirids, a significant decrease in soil fertility over time due to the cropping patterns, and increasingly long and intense droughts. This has a negative impact on cocoa production, resulting in almost 80% of the 800,000 Ivorian farmers living below the poverty line. There is therefore an urgent need to find solutions for these farmers, who do not wish to give up cocoa production because, among agricultural commodities, it is still sold at an attractive price despite its high market volatility. Although technical institutes, research centres and universities have made considerable efforts, the proposed solutions are either not adopted or are not adapted to the needs of farmers. After a first phase of diagnosis of agricultural practices, we conducted co-design workshops in three geographical areas corresponding to the three historical loops of cocoa production in Côte d'Ivoire. Our results clearly indicate that regardless of the age of the plantations, whether young in the west or old in the east of the country, there are significant agricultural difficulties for which solutions must be found. After defining design objectives with the farmers, participatory workshops were conducted. During these workshops, farmers and other stakeholders with relevant expertise in relation to the design target generated technical innovations. Original farming systems, some of which are presented in the article, combining different technical innovations and taking into account a diversity of production contexts, were developed collectively. Test areas in the plots of the farmers who took part in the approach will be set up in the coming months and will make it possible, in the longer term, to refine the innovations in order to better meet the objectives.

Keywords: technical innovations, participatory approaches, agro-ecological transition

Advances of Functional Genomics of *Theobroma cacao*'s defense against *Phytophthora palmivora*

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ABSTRACT

Plants have complex and dynamic immune systems that have evolved over many years to help them resist pathogen invasion. We have combined data from RNA-sequencing, un-targeted metabolomics, and whole genome sequencing to discover several genes and pathways that are associated with resistance, either within or between different cacao populations. Our results highlight distinct aspects of defense response across four divergent populations of *Theobroma cacao*, while simultaneously suggesting functional categories that are broadly essential for pathogen resistance in cacao. Bioinformatics and functional analysis of genes, up-regulated across all four populations will be discussed. Among these processes is phenylpropanoid biosynthesis, a metabolic pathway with well-documented roles in plant defense.

Keywords: *Phytophthora*, resistance, omics

Evaluation of the resistance against Frosty Pod Rot and Black Pod Rot of clones preserved in the International Cacao Collection of CATIE

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ABSTRACT

The International Cacao Collection of CATIE (IC3) was established in Turrialba, Costa Rica in 1944 with the main objective to promote the preservation, exchange and distribution of the genetic resources of cacao. Currently, it comprises 1250 accessions from different genetic and geographic origins. The valuable germplasm contained in this collection has a very important role in the future success of the cacao cultivation worldwide, and represents the assurance of the availability of the genetic diversity for the development of new improved cacao genotypes for the farmers. Some of the most common evaluations carried out in the collection, for having as much available information as possible of the conserved materials, includes self-compatibility test, organoleptic descriptions and artificial inoculations. Considering that Frosty Pod Rot (*Moniliophthora roreri*) and Black Pod Rot (*Phytophthora palmivora*) are two of the most limiting biotic factors for cacao production in America, identification of resistance sources for those diseases is a priority for CATIE. Adjusted artificial inoculation method to test the reaction against Frosty Pod Rot (Sánchez et al, 1987; Phillips and Galindo 1988), and the adjusted paper disc method to test Black Pod resistance (Phillips and Galindo, 1989) are routinely performed. The huge genetic diversity contained in the genebank makes possible to find a variable result in the performance of the evaluated clones to the artificial infection by those pathogens. From the evaluations already done, we found that Moniliasis resistance is a rare character present in the genebank, where approximately 5% of clones have some level of resistance, while resistance to Black Pod is more frequent, and about 30% of the evaluated genotypes registered some degree of resistance. Resistant genotypes identified to one or two of the diseases have been incorporated into CATIE's Cacao Breeding Program for the generation of high yielding-resistant clones generated and released for farmers. They have been also distributed to users (smallholders, institutions and researchers). Transferring these resistant clones to the International Cocoa Quarantine Centre, at the University of Reading (ICQC,R) with the results of the evaluation is other important impact of these evaluations, which facilitates the distribution to different regions such as Africa, where diseases as moniliasis are not present, but have the threat of been affected, that would causes losses of more than half of the total cacao production in the world.

Keywords: Cacao germplasm, Disease resistance, Genebank

Real-time Image detection of cocoa pods in natural environment using deep learning algorithms

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ABSTRACT

Estimation of crop yield along its different growth stages is essential when making decisions about disease management, harvest, storage, transport, and marketing. In the case of cacao (*Theobroma cacao*) yield estimation is typically based on manual counts, which are time-consuming, expensive, and often associated to huge estimation errors. Indeed, because of the unsynchronized pattern of flowering and yield development phases in cocoa trees, the estimation of yield and production rely on large sampling of individual trees on a weekly basis. Designing a low-cost machine vision system with strong operability for the real-time identification of cocoa pods in different growth stages under natural environments is of great significance for research and cocoa industry. Accurate cocoa pods detection is essential for several applications such as fruit counting, yield estimation and precision agriculture. The main goal of this study was to propose a simple and reliable method for cocoa pods segmentation and counting from RGB images acquired with mobile phones, using deep learning techniques. The method presented here involves four steps, namely (i) image acquisition, (ii) image annotation, (iii) training models [preprocessing and applied training technique] and (iv) model validation. For step 1, 794 images from cocoa fields located in Ivory Coast and in Cameroon were obtained with the main camera of a mobile device. For step 2, cocoa pods were annotated from images using the Zooniverse collaborative platform. For step 3, three deep learning recognition models, Faster-RCNN, Mask-RCNN and YOLOv3 were trained using 80% of the RGB images and annotations. The applied variants of Faster-RCNN were, RCNN-R-50-C4-3x, RCNN-R-101-C4-3x, RCNN-R-50-FPN-3x and RCNN-R-101-FPN-3x while R101-C4-3x and R101-FPN-3x were used for Mask-RCNN. For step 4, 10% of data were used for testing and 10% for validating the trained deep learning methods. Results showed that, among the

different models compared in this study, Faster RCNN was the best model in terms of accuracy of cocoa pods detection. Faster-RCNN-R-101-FPN-3x outperformed the other Faster-RCNN models and achieved a performance of 74%. Future work will focus on developing the models to further improve the detection accuracy. A larger dataset and effective sample preprocessing will be valuable for establishing a robust model. A reliable real-time model to detect cocoa pod may have large impacts on the efficiency of cacao management and production profitability. It can help inform cacao farmers early about the expected yield in order to assist in managing the correct fertiliser and pesticide application rate and timing.

Keywords: deep learning, pods detection, Faster-R-CNN

Regeneration of the cocoa agroforestry system: an innovative approach for small family farms in northern Haiti

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ABSTRACT

In Haiti, the cocoa sector is an economic, social, and environmental issue. Haitian cocoa farming is practiced in an agroforestry system. It is an old, multi-strata, highly diversified cropping system, which occupies an important place in small family farms. Grand'Anse/South west and the Northern Haiti are the major cocoa producing areas in Haiti. This applied research work seeks to determine the contribution of the regeneration of SAF cocoa trees in improving agricultural productivity, the economic situation of families and the preservation of biodiversity. This technique was introduced in the Northern Haiti by FECCANO with AVSF technical and economic support. It consists in rehabilitating agroforestry systems that are more than 25 years old, through pruning operations, the regularization of species densities and the diversification of associated crops. A survey was carried out with a sample of 127 farmers including 30 women, by valorizing the available information. Additionally, data were collected and analyzed from the farmers field school system set up to disseminate the regeneration practice and from a participatory monitoring system centered on producers using a register book. The data is collected by producers and technicians from the FECCANO advisory service. The results suggest that the application of regeneration while respecting agroecological practices improves the performance of cocoa SAF. The technical and economic analyses of the regenerated SAF show substantial improvement in production. Cocoa yield increased from 250 to 450 kilos of dried cocoa in the 150 regenerated plots. We observed an increasing resilience in rural households as well as their farms through diversification within the plots, including fruit trees, forestry, and food crops (reduction of climatic risks, less vulnerability to the vagaries of the cocoa market alone, increased capacity to self-consumption and additional income after the investments made). The regulation of trees density at plots level gradually making it possible to constitute real agroforestry systems with a positive effect on the environment (water conservation, mitigation of land degradation and loss of soil fertility, increase in cultivated biodiversity and restoration of natural biodiversity) by

capturing all the sun's rays. Today, through the organic and fair-trade certification mechanism, FECCANO, which is a network of small producers, has accessed the most profitable markets in Europe. This virtuous circle allows the enhancement of the terroir and a gradual improvement in managing agroforestry systems.

Keywords: Cocoa agroforestry system, family farm, regeneration, sector and cocoa

Infestation dynamics of mealybug vectors of the Cocoa swollen shoot virus in young cocoa plots surrounded by barrier crops in Soubré (South-West of Côte d'Ivoire)

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ABSTRACT

The Cocoa swollen shoot disease probably represents today the greatest threat to cocoa production in Côte d'Ivoire. The disease is caused by the Cacao swollen shoot virus (CSSV), a badnavirus transmitted to cocoa by about 15 mealybug species. At local scale, the propagation of CSSV outbreaks is closely related to mealybug dispersal behaviors. The ability of barrier crops to stop the disease spread has been demonstrated in Togo and Ghana, yet mechanisms involved are still not elucidated. The present study aims at better understanding these mechanisms by studying mealybug population dynamics in young plantations surrounded by barrier crops. A set of twelve 0.25 ha cocoa plots surrounded by 10 m large hedges of coffee (*Coffea robusta*) or acacia (*Acacia auriculiformis*), or without hedges (control plots), was implemented within large CSSV outbreaks in mature cacao plantations, in July and August 2019, near Soubré (South-West Côte d'Ivoire). First counts of mealybug colonies on cocoa and barrier crops were done in September 2019 and February, March and May 2020. From November 2020 to December 2021, populations were assessed monthly using a scoring scale, a score from 0 to 3 being given to each cocoa or barrier tree according to the size of the hosted population. *Pseudococcus longispinus* and *Ferrisia virgata* were the first species present on cocoa, but populations remained small until May 2020 with a maximum of 0.5% of trees infested by small populations of mealybugs. These two species have long waxy hairs that allow them to be transported by wind. Although very common in neighboring mature plantations, *Formicococcus njalensis* was first recorded in young plots in November 2020. Since then and until December 2021, *F. njalensis* was the dominant species on cocoa and coffee with 63.8% of the total community. *F. virgata*,

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Planococcus citri and *P. longispinus* represented 10.8%, 4.7%, 2.9% of the community, respectively. Total infestation rate remained small during the study period with minimum and maximum values of 0.94% in May 2021 and 3.73% in December 2021, respectively. Compared to other species, *F. njalensis* showed a more patchy distribution in plots, with populations initially aggregated on the borders of plots. Our results suggest that barriers of acacia or coffee do not prevent cocoa infestation by mealybugs and that infestation dynamics differ between species, according to their dispersion behavior.

Keywords: Pseudococcidae, Dispersion, Distribution

In vitro and in vivo screening and selection of microorganisms from five composts with antagonistic effects on *Phytophthora* spp., the causal agent of brown rot of cocoa pods (*Theobroma cacao* L.) in Côte d'Ivoire

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ABSTRACT

Cocoa production in Côte d'Ivoire is strongly threatened by brown rot of cocoa pods due to the pathogens *Phytophthora palmivora* and *Phytophthora megakarya*, as well as the decline in soil fertility. The management of these constraints through means that respect the environment and the health of the population has long been recommended. The present study proposed to formulate five (5) composts based on organic wastes (poultry manure, cattle manure, sheep manure, cocoa hulls, rice bran and panicum) and to study the effect of the microorganisms they contain in the control of brown rot of cocoa pods. To do this, a first screening was to chemically analyze these five composts (C1, C2, C3, C4 and C5) according to standard methods. It appears from this analysis that the C3 compost has the highest phosphorus and potassium content, followed by C1, C2, C5 and C4. For nitrogen the highest value was recorded in the C2 compost followed by C1, C3, C4 and C5. The second screening consisted in searching the different composts for microorganisms antagonistic to *Phytophthora palmivora* and *Phytophthora megakarya* in vitro and in vivo. Out of 55 selected mycelial colonies, 36 isolates apparently inhibited the growth of the pathogens in the direct confrontation test on agar culture medium. However, in the test for pathogen aggressiveness on cocoa pods, eight (8) isolates out of 36 effectively inhibited the development of brown rot on treated cocoa pods. This study proves then that it is possible that a biofertilizer (compost) can be used in the bioremediation of soils under cocoa trees and in the bio-control of brown rot in Côte d'Ivoire.

Keywords: Brown rot, Biofertilizer, Bioremediation

Promissory cacao clones with high yield potential, disease tolerance and quality to increase production in Latin America

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ABSTRACT

Cacao production represents the income source for more than 5 million farmers and 40 million people worldwide, however, conditions for farmers who depend direct or indirectly on the cacao crop, is threatened by losses due to fungal diseases and adverse effects of climate change. Under this scenario, the development of improved cacao clones in combination with good agronomic and agroforestry practices is a constant need. The Tropical Agricultural Research and Higher Education Center (CATIE) started its Cacao Breeding Program in 1996, with the objective of develop genotypes with high yield potential, tolerance to diseases and good industrial quality. In 2008, CATIE released a group of 6 improved clones, which are already established in 9 countries in Latin America. Since then, CATIE has continued with the evaluation of other promissory materials, to release improved genotypes. In 2005, 4-ha field trial was established in La Lola Farm, Limón, Costa Rica, comprising 160 clones, with 25 trees randomly distributed per clone. Management included routinely pruning, modest fertilization, and monthly harvest and sanitary control, under a similar shade canopy. Chemical control was not applied to prevent or to eradicate diseases, all trees have been exposed to natural conditions in an area where the incidence of Frosty Pot Rot and Black Pod is high. From second year on, monthly evaluations were done by counting the number of healthy pods and incidence of the two diseases mentioned. From the 9-year evaluations, CATIE selected the most promissory clones based on high yields, low natural incidences of diseases and initial quality evaluations. CATIE-R92, CATIE-R104, CATIE-R78, CATIE-R52, CATIE-R58, CATIE-R91, CATIE-R5 and CATIE-R6 registered the highest yield with an 9-year average over 1300 kg/ha/year and almost 2000 kg/ha/year in the last three years of evaluations. CATIE-R92, CATIE-R58, CATIE-R91, CATIE-R5 and CATIE-R6

were the most tolerant to Frosty Pod Rot, with a natural incidence below 8%. High inter-compatibility ($\geq 50\%$) was observed among the clones; while five clones are self-compatible with a retention $\geq 30\%$. Some of the clones showed interesting combination of intensity and softness cocoa, with fruit, floral, nutty and herbal notes. Next steps for releasing the clones include the preparation of a catalogue, the formal registration in the countries of the region and alliances with local partners to evaluate these materials in their local agroecological conditions and adding indicators of adaptation to climate change. CATIE is also willing to share improved materials beyond the Latin American region.

Keywords: Cacao Breeding, Disease resistance, Compatibility

Sustainable Cocoa Production – Current Practices in Côte d’Ivoire and Ghana

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ABSTRACT

Agri-food systems and agricultural production with its dependence on natural resources and ecosystem services are threatened by a changing climate, by biodiversity loss and landscape changes. At the same time is the expansion of agricultural cash crop commodities seen as a major contributor to these negative environmental impacts (Hagger et al. 2017). This also includes the cocoa value chain, which has received increased attention in recent years, both in cocoa producing and consuming countries, where concerns of both the environmental and socio-economic sustainability have been raised. In Côte d’Ivoire and Ghana, the two major cocoa producing countries in the world, many small-scale farmers opt for unshaded or low-shaded cocoa (Ruf, 2011), a production system developed in the 1960s (Jagoret et al. 2019) based on hybrid cocoa varieties and use of external inputs such as fertilizer and pesticides. Studies show that completely unshaded production systems have significantly lower species richness in comparison to shaded cocoa systems (Schulze et al. 2004). In comparison, the ecological benefits of agroforestry systems has been identified by a number of studies (Asigbaase et al., 2019; Blaser et al., 2017; De Beenhouwer et al., 2013) without causing an increase in pests and diseases (Armengot et al., 2020). Our study focuses on the identification of sustainable agricultural practices in the cocoa sector that balance biodiversity preservation and yield optimisation. First, we develop a sustainability scale based on ten indicators of sustainable farming practices related to agroforestry, soil conservation, pest and disease management and farm sanitation. Second, we analyse the effect of two measures of market participation and collective action, namely participation in sustainability certification schemes (such as Fairtrade, Rainforest Alliance and Organic certification) and membership in farmer cooperatives, on the uptake and application of sustainable practices. We take into account capacity building and training as a vehicle for change. We use a rich data set from a representative survey, implemented in Côte d’Ivoire and Ghana in 2019 with socio-economic and farm-level information of more than 1700 cocoa producing households. Initial descriptive findings show that certified cocoa farmers and those

engaged in farmer cooperatives are more likely to produce cocoa sustainably. We will further apply econometric approaches to analyse the data addressing selection bias that will allow us to make recommendations on how farmers can be supported to adopt of sustainable cocoa production practices.

Keywords: Sustainable Production, Certification Schemes, Farmer Cooperative Membership

Do abiotic soil factors influence the spread of Swollen Shoot disease in the Soubré area - South-West Côte d'Ivoire?

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ABSTRACT

Cocoa swollen shoot disease (CSSD) causes significant losses for cocoa producers, and constitutes a serious threat in Côte d'Ivoire. Despite numerous attempts of eradication, the disease still progressing across the country and let think to several environmental factors involving in the disease epidemiology, such as the soil fertility. This study was conducted to evaluate the implication of abiotic soil factors effects on the prevalence of the CSSD in infected areas. Relationship between the prevalence of the disease and some soil parameters have been investigated at two sites in Soubré area, Southwestern Côte d'Ivoire. The Land Degradation Surveillance Framework (LDSF) was used for data collection. This device has a sentinel site of 10 Km × 10 Km, divided into 16 Clusters of 2.5 Km × 2.5 Km. Each cluster includes 10 observation points called plots. Observations on CSSV disease and soil samples were taken within a radius of fifty meters around the center of each plot. In each plot, CSSV were detected based on the typical symptoms on the leaves and on the stems of cocoa trees. As for the soil samples, they were taken from the horizons of 0-20 cm and 20-50 cm deep and analyzed in the laboratory to determine the proportions of the different mineral elements. The data obtained were subjected to statistical analyzes in order to detect the soil differences between diseased and healthy plots. The results showed that granulometry, pH, C/N ratio and phosphorus actually influence the distribution of swollen shoot disease. These results should allow the development of an effective and sustainable management strategy to better control disease.

Keywords: Abiotic factors, swollen shoot disease, Côte d'Ivoire

Effect of temperature on the Cacao swollen shoot virus (CSSV, Badnavirus) vection by the mealybug *Planococcus citri* to cocoa seedlings in the laboratory

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ABSTRACT

Since the early 2000s, the cocoa industry in Côte d'Ivoire is experiencing the resurgence of the Cacao swollen shoot virus disease (CSSVD). Full-sun cocoa monocultures and low shade plantations are considered as a cause of the rapid spread of CSSVD in the country. The warmer and dryer microclimates prevailing here, aggravated by climate change, would be conducive to vector mealybug outbreaks and would exacerbate CSSVD damage. This has led cocoa sector to encourage shading practices. However, current practices are not supported by sufficient knowledge of CSSVD relationships to microclimate. The virus is transmitted by mealybugs (Hemiptera: Pseudococcidae) through a non-circulative semi-persistent transmission, that means that the virus remains located to the vector mouth parts and that a mealybug remains infectious no more than two days. The present study aims at characterizing the impact of temperature on CSSV vection by mealybugs. The study was conducted in the laboratory of the PRISM department of the Plant Health Institute of Montpellier, in France. The study included three steps: 1) an acquisition period conducted in a growth chamber at 6 different constant temperatures (20, 22, 24, 26, 28 and 30°C) for 24 hours, during which first instars of the mealybug *Planococcus citri* were enclosed in clip-cages on young symptomatic leaves of cocoa seedlings previously artificially infected with a recombinant *Agrobacterium tumefaciens* bacteria containing the cloned sequence of Agou 1 isolate of CSSTBV species ; 2) an inoculation period conducted at the same temperatures, where the young infective mealybug instars were transferred to sprouting cocoa beans and allowed to feed for 48 h ; 3) an incubation period at 25°C, where the cocoa beans were cleared of mealybugs and planted in a tray with potting soil, where they grew until CSSVD symptom onset, which was recorded. Molecular analyses by PCR, with

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specific primers of Agou 1 isolate, were performed 50 days and 180 days after inoculation period to detect the presence of the virus in cocoa seedlings. Results show that temperature has an effect on CSSV vection by mealybugs. Transmission rate gradually increased from 28 to 36% at 20°C to reach 82 to 95% at 26°C. The trend was not so clear for upper temperatures of 28 and 30°C. Observations on mealybug behavior suggested that the relationships between transmission and temperature could be explained by mealybug activity, which was stronger at higher temperatures. These results are discussed and perspectives are proposed.

Keywords: Thermobiology, Microclimate, Pseudococcidae

Influence of soil physico-chemical properties and cocoa growth characteristics on yield components

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ABSTRACT

Cocoa requires nutrient-rich soils and good management practices to achieve and maintain high productivity. Yet, little research has been conducted relating soil characteristics, allometric properties, and cocoa yield parameters. We investigated the relationships between soil properties, cocoa growth characteristics, and yield parameters. The study was conducted in Ntui, Ayos and Makenene districts in the Centre region of Cameroon. The dominant soils in the region are Ferralsols and Acrisols. Soil samples were collected at 0-30 cm depth on the edges and in the middle of each 2000 m²- plot. We sampled 64 (44 in forest and 20 in savannah) cocoa farms. Sampled farms were 8 to 22 years old. Soil pH in water (pH_w) and salt (pH_k), Ca, Mg, K, bulk density (BD), porosity, electrical conductivity (EC), Zn, Mn, Cu, Fe, sum of exchangeable bases (SEB), base saturation (BS), Exchangeable acidity (EA), total nitrogen (TN), organic carbon (OC), C/N ratio, exchangeable bases on total nitrogen ratios, cation exchange capacity (CEC), effective CEC, sand, silt and clay contents was assessed for soil properties. Crown depth, trunk circumference (tcirc) and tree height (theight) were assessed for allometric properties, while pod classes, number of pods (npod), pod yield (pody), fresh and dry bean yields were determined for yield components. Data were analyzed using principal component analysis (PCA), Pearson correlation matrix and stepwise regression for years 2020 and 2021 (R software). PCA revealed that amongst soil properties, pH_w, pH_k, EB, BD, CEC, Cu, and Mn exerted the most influence on cocoa yield component, while among the allometric properties, crown depth, tree height and trunk circumference did. Dry bean yields ranged between 298 and 1590 kg/ha across farms, and these were significantly correlated to EB ($r=0.29$), CEC ($r=0.25$), silt content ($r=0.26$), Cu ($r=0.21$), Mn ($r=0.17$), pH_w ($r=0.21$), EA ($r=-$

0.25) and t_{circ} ($r=0.16$), though the coefficients of correlation were relatively low. Results from Stepwise regression analysis showed that pod and bean yields were very highly significantly ($P<0.001$) influenced by BD, EB, EA, soil micronutrients, CEC, soil texture, soil organic matter, exchangeable K, available P, pod size classes, crown depth, tree height ($r^2 = 0.73$). Single soil and cocoa characteristics can barely explain cocoa yield performance, while a combination of properties does. Maintenance of adequate soil fertility (e.g., integrated soil fertility management) and good crop management for healthy cocoa plants could improve cocoa productivity in Central region of Cameroon and beyond.

Keywords: Soil characteristics, cocoa growth characteristics, Yield parameters

The “bean tegument” innovation system: bringing back to smallholders’ cocoa farms the fertility lost or transferred to agro-industry.

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ABSTRACT

When they sell their beans to a grinding company, growers give up a source of organic fertilizer: the tegument (the skin of the bean). The vast majority of growers are still unaware of this. Similarly, for the grindings multinationals, the teguments have long been considered bulky waste in the parks of the factories which had to be rid of. Part of it was recently sold to industrial sweet banana plantations. But at least in the San Pedro region, since the early 2010s, a whole network of smallholders, cocoa traders and intermediate staff in cocoa grinding factories had gradually realized the interest of teguments as fertilizers in cocoa farms. A few smallholders’ testimonies were collected around San Pedro as part of a research program on innovation tracking. Then in order to verify the claim, we launched a survey based on a questionnaire passed with some 80 smallholders in two villages. Clearly, a remarkable innovation system has been built from ‘below’. Quite informal channels have been set up to bring this tegument from the factories back to the cocoa farm plots, often going through a burning stage. Smallholders call this form of tegument ash “potasse”. Smallholders who have tested it, mainly in the form of burnt tegument, announce yield gains of 50% for 2 years after application. In the village studied near San Pedro, the rate of adoption of this “new fertilizer” increased from 0 to 70% of planters in 5 years. The idea is to convince the grinding giants to fill their trucks with the dose of teguments in proportion to the tonnage of beans received, around 7-10%. For a load of 30 tons of beans, the truck would leave with at least 2100 kg of tegument. Two cooperatives (actually ‘pisteurs’ who have renamed their private business as a cooperative) have started to take into account the demand of smallholders and sell them bags of “potasse”, produced by intermediaries. The grinding industry doesn't seem to know... But if the grinding and chocolate industry were to become an active partner in this system of innovation, if the industry really wanted to play the “sustainability” game, the potential beneficiary smallholders would number in tens of thousands of villagers. In the context of the war in Europe and the inflation exerted in particular on fertilizers, those who govern the cocoa value chain could reconsider the interest of this village innovation.

Keywords: Organic fertilizer, fertility transfer, Inflation

Monitoring framework of ecological performance indicators for soil health and climate smartness in cacao production systems

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ABSTRACT

Cacao (*Theobroma cacao* L.) is an important perennial cash crop in Latin America and the Caribbean. Unsustainable soil management applied to increase currently stagnating cacao yield can exacerbate the negative effect of climate change and soil degradation on the entire cacao food system. In addition, recently the EU imposed a stricter thresholds in Cd level content in cacao-derived products because the cacao pods can accumulate Cd naturally present in soil, and this, in the long term, can cause serious problems to human health. Here, we want to present a recently developed monitoring framework for gaining insight into the status and the changes of soil health and climate smartness in cacao agroecosystems as affected by soil management, in particular in Latin America, but also applicable to cacao agroecosystems in other areas of the world. This framework presents an approach to measure soil health in cacao farms through the use of soil health and key performance indicators, and should serve a variety of end-users involved in the cacao production chain to gain understanding and knowledge about the effect of agricultural practices on ecosystem services linked to soil health and climate smartness. The framework is a flexible decision support tool that end-users can apply in close collaboration with researchers, adapting its focus depending on the specific context, threats, needs and objectives of the system. This framework has been developed in the framework of the EU funded project ClimaLocal and it will be extensively tested and, where needed, adapted in various experimental trials and farms within the project. Ultimately, the framework will help in the creation of a sustainable cacao food system and cacao agroecosystems which sustain internal soil functioning and can cope with climate stresses. 1Fostering low cadmium and climate-relevant innovations to enhance the resilience and inclusiveness of the growing cocoa sectors in Colombia, Ecuador and Peru. Clima-Loca is a European funded project under the DeSIRA partnerships for innovation program

Keywords: Soil health, Climate smartness, Monitoring framework

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The morphological and genetic diversity of the cacao pathogen *Moniliophthora perniciosa* in the Peruvian Upper Amazon

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ABSTRACT

Moniliophthora perniciosa is the causal agent of witches' broom, one of the most important fungal diseases of cacao in Latin America. In this study, we evaluated the in vitro characteristics and the population dynamics of the pathogen in the Peruvian Upper Amazon, center of diversity and domestication of the crop. We collected fifty samples from six cacao growing districts: three with more intensive cacao cultivation and closer to urban areas, and three where cacao plots are more dispersed and are managed by people in native communities in remote Amazonian areas. All samples were isolated in pure culture and their macro and micro characteristics were evaluated. Isolates were also molecularly genotyped with an eleven microsatellite-marker. We identified nine morphological patterns of mycelial growth, which were related to the abundance or scarcity of clamp connection-bearing hyphae and culture growth rate, and had no relation with their origin. Conversely, the microsatellite genotyping revealed that the population genetics and dynamics of the pathogen in the region is shaped by the intensity of cacao cultivation. Districts with more intensive cacao plots had a reduced diversity (Shannon index, $H = 0.69\text{--}1.10$) compared to remote districts deeper into the Amazon ($H = 1.10\text{--}2.30$). Additionally, clustering, and minimum spanning network analyses revealed that all genotypes in the districts with more intensive cultivation derived from the genotypes in remote districts, i.e., the pathogen was introduced from areas located deeper into the Amazon. *Moniliophthora perniciosa* was first observed in the Brazilian Amazon in the 1780's and it spread to Bahia, the main cacao cultivation region of this country, not before 1989. Our findings reveal a similar pattern in the invasive history of *M. perniciosa* in Peru.

Keywords: Population genetics, Witches' broom disease, Peruvian native cacao

Changing gender norms for sustainable cocoa production

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ABSTRACT

This paper presents results based on an extensive research and strategy project led by the KIT Royal Tropical Institute and Pabla van Heck (independent) in close collaboration with Mars Wrigley, known as the Resilience Journey. The goal of this journey was to develop insight-driven recommendations for future investments to strengthen gender equality and women's empowerment in the cocoa supply chain. Using a design thinking approach, which is relatively new in cocoa research, the project's first stage focused on better understanding the daily lives of women and girls in cocoa-growing communities in Indonesia, Ghana and Côte d'Ivoire. KIT's team conducted qualitative research with adolescent girls, young mothers and their 'influencers' and stakeholders in the cocoa value chain. Participatory and iterative in nature, the research aimed to uncover the unmet needs of these women and illuminate the current state and root causes of their (dis)empowerment. One of the main findings of this phase was that cocoa community structures are deeply patriarchal and unequal gender norms are passed on between generations putting women and girls at a disadvantage. In the second phase the team analysed the viability of these findings against the sustainability priorities set by the cocoa sector. In this phase the team conducted interviews with a wide range of stakeholders. It became clear that cocoa operations and sustainability programs are channeled through cocoa's first mile, which is male-dominated and gender blind. Consequently, women tend to be excluded from potential benefits and existing inequalities are reinforced. Moreover, as cocoa's first mile is a key local institution, intertwined with the social fabric, this hinders achieving cocoa sustainability priorities such as child protection, improving farmer income and preservation of forests, which require the recognition of girls' and women's unique needs, rights, income contributions and household tasks. The overall conclusion is that there is a need and opportunity to transform cocoa's first mile to achieve sustainability goals and become a gender role model. Cocoa farmers are often mature men, with children and grandchildren. These men can be a channel to reach the next generation. Service providers, often men with a certain status, education and expertise could become change agents and help to

challenge traditional norms. To engage men as allies will require deliberate action and sensitization on gender inequalities and encourage them to act as change agents. It will also require caution, as transformation will not happen over-night and can go hand-in-hand with backlash.

Keywords: gender equality, norms, sustainability

Cocoa rehabilitation in Western-Ghana: Farmers' self-selection and short-term livelihood effects

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ABSTRACT

In Ghana, ageing cocoa trees and the spread of Cocoa Swollen Shoot Virus Disease (CSSVD) and climate change threaten future cocoa production and the livelihoods of over 800,000 smallholder cocoa producing households. Rehabilitation of overaged and diseased cocoa plots is necessary to protect future cocoa production, upgrade smallholders into more productive and sustainable production systems and secure their future livelihoods. This requires rehabilitation efforts at scale: Ghana Cocoa Board estimated in 2018 that a total area of 738,542ha, which constitutes about 39% of land under cocoa, requires replanting. However, farmers are reluctant to rehabilitate their farms because of, amongst others, the significant costs of planting material and other inputs, labour demands and drop in income in the first 3-5 years after replanting before the young trees come into production. Understanding the factors that influence smallholders' ability and willingness to replant their overaged and diseased plots is vital to reaching the required scale to effectively combat CSSVD and protect smallholders' future livelihoods. To this end, we analysed the characteristics of farmers who engaged in cocoa rehabilitation under the Shaded Cocoa Agroforestry Systems (SCAFS) project that SNV Netherlands Development Organisation implemented in 2016-2018 in the Western North Region of Ghana. By developing a counterfactual group of comparable households that did not enrol in the rehabilitation programme, we assessed what type of farmers were more likely to enrol. Using multi-variate techniques, we accounted for this self-selection effect to estimate the average treatment effect of the programme on short-term livelihood indicators (labour allocation, cocoa yields, and food security). We found that farmers with more than one plot, a higher number of household members and a higher education level were more likely to enrol. Controlling for these effects, SCAFS enrolment was associated with higher increases in the use of household labour and a decrease in the use of hired labour, but no significant short-term effects on cocoa

yields and food insecurity were found. The substitution of hired labour by household labour in combination with the distribution of food crops as temporary shade crops have been able to off-set part of the short-term livelihood effects. This demonstrates the need for an integrated approach towards cocoa replanting.

Keywords: rehabilitation, livelihood effects, integrated approach

Improving cocoa bean quality in the supply chain by mitigating free fatty acid accumulation in beans through improved farm practices

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ABSTRACT

Free fatty acids (FFAs) are a degradation product of cocoa butter resulting from the spoilage of beans and derived products. They are known to be generated in beans of poor quality or stored under poor conditions. High FFA content is a serious quality defect and reduces the technical and economic value of the cocoa beans. The present project aimed to mitigate free fatty acids (FFA) levels in beans delivered by farmers groups to ofi factories in Côte d'Ivoire. We first investigated the main factors leading to FFA accumulation in our supply chain, through a survey of harvest and post-harvest practices and the collection of bean samples. This investigation carried out in the West of Côte d'Ivoire, identified 4 main factors impacting FFA levels: inclusion of spoiled beans in fermentation, fermentation methods, low frequency of harvest and poor drying conditions. Beans fermented in heaps on plastic tarp contained significantly higher levels of FFAs than beans fermented on banana leaves. In the study area, this was related to the low abundance of plantain trees and led to the frequent use of plastic tarpaulin. Based on these findings, we selected eight farmer groups (3254 farmers) which delivered beans with higher-than-average levels of FFA during the 2019/2020 season and deployed the following approach: 1) Distribution of banana suckers to farmers; 2) Training of farmers on best harvest and post-harvest practices; 3) Regular monitoring of changes in practices (surveys, quality analyses of beans and regular sampling at farmer gates). We delivered 60750 banana trees to farmers in 2020, for planting close to fermentation areas and provided training to 80% of the farmers on banana upkeep and good harvest and post harvest practices. In the 2020/2021 season and before banana trees could provide enough leaves for fermentation, we started to observe a decrease in volumes of high FFA beans delivered by the cooperatives involved in the project, as compared to the 2019/2020 season (3% less volume above 1.75% FFA). This encouraging result suggested that farmers had started improving practices. Our survey and sampling

results showed more frequent harvesting and increase in banana leaf fermentation. This resulted in less overripe pods and more sorting out of the worst beans. However, other factors could have contributed to the improvement. Greater impact will require continuous training of farmers, full use of banana leaves and implementation of IPM practices such as pruning that contribute to improving pod and bean health.

Keywords: cocoa bean quality and FFA, good agricultural practices, cocoa bean fermentation

Determinants of the adoption of good cocoa farming practices and opportunities for increasing their uptake in the Centre region of Cameroon

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ABSTRACT

Achieving sustainable cocoa production systems requires among others an adoption of good agricultural practices (GAP) by farmers. Understanding the factors that influence farmers' adoption of these practices is essential to design better interventions. We examine the determinants of the adoption of GAP in the humid forest zone of Cameroon. More specifically, the study aimed to estimate the scale and extent of GAP adoption and to assess the factors influencing their adoption. Secondly, the barriers to adoption and options to overcome them as perceived by farmers were investigated. We administered a semi-structured questionnaire to 120 farmers in two different production areas. We computed adoption quotients and used them to group farmers under low, medium or high adoption categories. Then, an ordinal logistic regression was used in SPSS.25. We found an average adoption quotient of 71% (± 14). Furthermore, the regression's estimates indicated that farm location, household size, access to training, access to credit and sex were significantly and positively associated with the adoption of GAP. Factors such as farmer age, average plot age, experience in cocoa farming, farm size, education level and membership to producers' organisations were not significantly associated with adoption level. From farmers' perspectives, there were fourteen barriers, with different degrees of importance, to adoption of good cocoa farming practices. These were related to insufficient mastering of production techniques, lack of motivation (price incentives, quality control etc.), lack of productive resources (inputs, credit etc.) and others. To overcome these barriers, farmers suggested twelve actions. The findings show a high level of farmers' awareness about GAP. Moreover, farmers highlight the lack of incentives and insufficient support to encourage their implementation; suggesting to some extent the failure of extension service providers to address farmers' needs. This, therefore, calls for actions that ensure that farmers

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receive a fair price for their cocoa, and that good quality cocoa is rewarded; GAP implementation is effectively supported by extensionists and the farmers receive adequate information and knowledge. However, coordination between public and private (profit and not for profit) actors, and smallholders' inclusion in defining these actions remains the key for success.

Keywords: adoption, innovation, smallholders

Locally selected cacao cultivars perform better than international cultivars in both agroforests and monocultures

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ABSTRACT

Locally selected cultivars of cacao are supposedly better adapted to local environmental conditions compared with commercially selected cultivars. The objective of this study was to compare the performance of local cultivars with international cultivars and to test for interactions between cacao production systems and cultivars. In the 1990s, the Bolivian cacao farmers' cooperative El Ceibo carried out a selection programme in the Bolivian Alto Beni region, by collecting germplasm from well-performing cacao trees. From this, four cultivars were selected and tested together with four commercial cultivars and four full-sib families encompassing five different production systems: two monocultures and two agroforestry systems under organic and conventional management, and one successional agroforestry system without external inputs. The long-term field trial was established in 2009 in the Alto Beni region, Bolivia. Data were recorded for each tree every 15 days between 2015 and 2019. Across all years, the two monocultures were the most productive systems with an annual production of 1.6 kg dry cacao beans tree⁻¹ year⁻¹ under conventional- and 1.4 kg tree⁻¹ year⁻¹ under organic management. Conventional and organic agroforestry systems obtained an average production of 0.9 kg tree⁻¹ year⁻¹, while the successional agroforestry system had an average production of 0.7 kg tree⁻¹ year⁻¹. There was no significant difference between conventional and organic management. The higher productivity in the monocultures was driven by higher flowering intensity, fruit set, and aboveground biomass production. On the contrary, pod losses due to cherelle wilt and fungal diseases were not decisively different between production systems. The local cultivars showed significantly higher yield in the five production systems. The two best performing local cultivars showed an average production of 2.2 and 2.1 kg dry beans tree⁻¹ year⁻¹ while the international cultivars had an average production of 1.1 kg tree⁻¹ year⁻¹. The full-sib families performed very poorly with an average

production 0.3 kg tree⁻¹ year⁻¹. The local cultivars were more efficient in allocating assimilates towards reproduction instead of vegetative growth, i.e., trees were smaller but had higher yields. Even though they presented lower flower intensity compared with the international cultivars, they had higher fruit set, indicating that a higher percentage of flowers were successfully pollinated. Even though the interaction between production systems and genotypes tested significant, no cultivar or full-sib family was identified to be better suitable for a certain production systems, i.e., the best performing genotypes had good performance in all production systems and vice versa.

Keywords: organic farming, agroforestry, local selections

Towards a Sustainable Cocoa Production: Drivers of Adoption of Farm Management Practices among Smallholder Cocoa Farmers in West and Central Africa

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ABSTRACT

The productivity of smallholder cocoa farmers in West and Central Africa is between 300 – 700kg/ha, which is lower compared with South East Asia and South America (1600kg/ha). The major causes of low productivity and efficiency among West and Central African cocoa farmers is attributed to low soil fertility, poor agronomic practices and low adoption of new technologies. This study sought to find out factors that influence the adoption of agronomic practices (Chemical Fertilizer, Organic manure, Sanitary Pruning, Structural Pruning, Manual Weeding, Pest Management, Disease Management, Shade Management) among smallholder cocoa farmers in West and Central Africa. We used baseline data from the CocoaSoils-Sustainable intensification of cocoa production through the development and dissemination of Integrated Soil Fertility Management (ISFM) options program which was collected from 3280 cocoa farmers across Cameroon, Cote d'Ivoire, Ghana and Nigeria. The multivariate probit model was used to determine factors that influence the adoption of the farm management practices. Results show that, perception of low soil fertility has a positive and significant level of influence on adoption. Higher income from cocoa motivates farmers to re-invest and adopt. Membership to farmer-based organizations allows access to better extension and influence adoption. When there is more labour available to support labour intensive management practices, likelihood for adoption is higher. The more experienced a cocoa farmer is, the more they are knowledgeable about the timing and intensity of management practices. Being a male farmer makes you more likely to influence decision and have more access to resources than women hence more likely to adopt farm management practices. Statistically, perception of low soil fertility increases the likelihood of adoption by

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0.30 times in Cameroon, membership of farmer-based organization increases the likelihood of adoption by 0.99 times in Nigeria, availability of labour increases the likelihood of adoption by 0.30 times in Ghana and being a male farmer increases the likelihood of adoption by 0.38 times in Cote d'ivoire. The regression results suggest that, activities and policy design to enhance adoption of farm management practices must be targeted at addressing gender equity, labour supply, farmer co-operative formation, soil fertility and productivity among West and Central African cocoa farmers.

Keywords: cocoa productivity, farm management practices, adoption

Using decision supports tools to foster good agricultural practices among cocoa farmers, what is needed for success? A case study from Cameroon

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ABSTRACT

Decision Supports Tools (DSTs) are designed to assist users in selecting the best course of action when making decisions. They play several functions and have been promoted as one means to foster the transition toward more sustainable production systems. However, their actual adoption by African farmers has received little attention. We investigated the utilization of one DST (Farmer Development Plan (FDP)) in cocoa farm management in the Centre region of Cameroon. Specifically, we looked at the factors influencing farmers' use and willingness to use this tool and the conditions necessary for its effective use. FDPs are farmer-specific paper-based DSTs. Grounded on individual farmer production system characteristics, they are designed to display optimal production estimates and provide recommendations on good agricultural practices. In our study, we used a mixed research method. We conducted semi-structured interviews with 87 individuals (2 key informants, 14 extension agents and 71 cocoa farmers) purposefully selected based on their awareness of the FDP. We found that 37% of the farmers receiving the FDP use it; with respectively 35% and 43 % using it rarely and monthly. 77% of the non-users are willing to use it in the future. Besides, while all farmers use it for planning, respectively 24% and 12% use it to make projections and determine the quantity of fertilizer to apply. Less than 40% of farmers believe its use influences working relationships with peers and extensionists. The main barriers to FDP use are limited knowledge of how to use it (53%), its format (languages, character size, contents etc.) and limited resources to implement the recommendations. The effective use of

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FDP depends on better training and explanation of the tool's recommendations and usage (58%), regular follow up by providers (37%), input support (34%) and demonstration of recommendations (21%). The findings confirm the importance of visuals and content format in information sharing and suggest that the use of DSTs depends on its mastering by prospective users which can be achieved through their inclusion in the design process; something which is not accounted for in the FDP design. Secondly, recommendations should be supplemented by an enabling environment that favours farmers' access to material and immaterial resources necessary for their implementation. Paying attention to the diversity of farmers' needs in terms of decision supports and their change over time is important and as such dynamic DSTs, likely to be ICT based, would be relevant to assist cocoa farmers.

Keywords: adoption, decision support tools, inclusion

Pangenome analysis of *Theobroma cacao* reveals new genes and provides new insights into the diversity of the species.

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ABSTRACT

While two reference genomes of *T. cacao* are available (B97-61/B2 and Matinal-6), a reference sequence cannot capture the entire gene content of a species owing to structural variants. To address this issue, pangenomes have been constructed for a number of species and refers to a full genomic makeup of a species. In the recent years, high-throughput resequencing data of *T. cacao* genotypes have provided tools to discover allelic variants in the species but much of the genotype-specific information is often lost by direct mapping of short sequence reads onto a single reference genome. In this study, we report the first pangenome of *Theobroma cacao* and provide a detailed characterization of the genomic diversity of the entire species. We sequenced, assembled and annotated 195 accessions phylogenetically and geographically representative of the genetic diversity of *T. cacao*. We identified an additional 70.5Mb of genomic sequences containing 1,407 genes not included in the reference genome. Our analysis revealed that 27,687 genes are present in all individuals of the species (core genome) and 2802 are absent in some of them (dispensable genome) and may represent a gene pool for breeding for improved genotypes. For instance, detailed Gene Ontology functional analyses further indicates that genes associated with biotic resistance or quality traits are over-represented among the dispensable genome. Presence-absence variations (PAVs) analyses provided a novel genetic resource to better understand how natural diversification and domestication has shaped the genomic variability of *T. cacao*. Substantial gene loss was observed in the Criollo genetic group which strength the demographic scenario involved in the domestication of the Criollo varieties. Structure analysis based on PAVs also identified a new genetic group made up of accessions collected nearby the Caquetá River. The cacao pan-genome adds depth

and completeness to the reference genomes, and is useful for future biological discovery and breeding.

Keywords: Pangenome, Gene presence/absence variation, Functional analysis

Designing cocoa-based agroforestry systems based on farmers' perception of cultivated biodiversity

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ABSTRACT

Cocoa in Latin America is widely cultivated under agroforestry systems, together with a high number of associated crops. This cultivated biodiversity has been extensively described in the literature, not only for its conservation value but also for the many services it provides for farmers and their families. One of the main difficulties for designing innovative cocoa-based agroforestry systems is to make decisions regarding the choice of the most relevant species to be planted together with the cocoa trees. Whatever the methodology, from participative to top-down approaches, the designers will always have to consider ranking these species based on different types of criteria: their functions, the ecosystem services they provide, their interaction with other species including cocoa, the trade-offs they may generate among a panel of targeted services, their productivity or their connections to markets. In the Dominican Republic, cocoa is exclusively cultivated in highly biodiverse agroforestry systems where more than 35 cultivated species are found. In order to design innovative agroforestry models, we asked local cocoa farmers to rank these species, their products and the different uses of these products according to their own criteria. We organized 5 meetings with 51 farmers from the two main cocoa producing regions Duarte and El Seibo provinces. During these meetings, we adapted the “Peeble Distribution Method” (PDM) described by Sheil et al. (2004) and applied it in 5 communities. We found that the 36 plants species cultivated in association with cocoa in the Dominican Republic may provide up to 3 different products (leaves, wood and fruits) and that farmers may target up to 2 different services (production and light regulation) from a same species. We also found that the Dominican cocoa farmers may have up to 6 different uses for these products. These species were finally ranked according to the relative importance of their products and related uses, combined with the targeted ecosystem services. This approach combines a method relying on farmer's knowledge and priorities, with science-based evidences from other countries. It offers a solid base and a strong perspective for designing innovative agroforestry systems that create a bridge between disruptive new models and conservative approaches.

Keywords: Local knowledge, Cultivated biodiversity, Agroforestry practices

Isolates of Cocoa Swollen shoot virus from tolerant/resistant cocoa trees (*Theobroma cacao* L.) collected in cocoa orchards in Côte d'Ivoire show high genetic diversity

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ABSTRACT

Cocoa swollen shoot disease (CSSD) has caused enormous production losses in cocoa farms since its resurgence in 2003, thus affecting the sustainability of Ivorian cocoa production. Molecular characterization of CSSV isolates is a fundamental approach for an efficient genetic control of this pathogen. Indeed, the screening of cocoa trees for tolerance to swollen shoot must take into account the existing variability within the species. The objective of this study is to identify and characterize the different isolates of CSSV present in farmer accessions potentially tolerant to CSSVD and to determine the phylogenetic relationships between these isolates. The plant material used in this study is composed of 168 potentially tolerant and susceptible cocoa accessions to CSSVD. The genotypes were vegetatively multiplied in the greenhouse on rootstocks of Amelonado, a cocoa variety known for its susceptibility to diseases. Agronomic data collected during one year on the plants propagated in the greenhouse were mainly related to the presence or absence of CSSV symptoms on the graft and rootstock and the type of symptoms. The observed accessions were also subjected to molecular PCR, cloning and sequencing analyses to search, identify and characterize the CSSV isolates present in them. Thirty-two viral sequences (clones) were obtained from the PCR positive samples. Sequence sizes of identified clones ranged from 384 bp (B45-1) to 644 bp (B21-7). The sequences of isolates identified within the samples showed 70-97% similarity to

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groups D, B, and the BC subgroup, and a prevalence of group B. Also, an almost continuous distribution of APT and APS samples within the phylogenetic groups of isolates was demonstrated. Thus, the results showed on the one hand that the virus strains were not genotype dependent and on the other hand the high diversity of CSSV isolates identified within CSSV tolerant cocoa trees collected in disease-infected areas in Côte d'Ivoire. The use of genotypes having confirmed their resistance or tolerance to the disease in the current recurrent and reciprocal selection scheme in Côte d'Ivoire is proposed and discussed.

Keywords: Diversity, cocoa swollen shoot virus, tolerant genotypes

Cadmium uptake and translocation in *Theobroma cacao* L.: A ^{108}Cd stable isotope pulse chase experiment

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ABSTRACT

Recent EU limits on cadmium (Cd) in chocolate threaten the cacao industry in Central and South America. Genetics-based mitigation is likely the most suitable long-term solution to lower Cd in cacao. However, genetic screening is challenged by the unknown pathways through which Cd is taken up and loaded into the cacao beans. The cacao tree is a cauliflorous plant, i.e. flowers and fruits develop on the trunk and thicker branches. It has been suggested that Cd can be transported directly from roots to fruit (xylem-dominated), rather than indirectly via redistribution from the leaves as in most other plants (phloem-dominated). If that is correct, bean composition is affected by rootstock genetics rather than scion genetics. The aim of this study is to identify the pathways of Cd circulation in mature cacao plants, i.e. to what extent is bean Cd derived from xylem and/or phloem. A stable isotope (^{108}Cd) pulse-chase experiment was set up in the field in Ecuador. A ^{108}Cd spike dose of 20.5 mg was applied to the soil directly surrounding the trunks of two fully mature cacao trees (Nacional cultivar) in December 2020. That spike dose corresponds to an enrichment of ^{108}Cd in the topsoil (0-5 cm) from 0.89 % (natural abundance) to 17 %. The gradual accumulation of the isotope in the different plant tissues was measured to confirm or refute the hypothesis that xylem is the main pathway for bean Cd loading. Plant tissues included leaves at different stages of development (immature to mature), nibs, testa, cherelles, and flowers; and were collected monthly. The abundance of ^{108}Cd in plant tissues was determined by microwave-assisted nitric acid digestion followed by ICP-MS analysis. A marked increase in the abundance of ^{108}Cd was detected in the beans (nib and testa) and immature leaves after 90 days; and in the mature leaves after 120 days. A logistic growth model with lag phase will now be fitted to the data to allow comparison of the increase in isotopic abundance of ^{108}Cd in the different plant tissues, while also considering the different growth rates of the tissues. A faster increase of the ^{108}Cd isotopic

abundance over time in the nibs compared to the leaves (i.e. larger growth rate r in the logistic growth model) would indicate direct Cd uptake from the xylem, rather than recirculation via the phloem. Data modelling will be finalized in April 2022. Results will be communicated at the conference.

Keywords: Cadmium, Stable isotope pulse chase, Uptake and translocation

Development of an in-field detection kit for Cocoa Swollen Shoot Disease in Côte d'Ivoire and Ghana

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ABSTRACT

Cocoa swollen shoot disease (CSSD), caused by badnaviruses, is among the most prevalent diseases affecting cocoa production in Côte d'Ivoire and Ghana and has been causing serious economic losses to farmers since it was first reported in Ghana in 1936. Diseased cacao plants are often asymptomatic with the virus remaining undetected for several months post-infection during field monitoring and surveillance operations. Once symptoms develop, the trees become unproductive, decline, and die within 3-5 years. If detected early, trees can be removed from the nursery or plantation to prevent virus spread to an entire farm, making early detection fundamental to propagate virus-free high-quality cocoa planting material. An easy-to-perform field test kit for CSSD detection is in development, enabling field personnel to test cocoa trees in less than 60 mins using flush leaves as the test sample. The kit is built on SwissDeCode's DNAFoil technology, incorporating underlying research findings on CSSD badnaviral diversity with support from Mars Wrigley in partnership with ICRAF, CRIG, CNRA, and The University of Arizona. The limit of detection (LOD) threshold of the kit has been evaluated in the laboratory conditions and ascertained to have the potential to detect as little as 160 copies of the viral genome per sample. The sensitivity and specificity of the kit have been validated in laboratory and field settings. Customer surveys with suppliers, Co-op leaders, male, and female farmers have been carried out, affirming to confirm the desirability of the use of this technology to help alleviate CSSD outbreaks and limit further infections in Côte d'Ivoire and Ghana.

Keywords: CSSD, Diagnostics, Badnavirus

Pollination, a matter beyond the visible

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ABSTRACT

Pollen viability is defined as a male fertility mechanism, necessary for plant reproduction, since its mission is the fertilization of ovules for seed formation. Knowing this process is key to improve the techniques of quality and germination capacity of the grain, which are related to the biology of the flower, used to refer to germination and viability, which directly or indirectly influence the fertilization process in flowers. The development of the cocoa flower is subject to genetic, environmental, pathological and nutritional factors; alterations among these affect fertilization and production in cocoa plantations. Heterogeneity in crops can present low yields, among them can be associated with the reproductive development of the crop, fruit size, number of seeds, which could be associated with pollen viability, these being an important tool in genetic improvement programs. Sexual compatibility increases the possibility of successful fertilization and is a key aspect for increasing productivity. Sexual incompatibility considerably limits the productivity of trees, since they cannot fertilize themselves or with different material, making partial or total fertilization difficult due to inhibition by chemical and physiological causes or by lack of stimulating substances for the growth of the pollen tube. The present study was conducted by the National Federation of Cocoa Growers with resources from the National Cocoa Fund, through the research program, where the objective was to evaluate the qualitative and quantitative differentiation of viable pollen grains to calculate the germination percentage in 36 cocoa materials, through in vitro tests in culture media, each one evaluated with five flowers, with counts in 250 pollen grains taken at random per flower, 50 per anther, for a total of 1. 250 grains, the germination percentage was carried out two hours after sowing. The results indicated that the materials FCHI8, FLE3 and FLE4 obtained 90% compatibility, FGI4 82% with 1,022 germinated grains. FLE4 had 2%, FEC2 4%, FYC2, FMAC11 9%, and clones FSV80 and FLE2 showed low germination percentages. This allowed the identification of differences among the materials evaluated with respect to the capacity of pollen to germinate, complementing the evaluations of sexual compatibility.

Keywords: Viability, pollen, cocoa

Different households – different challenges? Understanding the impacts of cocoa producers' household characteristics on their ability to apply sustainable production techniques

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ABSTRACT

Over the past decade, in West African cocoa production, efforts to deliver trainings on more sustainable production techniques or on more business-oriented approaches, such as Farmers Field Schools and Farmers Business Schools, have been undertaken by various public and private actors. Yet, success of these interventions seems to be limited, especially given the continuous low incomes of cocoa farmers, high rates of deforestation and many other persisting challenges in the cocoa sector. Focussing on the variances between different household types in their perceptions regarding most pressing challenges, difficulties with the application of training contents, and needs for change, this study seeks to contribute to an improved understanding of impact factors for successful sustainability interventions. The main research questions are as follows: How do household characteristics impact cocoa farmers' livelihoods and production challenges, including the ability to adapt training contents? Where do the different household types see most need for change regarding sustainability interventions and in their local enabling environment? In the frame of accompanying research, this study investigates perceptions of cocoa farmers in two cocoa areas in Côte d'Ivoire (Divo and Yamoussoukro) targeted by the Pro-Planteurs project. Over the past two years, these cocoa farmers receive training in Farmer Business Schools and other sensitization measures, as for instance on agroforestry and income diversification. To assess household differences and related impacts, focus group discussions with targeted and non-targeted cocoa farmers will be held as well as a participatory multi-stakeholder workshop on implementation challenges and experiences conducted. Additionally, a household survey among approximately 300 targeted and non-targeted cocoa farmers will be realized in order to quantify farmers' perceptions towards implementation and other livelihood challenges. Based on socioeconomic, production, geolocation, and institutional factors, the households of respondents will be clustered by typical characteristics, in order to allow for a more nuanced analysis on how these shape the position and perceptions of cocoa farmers

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on challenges and project interventions. The overall objective of this accompanying research is to identify best fit strategies and enabling environments for the achievement of cocoa farmers' living income. By answering the presented research questions, the study seeks to provide the basis for an enhanced understanding and evaluation of strategies' success factors and opportunities for improvements.

Keywords: Cocoa, Household clusters, Côte d'Ivoire

Beyond Certification: A Typology of Instruments of Private and Community-Based Sustainability Governance in Agri-Food Value Chains

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ABSTRACT

Certification of voluntary sustainability standards have become a main strategy to enhance human well-being of producers, workers and communities involved in agri-food value chains. Accumulating evidence however points to the limited and sometimes even adverse effects of certification schemes. Partly in response to these mixed results, agri-food companies and producers have developed various alternative and complementary governance approaches to promoting sustainability in value chains. These include inclusive business, direct trade, and solidarity economy. This growing institutional diversity in approaches to sustainability governance creates an empirical and theoretical challenge of mapping the range of instruments applied in different strategies. Existing typologies in this field classify instruments at a broad level, without disentangling the precise institutional details regarding, e.g., ownership, voice, and the distribution of benefits, risks and costs. The proposed paper addresses this challenge by developing a typology of instruments of private and community-based sustainability governance. It will therefore examine and compare certification, inclusive business, solidarity economy and other strategies with regard to the specific instruments intended to enhance human well-being of producers, workers and rural communities. Empirically, this study presents the results of an extensive survey of organizations based in Peru and Switzerland that are involved in the production, processing, trading, selling, and certification of coffee and cacao and derived products. Analytically, the study is rooted in the institutional analysis and development (IAD) framework which structures the typology and embeds the discussion of sustainability governance instruments in larger policy analysis. The expected results demonstrate, first, that value chain actors combine instruments of different strategies into their portfolio which reflects their specific

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value chain position, organizational mission and motivations regarding sustainability governance. Certification, inclusive business, direct trade, and solidarity economy strategies are therefore neither pure alternatives nor purely complementary. Second, the typology disentangles the precise similarities and differences of these strategies in terms of governance instruments used and underlying theories of change. In the context of renewed demands to solve persistent sustainability issues in the agri-food sector, the presented typology of instruments associated with strategies including and beyond certification sheds light on important dynamics of partial transformation of private and community-based governance. It may also become a useful tool for further analysis of strategies and instruments of sustainability governance. Finally, it can serve as a foundation for empirical studies tracing the effects of specific instruments and instrument portfolios on various sustainability outcomes.

Keywords: Sustainability governance, Inclusive Business, Solidarity Economy

Effects of Cocoa Policies in Ghana on the Achievement of the Sustainable Development Goals (SDGs) in The Cocoa Sector

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ABSTRACT

Cocoa production is a key contributor to the economy of Ghana; at the macro level, it contributes about 25% of the country's export earnings, 7% of GDP and offers employment to 750,000 farmers. At the micro-level, these 750,000 farm households earn 70% of their revenue from cocoa. Due to its importance in Ghana, there exists several state and parastatal organizations as well policies and programs setup over the country's history to support improvements in the production of cocoa and farmer welfare. To ensure efficient targeting and deployment, the effects that these policies and programs have on sustainable development at the farmer level in current times needs to be ascertained. Leading from this there is the need to identify and map the various policies and key programs instituted in the sector. The main aim of this study was to assess how existing cocoa policies support or inhibit the implementation of the SDGs and to propose alternative policies to influence reforms. The study employed a mix of primary and secondary sources of data, with primary data from field interviews with cocoa farmers in 4 different districts, and key informant interviews with officials of key institutions. Secondary data was also obtained from journals, articles and policy documents. The results indicate that at each level of the value chain, legislation and policies have been put together to achieve several key objectives. The findings of the study also showed that cocoa sector activities and interventions contribute in one way or the other to the achievement of especially SDGs 1, 2, 3, 8, 9, 10, 12, 13 and 17 and somewhat SDG 5. The study also discovered that current policies create a more bureaucratic environment; the main incumbrance facing many actors in striving to contribute to the achievement of SDGs. Furthermore, the policies in the cocoa sector enable farmers to work directly and indirectly towards achieving the SDGs through increased income and productivity, sustainable land management, contribution to climate change mitigation and building of better social standing (livelihoods) in their respective societies. In terms of policy alternatives and advocacy needs, among others, the study identifies that smallholder farmers (mainly women and youth) need to be

assisted (through group engagement initiatives) to diversify cocoa production revenue investments in alternative livelihood options and that CSOs and other actors working in the cocoa sector, must scale up successful interventions for the benefit of a wider range of farmers herein.

Keywords: Cocoa, Policy Analysis, SDGs

Procedures for Safe Movement of Cocoa Germplasm

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ABSTRACT

A.J. Daymond¹, M.J. End², H. Canning¹, S. Poole¹, C.J. Turnbull¹, I. Ullah¹, P. Hadley¹ ¹School of Agriculture, Policy and Development, University of Reading, Whiteknights, Reading, UK ²Cocoa Research Association, <https://www.cocoaresearch.org.uk> Increased productivity on cocoa farms can be achieved through a combination of supplying improved planting materials with good agricultural practice. Targets for improved genotypes typically include high yield potential, good bean size and fat content, resilience to pests and diseases and, increasingly, resilience to environmental stresses (e.g. drought). Access to a diverse range of germplasm is key to the breeding and selection activities that ultimately provide improved planting materials to farmers. However, any movement of germplasm to meet the requirement for such diversity brings with it the concurrent risk of the spread of pests and diseases. Therefore, all movement of cocoa germplasm must adhere to safe movement protocols and quarantine procedures. The Technical Guidelines for the Safe Movement of Cacao Germplasm were originally published by the Food and Agriculture Organisation (FAO) and since 2010 have been updated under the auspices of CacaoNet and published by Bioversity International (now Alliance of Bioversity International-CIAT). The most recent update was published in 2021 and is available on-line, free of charge, in English, French and Spanish. The first part of the guidelines consists of information on the geographical spread of important pests and diseases of cocoa and general recommendations on safe movement procedures. The second part includes up-to-date information on specific pests and diseases each authored/updated by one or more experts of the respective pest/disease and specific information on quarantine measures required. The latest update also includes information on more recently characterised viruses and on pests of emerging importance (e.g. Carmentia spp. in S. America). The International Cocoa Quarantine Centre at the University of Reading

(ICQC, R) provides the main hub for international movement of cocoa germplasm and has been in operation for over 35 years. Procedures in place within the facility include visual indexing for viruses over a two-year period combined with PCR testing with a suite of primers that are periodically updated according to current information on viruses of cocoa. The list of germplasm available at ICQC, R can be found at www.icgd.reading.ac.uk/icqc/ and detailed information on specific genotypes is provided through links to the International Cocoa Germplasm Database (ICGD).

Keywords: Safe movement, Quarantine, Pests and disease

Determining the risk of cacao pod diseases and yield losses through survival analysis and microclimate

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ABSTRACT

The epidemiological study of tropical diseases in perennial crops such as cocoa is a complex task, especially for a long-cycle disease as Frosty Pod Rot (FPR), caused by the fungus *Moniliophthora roreri*. FPR is considered as the biggest risk of cacao cultivation in Latin America. In addition, there is a constant threat of the arrival of FPR in countries such as the Dominican Republic and the main producing countries in West Africa, which will lead to major crop losses resulting in disruption of the world cocoa industry. To develop efficient management options to control this disease, we need to better understand the influence of microclimate variable on the epidemiology of FPR, which in turn, will affect cacao yields. A data set of +10000 cacao pods was retrieved and fortnightly observations for 55 weeks were undertaken. Weather records for this same period were also compiled and used to explore cause-effect relationships on FPR epidemiology and pod infection dynamic. To do so, a three-step analysis was followed: 1) a descriptive analysis using a Kaplan-Meier approach was applied to analyze the potential non-climate factors on the FPR hazard. The average time until the FRP is detected was 68 days (± 4 days) and survival behavior is influenced by fruit position along the tree trunk ($p < 0.001$), 2) the preliminary modeling of the survival behavior using covariates: bag (presence or absence of plastic bags before the observation period), trunk position, clones, pod generation (week when the pods were tagged and the observation started) was done which confirmed that clone is significant in avoiding FPR hazard and 3) modeling of the survival behavior with a mixed-effects Cox model with time-dependent covariates tested the significance of pod size and microclimate variables on FPR dynamic and pod hazard avoidance. We confirmed that (1) the clones CC-137 and Pound-7 were 2.7 and 2.9 times more prone to be affected by FPR, respectively;

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compared to CATIER4 and CATIE-R6; (2) A high position of the fruit (1.5 m above ground) reduces significantly the hazard rate by 6.5% compared to a low position along the tree trunk (below 1.5 m) and (3) the FPR hazard rate is increased significantly by 6.2% when pods are not placed in a plastic bag before the observation period. Our findings reinforce the importance of the selection improved genetic planting material and weekly pod removal to better manage FRP impacts on yields.

Keywords: Frosty Pod Rot, Disease modeling, Genetic resistance

Genotypic responses of cocoa (*Theobroma cacao* L.) under field establishment stress in Nigeria

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ABSTRACT

Increased mortality rates during the first three years of cocoa establishment has become a serious threat to the sustainability and expansion of cocoa farming. This trial tested various available cocoa varieties for their survival and growth under establishment stress. Ten cocoa clonal materials (AMAZ 15, ICS 95, IMC 4, MAN 15, NA 32, N 38, PA 7, SCA 6, SPEC 54 and UF 676) selected from the International Cocoa Clonal Germplasm of Cocoa Research Institute of Nigeria, Ibadan were evaluated alongside two commercially released F3 Amazon and TC8 varieties. Their survival and growth under imposed water stress in the greenhouse were evaluated and later their seedlings were established in the ideal and marginal cocoa field environments. Data were collected on the Plant height, Stem diameters, Number of leaves, Cuticular transpiration and Leaf Relative Water Content to determine their abilities to survive and grow over two separate dry and wet seasons. There were variations in the performance of the variables measured with SCA 6 and F3 Amazon having higher growth values during dry seasons than N 38 and TC8. The key outcome of the study was that cocoa families with higher establishment success in marginal environments can be obtained from the currently available germplasm in Cocoa Research Institute of Nigeria

Keywords: Cocoa, Varieties, Establishment

A dual transcriptomic in the *Phytophthora palmivora* and *Theobroma cacao* interaction

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ABSTRACT

Colombian cacao has a growing demand due to its appreciated flavor and aroma; this crop is affected by pests and diseases that mitigate its production. Different species of the oomycete *Phytophthora* produced the Black pod disease around the world. The species *Phytophthora palmivora* Butler is present in all cacao producer countries and is the cause of 20 to 30% of the production loss and 10% of the death of cacao trees. In Colombia, pod production and the generation of seedlings in nurseries are severely affected by this disease. The purpose of this study was to better understand the defense mechanisms related to the plant response during the pathogen infection. We used a transcriptomic approach to obtain information about the genes involved in the resistance to diseases. Dual RNA-sequencing permitted the simultaneous capture of pathogen-specific transcripts, and the plant defense expressed genes during infection, providing a complete view of the interaction. Our goal was to identify the pathogen and plant genes expressed during the early stages of black pod infection (0h, 24h, 48h, and 96h) comparing the expression patterns in two cacao genotypes with contrasting responses, the susceptible genotype CCN-51, and the tolerant genotype SCA-6. Dual RNAseq libraries were prepared and sequenced with Illumina technology. Multiple differentially expressed genes were recognized. A higher proportion of genes were expressed between 48 and 96 hours post-infection. The analyses showed a presence of genes with a role in the signal transduction related to the plant defense response and pathogen effectors. These results are promissory to develop marker genes associated with early pathogen resistance that can be further useful to select disease-resistant materials.

Keywords: Transcriptomic, *Phytophthora palmivora*, Colombia

Development of the DEXiCacao multi-criteria decision support tool adapted to the Vietnamese cocoa production context

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ABSTRACT

The Vietnamese regions surrounding Ho-Chi-Minh City have a climate adapted to cocoa production. However, the lack of bibliography and references does not allow the design of specific cropping systems adapted to the agronomic and environmental conditions of the area. Used ex-ante, a Decision Support Tool (DST) allows to build and evaluate theoretical Cultural System (CS) and to improve them before their implementation in the field. DEXiFruit is a multicriteria DST initially defined for apple and peach tree crops in the context of metropolitan France. The adjustment of DEXiFruits to cocoa production and to the Vietnamese tropical context allowed the development of a DEXiCocoa capable of characterizing and evaluating the cocoa-based CS of the area. DEXiFruits is based on the DEX method, which consists of modeling a situation including several criteria by assigning them a qualitative or quantitative value (Bohanec et al., 2013). The input criterias correspond to the variables of the situation and are gathered in aggregated criterias. A weighting is associated to each of the criteria defining their respective impact on the aggregated criteria they compose. The first result is the creation of DEXiCacao. To make it operational, seven simple modifications (concerning the name of a criteria, its classes, or its weighting) and seven structural modifications (addition of criteria) were made to DEXiFruits. For example, DEXiFruit has a generic input criteria Yield with an inaccurate qualitative class scale (from Very Low to High). In DEXiCacao, this input criteria becomes Pod Yield, and its class scale becomes a precise quantitative scale (from 240t to 330t) specific to the yields of the region. Also, the aggregate criteria Leaching risk composed in DEXiFruits of the input criteria Sensitivity of the land to leaching and Land use area is completed by the addition of the criteria Pluviometry related to the annual volume of rainfall having a strong impact in the tropical context. The DEXiCacao tool remains a generic tool that is not specific to different types of cocoa production. It will require progressive improvements as well as a new sensitivity analysis. In order to be more adapted, the Cacao4Future project developed by CIRAD should focus on taking into account the

pedoclimatic conditions of cocoa growing areas, the level of knowledge of future users, include agroforestry aspects and integrate the notion of seasonal periodicity and the life cycle of cocoa cultural systems.

Keywords: Coca-based cultural system, Multi-criteria decision support tool, Evaluation ex-ante

Inventory of ant species associated with mealybugs, vectors of cocoa swollen shoot virus at the CNRA-Divo research station, Côte d'Ivoire

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ABSTRACT

Swollen shoot is a serious disease of cocoa trees in Côte d'Ivoire. It is caused by a complex of Badnaviruses and is transmitted by mealybugs. The control of these mealybugs is difficult because they are protected by earthen shelters built by ants. In return, the mealybugs provide them with honeydew. In order to effectively control CSSV mealybugs, it is important to identify the species of ants associated with cocoa mealybugs. Thus, an inventory of ant species present on cocoa trees was carried out in cocoa farms at the CNRA research station in Divo. Four (4) blocks of cocoa trees of different characteristics were chosen (cocoa trees close to forests, surrounded by coffee plantations, young cocoa trees, adult cocoa trees with the presence or not of pods, etc.). In each block, four (4) sub-blocks composed of 3 lines of 17 cocoa trees were randomly selected. The ants were collected from all the trees in these sub-blocks and then preserved in Eppendorfs tubes containing 70% alcohol. These specimens were identified with a binocular magnifying glass with a magnification of 10 to 60 X. The abundance of ants as well as the mealybug species with which they were associated were also determined after counting the colonies. As results 29 species of ants divided into five (5) subfamilies (Dolichoderinae, Dorylinae, Formicinae, Myrmicinae and Ponerinae) were identified. Among the ant species identified, *Teratomyrmex greavesi* was the most abundant (31.86%), followed by *Oecophylla longinoda* (21.32%) and *Crematogaster kelleri* (20.96%). The ant species most associated with mealybugs were *Teratomyrmex greavesi* (28.29%), *Crematogaster emeryana* (17.80%), *Crematogaster kelleri* (16.59%) and *Pheidole* spp (13.41%). In addition, six (6) species of mealybugs were also identified. Among them, *Formicococcus njalensis* (63.17%) and *Planococcus citri* (31.21%) were the most associated with ants. These results indicate that several ant species are

associated with mealybugs. It would be interesting to take them into account in the control strategies of swollen shoot mealybug vectors.

Keywords: Association, Ants, Mealybugs

Is morphological distinction of cacao trees still relevant in seedling-based hybrid populations? Study of the links between morphological descriptors, growth and yield.

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ABSTRACT

In Côte d'Ivoire, farmers and agronomists often refer to cacao “varieties”, using names such as "Trinitario", "Amelonado", "Togolese", "Ghanaian" or "Mercedes" cacao. This habit of naming cacao germplasm, based on its geographical origin, commercial name or typical cultivar classification, allows to differentiate cocoa populations with distinctive agronomical characteristics. This categorization was especially useful when selected hybrid varieties started to replace typical cacao varieties, as each kind of germplasm was associated to distinctive agronomical or quality traits. Nowadays, the many crosses and recombinations that occurred between trees with various genetic parentages, first in breeding trials, then in farmers' fields, are responsible for a widespread increase in genetic diversity in smallholder's farms. It is now usual to find highly heterogeneous phenotypes of cacao in an ordinary farmer's orchard, and high variability in vegetative and reproductive traits between trees is often reported. However, it is still common to assume the variety of single cacao trees based on specific morphological features of the plants, mostly pod shapes and colours. This instinctive categorization is used to predict the agronomical characteristics and quality of the tree, based on knowledge of the “variety” features, and may be used to adjust its technical management. Considering the high phenotypic variability found in modern orchards of Côte d'Ivoire, as well as the many recombination that may have occurred since the original parental “varieties”, this practice is questioned. In this purpose, we described 250 cacao trees from two contrasted hybrid populations of Côte d'Ivoire, using typical morphological descriptors used for phenotypic classification, and further studied their links with growth and yield variables. The results of the study showed high variability in combinations of morphological characteristics of the trees. No relation was found between morphological descriptors and behavior traits and thus, no way of predicting a specific feature of interest with the use of extensive morphological characterization of a tree. We conclude that the practice of evaluating

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the agronomical characteristics of cacao trees, based on outdated morphological descriptors and categorization in “varieties”, such as used by many farmers and technical advisors, can be misleading and should be discouraged in context of seedling-based cacao production with broad genetic origins. The terminology of “variety” and “cultivar” should be restricted to populations with specific genetic affiliations, or narrow agronomical and/or quality features.

Keywords: Hybrid germplasm, Phenotyping, Agronomical traits

The insect *Pseudotheraptus devastans* Distant (Hemiptera: Coreidae), a new threat to cocoa production in the Haut-Sassandra region of Côte d'Ivoire

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ABSTRACT

In Côte d'Ivoire, cocoa farming is a strategic product because it remains the world's leading producer. National production for the 2020-2021 season was estimated to 2,200,000 tons. Despite this performance, cocoa farming is subject to strong parasite and pest pressures. The main insect pests in Ivorian cocoa production are mirids, stem borers, stink bugs and caterpillars, which cause 30-40% of production losses and contribute to the degradation of the orchard. In addition to the above constraints, there is a proliferation of emerging insects. This is the case of the species *Pseudotheraptus devastans*, a biting-sucking insect that causes significant production losses in coconut trees. Since 2014, this insect, which is increasingly present in the cocoa orchard, has been attacking the aerial organs of the tree, particularly immature and mature pods, chupons and young shoots. The bites of this insect cause the abortion of immature pods, the deformation of the mature pods and a depreciation of the beans. In order to determine the outbreak period of this insect, a trial was set up in the Haut-Sassandra region where its damage is significant. Six cocoa farms were selected on three different axes with two cocoa farms per axis. On the basis of the presence or attacks of the insect in the plot, 12 cocoa trees were selected and covered each month during two years. A total of 72 cocoa trees were marked and treated with high dose in order to eliminate all of the insects. Five hours after treatment, the larvae and adults of *P. devastans* that fell on the tarpaulins were counted. This study revealed two periods of outbreaks of *P. devastans* in the region, from June to December with a peak in September of 325 individuals per 100 cocoa trees and from January to May with a peak of 150 individuals per 100 cocoa trees in February. The

periods of high outbreaks seem to coincide with the presence of fruits on the cocoa trees. A control strategy against this insect is being considered.

Keywords: Cocoa farming, outbreak, *Pseudotheraptus devastans*

Understanding the links between cocoa management, productivity, biodiversity and ecosystem services in West Africa

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ABSTRACT

In West Africa, cocoa production is a major cash earner for smallholder farmers. Yet they remain overwhelmingly poor. Monoculture systems have been promoted in major producing countries such as Ghana and Côte d'Ivoire, but smallholder farmers are rarely able to invest in maintaining productivity in these systems. As a result, biodiversity on cocoa farms is declining, low yields drive cocoa expansion into forests and climate change further threatens future cocoa production and the livelihoods of cocoa farmers. Cocoa agroforestry, where cocoa is associated with timber, fruit and other trees, attracts growing attention as a solution to help address these challenges. This requires a transformation of current cocoa systems towards more efficiently designed and properly managed tree and crop diversity and intensity. There is evidence that well managed cocoa agroforestry can support more sustainable cocoa yields, increased and more diversified farmer incomes, biodiversity on cocoa farms, help reduce pressure on forests by increasing farmland productivity and increase carbon stocks. Yet there is little understanding on how agroforestry system design (e.g. shade tree configurations and species) and management affects the interaction between productivity and biodiversity and how synergies and trade-offs are affected by agroecological conditions, land use history and socioeconomic factors. Such understanding would help devise more context appropriate and successful interventions that seek to achieve combined production, livelihoods, biodiversity and climate adaptation and mitigation outcomes in cocoa growing areas. This study seeks to contribute to this understanding by investigating the links between productivity, biodiversity, ecosystem services and management in cocoa systems using empirical data. Using data from a network of on-farm cocoa soil fertility treatment trials across different agroecological zones in West Africa, we combine detailed information on management practices, yields, associated (shade) tree and plant species and their uses, habitat for insects and other fauna to build this understanding and feed scientific evidence into company and government cocoa sustainability efforts looking to achieve multiple objectives in cocoa landscapes.

Keywords: Productivity, Biodiversity, Ecosystem services

Farmer's perception of development opportunities of cacao agroforestry in growing cocoa-producing districts of Uganda

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ABSTRACT

Cocoa farming in Uganda has been rapidly expanding over the past 20 years, as illustrated by exports growing from 2.130 Metric tons of commercial cocoa in 2001, up to 35.000 MT by the year 2020. While most of the national production is still supported by the small district of Bundibugyo, where the majority of the estimated 15.000-18.000 smallholders are found, the high demand in Ugandan cocoa, driving a rather high and steady farm-gate price for the product, has triggered the interest of farmers from various other districts. Farmers dedicated to coffee and staple-crop production now start planting cacao at different rates in mixed design on their farms. If the contribution of those “pioneer farmers” to national production is still minor, the cacao-planted areas are quickly extending, with a growing number of farmers experimenting cacao cultivation each year. The trend draws both on farmer's experience in other perennial crops - mainly coffee, and the Ugandan expertise on cocoa - mostly built from Bundibugyo's experience, with established cropping practices and crop associations promoted by extension services. This combination prompts some interesting opportunities for the development of novel and efficient context-related cacao cropping systems, combining cacao with other crops or trees in cacao-based agroforestry systems. In the framework of the “Market Access Upgrade Program” (MARKUP), two surveys were conducted in Uganda to explore (i) the characteristics of the current cocoa production sector, (ii) its potential for development and (iii) the agronomical innovations experimented on farms. One of the main objectives of the survey was to assess the variety of cropping practices used by cocoa farmers, in both historical cocoa production areas and more recent “pioneering” areas, looking for opportunities to support the development of the production sector based on economically and environmentally sustainable cropping systems and management practices. This poster presents some of the main results produced from this survey. First, (i) the current situation of cocoa farming in Uganda is described through a typology of cocoa-farms and farms developing a cacao

activity. Then, (ii) a summary of the actual agroforestry practices found in those various farms-types is presented. Finally, (iii) the results from a consultation of farmers on SWOT analysis, around the development of cocoa components in their farms, are commented. Those results provide some interesting insights on innovative agronomical strategies displayed by smallholders experimenting cocoa production in Uganda.

Keywords: Uganda, Agroforestry, Cropping practices

The level of competition between cocoa trees depends on the average diameter of the trees and their genetic origin

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ABSTRACT

Competition between trees in cocoa production remains a little studied area. The origin of this phenomenon, which has a strong impact on varietal selection, is often unknown. The aim of this study was to determine the factors of intraspecific competition on cocoa populations used in Côte d'Ivoire. The study was conducted in two cocoa plots monitored for 13 years for collar diameter and production. Each plot consisted of one population and three control families common to both plots. The first plot consisted of full-sib families from a cocoa population originating from the Upper Amazon (population UA). The second plot consisted of a mixed population of full-sib derived from crosses between Lower Amazonian and Trinitario (population LAT). The two plots were contiguous and planted in total randomization, with a spacing of 2.5 x 3 m, in full sun, without fertilizer. A mixed model was used to evaluate the different sources of variation in the estimated genetic value of individuals, including related to direct genetic effects, spatial effects and competition between cocoa trees. The results showed that cocoa trees in population LAT had a smaller collar diameter and cumulative production than those in population UA. The competition effects appeared later in population LAT than in population UA. In contrast, the controls had similar production and collar diameter in both plots. Overall, the level of competition increased linearly with the mean annual diameter of both populations. For the effect of competition on the diameter of neighboring trees, the increase in the level of competition depended only on the change in the mean diameter of the trees. However, the level of competition was always higher for the same diameter in population UA than in population LAT. The effect of competition on the cumulative production of neighbouring trees depended on the interaction between the evolution of the average diameter of the trees and their stand of origin.

The factors involved in competition between trees are presented and their impact discussed.

Keywords: Intraspecific interaction, Production, Collar diameter

Identification and Distribution of Novel Badnaviral Sequences Integrated in the Genome of Cacao (*Theobroma cacao*)

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ABSTRACT

As part of an ongoing study to understand the diversity of the badnavirus complex, responsible for the cacao swollen shoot disease in West Africa, evidence was found recently of virus-like sequences in asymptomatic cacao plants. The present study exploited the wealth of genomic resources in this crop, and combined bioinformatic, molecular, and genetic approaches to report for the first time the presence of integrated badnaviral sequences in most of the cacao genetic groups. These sequences, which we propose to name eTcBV for endogenous *Theobroma cacao* bacilliform viruses, varied in type with each predominating in a specific cacao genetic group. Additionally to the viral insert of type VI first identified, we recently described, with the help of Oxford Nanopore technology, a viral insert of type I and a viral insert of type III. A diagnostic multiplex PCR method was developed to identify the homozygous or hemizygous condition of the specific insert of type VI, which was inherited as a single Mendelian trait. These data suggest that these integration events occurred before or during the species diversification in Central and South America, and prior to its cultivation in other regions. Such evidence of integrated sequences is relevant to the management of cacao quarantine facilities, and may also aid novel methods to reduce the impact of such viruses in this crop.

Keywords: viral integration, cacao genome diversity, oxford Nanopore sequencing technology

Cocoa4Future: A research in partnership project contributing to the agroecological and organizational transition of cocoa production in West Africa

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ABSTRACT

In 60 years, African cocoa production grew at the expense of forested areas that have practically disappeared in Côte d'Ivoire and Ghana. Besides, both countries are also currently concerned with ageing cocoa orchards whose rehabilitation is jeopardized by the cocoa swollen shoot virus. In the coming decades, climate change will also limit the areas suitable for cocoa farming. The unsustainability of cocoa production in West Africa will ultimately increase the vulnerability of cocoa farms relying on this crop. In such a challenging context, there is an urgent need to design and disseminate sound cocoa cropping and farming models, able to guarantee a decent livelihood for family farmers while avoiding environmentally detrimental practices. This is the aim of the Cocoa4Future project, which gathers Ivorian and Ghanaian research and training institutions, several cooperatives and companies in the cocoa sector. Cocoa4Future proposes an ambitious scientific framework enabling these partners to conduct a broad range of research to i) disseminate agronomically and ecologically efficient and resilient agroforestry systems, ii) promote levers to ensure the socioeconomic sustainability of cocoa farms. Cocoa4Future combines two complementary and, so far, unseen approaches in the cocoa sector: i) an integrative approach with different levels of analyses: from the cocoa plot to the farm, from the cropping system to the cocoa production sector; ii) a multidisciplinary approach linking agronomy to technology, entomology to virology, advisory services to the cocoa value chain. It acts in areas representative of the main cocoa growing regions in Côte d'Ivoire and Ghana and mobilizes networks of cocoa plantations and farms, which are closely connected. Results from the project aims at enabling the West African cocoa sector to meeting the major challenges it currently faces while - this time - placing people and the environment at the core of tomorrow's cocoa production.

Keywords: Agroforestry, Sustainability, agroecological transition

Somatic embryogenesis in native cacao from Amazonas using Thidiazuron

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ABSTRACT

Mass propagation of superior genotypes by plant tissue culture is a necessary tool for the implementation and renewal/rehabilitation of plantations with high-quality genetic material. Several authors have explored somatic embryogenesis in cacao, with variable results in terms of embryogenic frequency and number of embryos obtained. The composition of the culture media and the genetic background of the cacao cultivars have been identified as the cause for this high variability. Therefore, plant regeneration via somatic embryogenesis is still limited to a few genotypes and to the specific culture media. The objective of the present study was to evaluate the effect of Thidiazuron (TDZ) concentration in the culture medium on the embryogenic response of floral estaminodes from 10 genotypes of fine aroma native cacao (CNFA) from the Amazonas Region, Peru. We found the genotypes evaluated have different responses to the induction process. Callogenesis averaged between 20 and 100%. However, callus development did not guarantee subsequent embryogenesis as only 5 genotypes in 8 treatments reached the formation of primary somatic embryos. The INDES-52 genotype had the best response, since up until the 70th day in culture it produced 276 embryos in medium with 20 nM TDZ/L. The embryogenic genotypes obtained frequencies between 2% and 20%, with average values per explant between 1 and 22 embryos. This study contributes to the adaptation and establishment of methodologies and protocols for the efficient regeneration of somatic embryos in superior genotypes of CNFA. It would also help the recovery and conservation of cocoa diversity in the region.

Keywords: elite genotypes, growth regulators, somatic embryos

The Effect of Pruning on Light capture, Flushing and Pod production in adult cocoa plants

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ABSTRACT

In cocoa cultivation pruning is considered an essential yield-enhancing practice. Yet, the effects of pruning on cocoa tree growth and yield, and the relation to tree size and competition are poorly understood, limiting the options to improve cocoa management. Here, we evaluate the impact of experimental pruning on tree light interception and vertical distribution, leaf flushing and number of flowers and developing and wilted pods on the stem and on the number of harvested pods both on the stem and in the canopy. The pruning treatment aimed to create an open cup-shaped crown thereby reducing competition with neighboring trees. Stem basal area and sum of neighbor basal area were used as proxies for tree size and tree competition respectively. All response variables were analyzed at tree level as a function of pruning, tree size and tree competition using generalized linear mixed effect models. After one year, pruned trees recovered from the initial losses caused by pruning in light interception but maintained a more uniform distribution of light in the canopy. Pruning directly increased flushing activity, while the effect on the other variables depended on tree size and tree competition. Pruning increased the positive effect of tree size and competition on flower and small pod number. The effect on pods was counterbalanced by an increase of wilting in pruned trees under high competition, resulting in similar numbers of large and harvested pods on the stem in pruned and unpruned trees. For pods in the canopy, pruning did enhance the positive effect of tree size and strongly reduced the negative effect of competition on pod number. As canopy pods made up the majority of the total, similar pruning effects were found for the total number of harvested pods. The predicted net effect of pruning on the number of harvested pods varied greatly with tree size and competition, ranging from a negative effect for small trees under low competition, to a strong large effect for large trees under high competition. The large variability in responses to pruning stresses the importance of individual-level analysis to quantify

pruning effects and calls for more attention to individual tree characteristics in training and practice of cocoa pruning. Additionally, the mitigation of competition effects by pruning suggests that adequate pruning may help to realize cocoa stands with a higher planting density.

Keywords: Plant competition, Tree level analysis, Mixed effect model

Developing a functional-structural plant model for cocoa trees to explore pruning-shade interactions

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ABSTRACT

Currently, realized cocoa yields are typically about 20% of potential yield due several factors, one of which are sub-optimal pruning practices. Pruning impacts tree functioning and tree architecture through changes in resource acquisition, allocation and branching patterns, and depends as well on level of shading applied. Detailed information on cocoa branching patterns in response to pruning are missing for cocoa, but are required in order to improve cocoa pruning effectiveness. Experimental trials are constrained by the longevity and size of cocoa trees. “In silico” pruning experiments within functional structural plant (FSP) models offer a powerful and flexible way to evaluate pruning effects on light capture, plant growth and productivity. FSP models dynamically simulate the development of plant 3D architecture as a result of underlying physiological processes, and the responses to changes in light capture caused by interventions such as pruning. We developed an FSP model of cocoa to assess the effects of pruning practices on cocoa architecture and canopy photosynthesis at young stage at different shade levels. The model simulates growth and development of cocoa architecture in response to shading and pruning. Architectural and developmental characteristics specific to cocoa plants were included, such as orthotropic and plagiotropic branches, jorqueting and leaf flushing. Light interception is calculated at leaf level, driving leaf photosynthesis. Growth is an emergent property of source-sink driven allocation of assimilates. Branching pattern is simulated following probability distributions of axillary bud break as a function of bud position in the branch. These probabilities are modified by the removal of branches, or portions of branches. The probability distributions of bud break in presence or absence of a pruning intervention were quantified in a pruning experiment on two-year old plants. In the experiment we applied five pruning treatments, including a control. Treatments consisted in the removal of branch tips, the removal 66% of a branch and the removal of one or two entire branches. Before cut and after the first flushing episode, total number of buds,

number and position of secondary branches were counted. The cocoa FSP model serves as a tool to address relevant issues in cocoa production, such as the development of more efficient pruning practice, tailored to different shading and density regimes. In addition it can be used for screening promising trial options and for ideotyping plant structure for breeding purposes. The 3D visual output makes the model a communication tool for academic and non-academic audience.

Keywords: Branching pattern, Tree architecture, Light interception

Performance of agricultural innovation support services : the case of cocoa agroforestry in savannah in Cameroon

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ABSTRACT

In Cameroon, the afforestation of degraded savannah through cocoa agroforestry is a grassroots innovation that is spreading on semi-arid lands. This study aims to understand the support services which drive the process of this innovation according to farmers and build performance indicators for those services. The data used were collected through individual interviews, focus groups, and workshops with farmers and other stakeholders of the process. Academic and non-academic literature was also used. The analytical process was mostly inductive. The Impact of Research in the South (Impress) ex-post approach serves to build the historical timeline. Then a thematic analysis serves to categorize the performance indicators. Starting in 1930, the afforestation of degraded savannah through the cocoa agroforestry process has three main phases. The first phase, from 1930 to 2003 is characterized by pioneers' experimentations and sensibilization of their siblings and the innovators benefited from generic public support services for the cocoa sector. During the second phase, from 2003 to 2014 the creation of local financing services and the intervention of international researchers leads to the identification of agroforestry associations with higher yields and accelerates the adoption of the innovation. During the third phase, despite the withdrawal of research, public and private support services, the innovation continues to spread through the migration of farmers. The main services identified by cocoa growers are first training to develop skills, then material and financial support to start and expand their activity. Generally, farmers evaluate performance with posture, attitudes, and competencies of service suppliers while the latter's criteria are quantitative. Generally, although farmers consider training as essential to build skills they aim to get autonomous from support services in their activity. These results call for the dedication of specific services to this innovation to reap the benefits of reforestation in semi-arid areas in Cameroon.

Keywords: Support services, Innovation, Agroforestry

Identification of new host plants of swollen shoot virus other than cocoa in Côte d'Ivoire

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ABSTRACT

Swollen shoot disease is one of the most serious threats to cocoa production in Côte d'Ivoire. One of the actions undertaken to fight this disease is the identification of alternative hosts of CSSV within food crops. In order to identify new host plants for the virus, a trial was set up at the experimental greenhouse in Bouaflé, a swollen shoot endemic area. The plant material consisted of 13 food crops [*Dioscorea alata* (variety betê betê and variety florido), *Arachis hypogaea*, *Phaseolus vulgaris*, *Vigna subterranea*, *Solanum melongena*, *Glycine max*, *Manihot esculenta*, *Xanthosoma mafaffa*, *Capsicum frutescens*, *Carica papaya*, *Abelmoschus esculentus* and *Corchorus olitorius*] and a positive control (cocoa). The methodology used consisted, on the one hand, in inoculating the plant material under controlled greenhouse conditions with the CSSTBV virus species through viruliferous mealybugs and, on the other hand, to observe the symptoms and to carry out a molecular diagnosis of the leaf samples with the ORF3A primer, two (2) months after the inoculations. Food crops found to be reservoirs of CSSV were used as sources of inoculum from which new mealybugs were trapped to acquire the virus. The viruliferous mealybugs were used to infect healthy cocoa trees. Two months later, leaf samples from these cocoa trees were collected for molecular diagnosis. Disease symptoms were chlorosis and leaf distortion in the different food crops inoculated with the CSSTBV virus strain. In contrast, symptoms of red stripes along the secondary veins were observed on cocoa leaves. The results of the molecular diagnosis revealed the reservoir status of eight (08) new food crops [*Dioscorea alata* (variety betê betê and variety florido), *Arachis hypogaea*, *Phaseolus vulgaris*, *Vigna subterranea*, *Solanum melongena*, *Glycine max* and *Abelmoschus esculentus*] and confirmed the reservoir status of five (05) (*Xanthosoma mafaffa*, *Capsicum frutescens*, *Carica papaya*, *Corchorus olitorius*

and *Manihot esculenta*). Moreover, after the retro inoculation, molecular diagnosis revealed the host status of *Xanthosoma mafaffa*, *Dioscorea alata* (variety *bêê bêê* and variety *florido*) and *Abelmoschus esculentus*. Sequencing of the amplified PCR products is envisaged in order to enrich the catalog of CSSV reservoir and host plants, which constitutes a decision support tool for the control of swollen shoot disease.

Keywords: food crops, reservoir /host, Swollen shoot

An investigation of species associated with stem cancer of cacao in Sulawesi under climate change

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ABSTRACT

Phytophthora palmivora Butl. causes various diseases in cocoa, including *Phytophthora* stem canker (or cacao stem canker) and *Phytophthora* pod rot. However, in Sulawesi, another pathogen has been reported to infect cocoa causing stem canker and dieback. This study aimed to investigate the fungal/oomycetes species associated with stem canker lesions in Luwu Timor, Sulawesi, Indonesia and thereby identify the main putative pathogen causing stem canker of cocoa in the region. The research was carried out in the field and in the Laboratory of Plant Pests and Diseases of the Muslim University of Indonesia. The study consisted of several stages, namely sampling, preparation of various types of comparison media, isolation from tissue in stem canker lesions, culture and microscopic observation. The test plants consisted of 11 clones (9-10 year-old trees), including 5 clones showing symptoms of stem canker, namely M01, M06, Sul1, Sul2 and clone 45 (MCC02). Infected tissue excised from stem canker lesions was transferred to media plates (V8, PDA). Subcultures resulted in colonies producing hyphae and sporangia identified as *Phytophthora* spp., consistent with previous reports that *P. palmivora* causes stem canker in cocoa. Furthermore, inoculation of healthy pods of four clones (both attached and detached) with infected canker tissue resulted in lesions demonstrating *Phytophthora* pod rot symptoms. Lesion diameter determined daily for 8 days, indicated that the largest lesions developed in M06 (101,8 cm) and the smallest in Sul1 (5,8 cm), demonstrating variation in clone resistance to *P. palmivora*. Re-isolation from the pod lesions caused by inoculations resulted in *Phytophthora* colonies and sporangia. These results are consistent with previous reports, namely that *P. palmivora* is the principle cause of cacao stem canker. Keywords: cocoa, symptom, stem cancer, clone, culture,

Keywords: cocoa cacao, symptom, stem cancer

Screening of markers for drought tolerance in cocoa hybrids

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ABSTRACT

The genetic variability of agromorphological, physiological and biochemical characters in relation to drought tolerance were studied in cocoa hybrids in greenhouse condition. The hybrids were subjected to water deficit regime in the greenhouse. The first treatment, with daily watering, the water content of the pot was maintained at its field capacity, the second treatment kept at moderate stress, soil moisture corresponding to 50% of the field capacity and the third treatment was under severe stress, with an addition of water only to 20% of the field capacity. Agromorphological traits (vegetative vigor, leaf emergence, leaf area, biomass), physiological parameters (mortality, plant water potential, epicuticular wax, chlorophyll content, chlorophyll fluorescence, stomatal resistance, photosynthetic activity, and transpiration rate) and biochemical parameters (proline content, free amino acids, total soluble sugars, reducing sugars, starch, proteins, phenol, enzyme activities (PPO, POX, CAT, SOD and lipid peroxidation) were assessed. A significant effect was observed for the water treatment x cacao interaction ($p=0.024$) indicating the influence of treatments on morphological traits. Significant differences were also observed among varieties for vegetative vigor ($p=0.0001$), biomass ($p=0.0001$), total leaf area ($p=0.0001$), leaf emergence ($p=0.0001$) and mortality ($p=0.0016$) as well as for physiological parameters. The multivariate principal component analysis of morphophysiological traits observed under induced water deficit stress and the hierarchical ascending classification made it possible to distinguish two large groups according to their sensitivity. The first group of hybrids (I-14 x NC29/66, I-21 x NC42/94, I-21 x NC29/66, II-67 x NC42/94), characterized by their vegetative vigor correlated to its biomass with a strong stomatal resistance and a good photosynthetic activity. The second group (I-56 x NC23/43, I-29 x NC23/43, I-14 x NC42/94, I-29 x NC42/94, II-67 x NC29/66, I-21 x NC23/43) characterized by their mortality rate, strong transpiration correlated to strong stomatal conductance. The second part of this work, based on the results of the first, consisted of a comparative study of genetic markers associated with tolerance to water deficit stress. The identification of biochemical markers related to the growth of hybrid cocoa varieties under induced water deficit stress shows that the hybrid

varieties constituting group 1, which are said to be tolerant to water stress in a controlled environment, have a higher cytoplasmic accumulation of proline, free amino acids, proteins and a higher activity of peroxidases (POD) and superoxide dismutase (SOD) than those of group 2. these physiological and morphological markers are breeding pathways for drought tolerance in cacao.

Keywords: Cacao, drought, morpho-physiological

On the use of Mathematical Modeling to improve control strategies in the cocoa and black pod disease pathosystem

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ABSTRACT

Black pod rot of cocoa, due to *Phytophthora* spp. is a major concern in cocoa production and much attention has been dedicated to it. However, there are still many questions regarding the factors that govern disease dynamics. Here we explore the use of mathematical modelling to understand the spatial dynamics of black pod disease caused by *P. megakarya* and notably the impact of shade on disease dynamics. The results were exploited as a base for an in-vitro investigation on the impact of light on growth and sporulation of *P. megakarya*. A mechanistic–statistical approach was used to estimate the spatio-temporal model parameters from real observations of a specific cocoa plot. Shading data collected in the cocoa plot led to refined numerical simulations of disease dispersion and to identify a greater number of infected pods located in areas of the plot with higher shading values. Following the investigation on the effect of shading on system dynamics, the effects of different light wavelengths on *P. megakarya* biology (growth and sporulation) was assessed. Experiments carried out revealed that all the study strains grew relatively better in the dark compared to exposure to light, and it was noted that light in general was a stimulating factor for the sporulation of *P. megakarya*. The increase in the growth rate of *P. megakarya* in the dark may attest that shaded systems are favorable to the development of *P. megakarya*. Hence, recommendations in terms of promoting cocoa farming in systems with low shading intensity may be evident if these results are confirmed.

Keywords: black pod disease, epidemiological model, shade

Partnership for Delivery: A sustainable pathway to generate and transfer knowledge from research to cocoa farmers

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ABSTRACT

The CocoaSoils program is made up of two strongly linked components: Research for development (R4D), and Partnership for Delivery (P4D). The novelty this is to link research to existing policies in Cameroon, Cote d'Ivoire, Ghana, and Nigeria. The goal is to facilitate research in cocoa intensification and transfer generated knowledge in real time to cocoa farmers. To do this P4D committees were created in the four countries to serve as fora for coordination and validation of research recommendations. They also served as platforms for transmitting farmers' perceptions and aspirations. Membership of these Committees consist of: (i) Ministries in charge of Agriculture, (ii) National cocoa institutions, (iii) National research institutes (iv) Private cocoa companies, (v) Civil societies and (vi) Farmers. The first generation of project training manuals for the dissemination of existing knowledge on Good Agricultural Practices and Integrated Soil Fertility Management have been presented to policy makers and farmers through the dissemination networks of private partners, in each country. The project has experimented with the digital dissemination of agricultural knowledge to cocoa farmers. The digital approach transmits a greater mass of information on cocoa production at unparalleled speed. Nevertheless, it is still much dependent on the physical contact with extension agents. In almost two years, partners' dissemination networks led by extension agents and digital dissemination platforms have trained approximately 60,000 farmers in the four countries. The main lessons learned are: • The construction of a public-private-civil society partnership is an essential asset for national cocoa research institutions, and more than ten private partners in the four countries as it enables sustainable knowledge dissemination through complementary systems and approaches. • Synergy with other programs and initiatives on cocoa sustainable production brings more consistency and visibility. • The existence of the two components (R4D and P4D) implicitly leads to efficiency and pragmatism in the formulation of recommendations. The biggest challenge remains the permanent

adaptation of the strategy by private partners and its integration into the policies and laws of each specific' country context.

Keywords: partnerships, good agricultural practices, scaling

Promoting gender equality and social sustainability in cocoa- producing communities: an analysis of best-practices in Cote d'Ivoire

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ABSTRACT

To date, promoting sustainability in the cocoa industry has focused on men and children. According to available data, cocoa production in West Africa today is considered a "men's business. Women who work in cocoa production often do so unpaid, as family members or as casual labor, and their contribution is not fully recognized. The African Development Bank reports that on cocoa plantations, women represent about 68% of the active workforce (as owners or workers) but earn only 21% of the income generated. Although little known, women's work in the cocoa industry is an important part of the cocoa economy, providing nearly half of the jobs. They are therefore essential to the sustainable development of the cocoa economy and the people who live off it. It has even been observed that on the market, when women are sufficiently supported, they produce better quality crops than men and thanks to this, they are able to control their income or that of their family and reinvest it in their family and their communities. Despite the central role women play in cocoa production, their needs as cocoa farmers are not being met. Less than 5% of agricultural extension services reach women and only 15% of staff are women; they receive only 10% of loans to smallholders and are 30-40% less likely than men to have access to essential agricultural inputs. Understanding and recognizing the contribution of women in this process is the first step towards improving sustainable cocoa production. This study aims to identify emerging good practices in so-called priority areas to determine the role of women cocoa farmers, thereby promoting gender equality in the sector; but also, to provide market incentives to increase women's income or improve access to productive resources. In conclusion, facilitating equal access to agriculture, creating conditions for women to contribute (and not just receive information), and participating in the promotion of gender equality and women's empowerment, will contribute to the advancement of good cocoa sustainability practices. This will promote sustainable and entrepreneurial agriculture and contribute to improved productivity and community development.

Keywords: Women, Sustainable cocoa, Concept of sustainability, GENDER

Transportation inefficiencies in the cocoa value chain in Ivory Coast: Is sustainability possible?

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ABSTRACT

We examine transport inefficiencies and the sustainability of cocoa value chains (CVCs) in Ivory Coast. Based on the findings, actionable recommendations are suggested to improve the sustainability of cocoa transport from farm gate to export harbour. In terms of method, we begin with a literature review of transport inefficiencies in Ivorian CVCs from farm gate to export harbour. This is followed by primary research conducted on-site in Ivory Coast. Qualitative and quantitative data were gathered, based on a 57-question questionnaire, and in-depth interviews with key stakeholders. Respondents include two main cooperatives - Société Coopérative des Planteurs d'Iratéké (SOCOOPI) and Société Coopérative Agricole Badéya Soubré (SOCOOABAS) – and three different villages - Djihimbo, Iratéké and Konédougou. Special function actors from the Soubré, San-Pédro and Grand-Béréby corridors also participated. CVCs function within a combined micro, meso and macro business enabling environment. The micro environment holds the CVC that is the focus of this study. The steps of the CVCs flow horizontally and sequentially. Planters, cooperative management, exporters, ports, chocolatiers, and supermarkets are the major actors in the different steps of the CVCs with each actor also having its own value chain. The lines that these actors engage in, flow vertically and are called primary and support activities. These lines serve the purpose of achieving competitive advantage. The micro environment is surrounded by the meso environment including medium-sized actors and the macro environment, in turn, surrounds the meso environment including larger entities. Trucks and motorcycles are the dominant forms of transport from farm gate to export harbour. Significantly, there is no railway system that could efficiently be used in the CVC. Transport inefficiencies include insufficient village collection points, blocked roads during rain due to lack of profiling and tar, excessive reparations costs due to potholes and low-quality roads, excessive pollution caused by trucks, “pisteurs” lowering the value chains’ credibility, and a lack of bank branches at junctions where trading takes place. Sustainable transport is measured using the United Nation’s criteria of which the results show that transport is mostly unsafe, unaffordable, inaccessible,

inefficient, not resilient and that the emission of carbon and other gases are not sufficiently minimised. In conclusion, cocoa transport in Ivory Coast is unsustainable in its current form. However, with the correct implementation of policy measures, financing and technological innovation, there is significant potential to improve the status quo.

Keywords: Transport Sustainability, Cocoa Value Chain, Ivory Coast

Influence of mycorrhizal fungi, cocoa pod husk biochar and pig manure on the growth and health status of cocoa plants (*Theobroma cacao* L.) during nursery stage

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ABSTRACT

Ensuring good growth and health of young cocoa trees in the nursery is a major issue for the successful rehabilitation and development of cocoa orchards. For that, our work aimed at the research of alternatives, for the improvement of the quality of the seedlings of cocoa trees in nursery by studying the influence of Arbuscular mycorrhizal fungi (AMF) in combination with the cocoa pod husk biochar and the pig manure on the growth attributes and health status of cocoa seedlings. The experiment was carried out in a farming environment in Nkolandom in southern Cameroon. A 2 x 3 factorial design in a completely randomized block design was used. Treatments resulted from the combination of two factors, the presence of mycorrhizal fungi in the substrate (with mycorrhizae and without mycorrhizae) and the type of organic fertilizer added to the substrate (simple substrate, substrate + 9 g of biochar kg⁻¹ of soil, substrate + 30 g of pig manure kg⁻¹ of soil). The growth of cocoa seedlings was significantly ($p < 0.05$) improved by biochar and the mycorrhizae-biochar combination; which showed the best results in terms of height, stem circumference, leaf area, fresh and dry biomass compared to the control and pig manure after twelve weeks in the nursery. Evaluation of health status revealed that mycorrhizal and non-mycorrhizal plants, in combination with biochar, were the least susceptible to the observed symptoms (leaf necrosis and stem lesions) in contrast to pig manure treated plants and the control. The results imply that mycorrhizal fungi and cocoa pod husk biochar can positively improve the growth and health status of cocoa trees in the nursery, which is an important basis for promoting the adaptability of transplanted cocoa trees in their future agroecosystem.

Keywords: *Theobroma cacao* L., Mycorrhizal fungi, Nursery

Analyzing influencing factors and incentives for producers' compliance with certification environmental requirements in cacao sector in Côte d'Ivoire

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ABSTRACT

Purpose: Certification faces uncertainty regarding farmers' compliance with the requirements of certification standards. The following paper addresses this issue by exploring the influencing factors and incentives for farmers' compliance with five selected certification requirements. **Methods:** Data were collected through a survey of 193 cocoa producers who have been certified for at least 3 years in Côte d'Ivoire. We apply a count data modelling framework to account for the number of certification requirements adopted by certified cocoa producers. This is augmented by a qualitative analysis of the main thematic reasons for adoption. **Results:** Results indicate that trends in the adoption of certification requirements are low and that partial adoption is commonplace. The qualitative analysis shows that a diversity of reasons motivates producers to adopt or not practices promoted by the studied certifications. These include farming conditions and economic dimensions. An econometric analysis showed that the household level variables that influence the adoption intensity include the education level, the certified farm size, and the quantity of cocoa harvested. Several advisory services and plot level variables related to certification requirements have a significant effect on the number of certification requirement adopted. **Conclusion:** The results suggest that to improve compliance standards, advisory services related to certifications should adopt a more holistic participatory approach to take into account local conditions and producers' constraints.

Keywords: Certification standards, Innovation adoption, Cocoa

Recommendations for the conservation of cacao intraspecific diversity based on a typology of production systems in Cusco, Junín and Piura, Peru

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ABSTRACT

Peru is a centre of origin for cacao. The diversity encountered in this country is relevant for the conservation of cacao and the maintenance of its cultivation in the tropics. This diversity holds the potential to improve the productivity and quality of cacao production, as well as its ability to resist biotic and abiotic stress factors, despite the challenges posed by climate change, deforestation, and land use changes. Peruvian cacao production is often divided into two cultivation systems. We distinguish 1) old plantations of large and tall cacao trees of native and/or improved varieties growing at low density under a diversified shade system, and 2) young plantations of mostly homogenous improved cacao varieties planted at high density in monoculture or under low shade. However, these two broad categories do not exactly represent the variety of production systems found in the fields, but rather the two extremes of a gradient present in the 16 departments where cacao grows in Peru. A typology of the production systems used in Peru could allow us to develop specific recommendations for the conservation of cacao intraspecific diversity, based on the characteristics of the system. We carried out investigations in three departments renowned for their native diversity of cacao, Cusco, Junín and Piura. We characterized the production systems of 442 cacao farms according to their management practices and cacao diversity. Meanwhile, a preliminary version of the typology including six production systems was developed from meetings with cacao experts and observations made during fieldwork. This preliminary version was sent to 30 experts for comments and observations. We then compared the data of 442 cacao farms with our preliminary typology to develop a final version which we validated with a last group of experts. Establishing a typology of production systems is a realistic, inexpensive, and easily scalable way to deliver recommendations on the management of intraspecific cacao diversity on the farm. It makes it possible to develop recommendations based on the characteristics of the production systems, the management in place, the cacao intraspecific diversity present and desired, while

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acknowledging the diversity among cacao growers and their respective objectives regarding their production.

Keywords: conservation of cacao intraspecific diversity, typology, cacao production systems

Welfare Dynamics: Sustainable Rise or Fall among Cocoa Farming Households in Southwest, Nigeria

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ABSTRACT

Little research currently exists on the welfare dynamics and its determinants on the cocoa farming households (CFHs). This paper attempts to fill this gap by proposing welfare category lines that can be estimated straightforward with panel household survey data collected in the two seasons, heavy and light cocoa harvesting seasons from southwest, Nigeria. Data on socio-economics, farm characteristics and household expenditures were subjected to descriptive analysis and Ordered Probit regression models. Empirical results reveal that a higher proportion of the households (89.1%) are male headed. The mean age and household size of respondents were 54 ± 12.64 years and 7 ± 3 persons. The mean per capita household expenditure in Heavy and Light seasons were N38, 818.04 \pm 14,227.79 and N29, 194.68 \pm 17,792.80 respectively. A unit increase in literacy, land tenure, price stability, good harvest and extension are associated with likelihood of rise in welfare of CFHs by 0.05, 0.09, 0.08, 0.14 and 0.05; while increased poor access to credit, poor collateral and unfavourable government policies were related with no change in welfare by 0.04, 0.06 and 0.03; gender of household head, poor access to credit, poor collateral and unfavourable government policies are associated with increased fall in welfare of CFHs by 0.02, 0.03, 0.04 and 0.02 respectively in southwest, Nigeria. The study has revealed that variables positive for rise in welfare are improved upon for cocoa farming households in the zone, then the production of cocoa and income of farmers can be sustainably improved. Keywords: welfare dynamics, cocoa, sustainability, ordered probit regression, Nigeria

Keywords: welfare dynamics, sustainability, cocoa

Adaptation to climate variability: farmers' practices and perspectives in cocoa farming in Côte d'Ivoire

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ABSTRACT

Côte d'Ivoire supplies over 40% of cocoa production worldwide. Climatic variability threatens to significantly reduce the area suitable for cocoa cultivation. Cocoa farmers have already leveraged their intimate knowledge of the local climate to adapt their production systems to climate change. However, their practices have not been well documented or evaluated. In response, this study aims to assess climate-smart cocoa practices for scalability recommendations. The study was conducted across three zones of predicted climate impacts on cocoa production: low impact, high impact, and a transformational impact. Climate-smart practices were inventoried, analyzed, and synthesized in different production contexts and by household categories in terms of well-being and asset endowment. The list of practices were then validated in a national stakeholder workshop in terms of agricultural productivity, food security, income generation, climate resilience and ecosystem services, economic viability and sustainability, and adoption probability. The resulting recommended practices are presented according to climate hazard. These recommendations represent local experiential knowledge consensus, and offer valuable options for sustainable cocoa management in a changing climate. Our results show that Ivorian cocoa farmers broadly believe climate change will continue to worsen, and have already widely adopted several of the recommended practices, particularly agroforestry. However, nearly none of the farmers across all three impact zones anticipate that cocoa production will become unviable. Climate information services offer significant potential for addressing this information gap and further supporting farmers' decision making in the face of climate change.

Keywords: climate-smart practices, resilience, diversification

Geospatial distribution of heavy metals in Cocoa Plantations across Nigeria

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ABSTRACT

GEOSPATIAL DISTRIBUTION OF HEAVY METALS IN COCOA PLANTATIONS ACROSS NIGERIA 1* Aikpokpodion, P.E., 1 Ogunlade M.O. and 2 Aikpokpodion P.O. 1 Cocoa Research Institute of Nigeria, Idi-Ayunre, Ibadan, Nigeria 2 University of Calabar, Calabar, Nigeria *Corresponding author email: paulaikpokpodion2@yahoo.com Abstract Concentration of heavy metal residues in cocoa beans is one of the factors that determine the quality of cocoa at the international market. The amount of heavy metals in cocoa soils can influence the transport and accumulation of trace metals in cocoa beans. Comprehensive evaluation of heavy metals in cocoa plantations across all the cocoa producing States in Nigeria is limiting. Consequently, it has been difficult to produce maps showing the distribution of heavy metals in Nigeria. Evaluation of metals of importance (Cu, Pb and Cd) was done in soil samples collected from one thousand and fifty (1,050) cocoa farms across all the States (Provinces) that produce 99.39% of the nation's cocoa output. The soil samples were analyzed in the laboratory according to standard procedures. Data obtained were geo-statistically analyzed for creation of heavy metal maps. Kriging was used for spatial interpolation. Result showed that a total of 104,286 hectares of cocoa plantations (16.45% of total cocoa hectareage in Nigeria) had Cu concentration (11.00-58.00 mg/kg) above the permissible limit (10mg/kg) set by World Health Organization. Only four cocoa producing States (Ondo, Cross River, Edo and Osun) had Cu concentration in soil higher than 10mg/kg while other States were within the set limit. Statistics shows linear correlation between cocoa production output and Cu accumulation in soil occasioned by the long term use of copper-based fungicide in the control of black pod disease of cocoa. A total number of 18,329 hectares of cocoa farms (2.9% of total cocoa hectareage in Nigeria) had traceable Pb (0.46-5.6 mg/kg) while 11,689 hectares of cocoa plantations (1.84% of total cocoa hectareage in Nigeria) had traceable amount of Cd (0.21-0.32mg/kg). Traceable Pb was found in some cocoa farms in Osun, Ondo and Cross River States while traceable Cd was found only in some cocoa farms in Oyo State. The amount of

Pb and Cd obtained in all the examined cocoa plantations in Nigeria are within the permissible limits (Pb: 80mg/kg, Cd: 5.33mg/kg). The maps produced from the study show at a glance the distribution of Cu, Pb and Cd across Nigerian cocoa soils as well as indicate area of interventions.

Keywords: Cocoa, Heavy metals, Geospatial

Effects of Nitrogen, Phosphorus and Potassium Fertilizers on Mature Cocoa in Indonesia

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ABSTRACT

Cocoa is one of Indonesia's primary cash crops, supporting an estimated 900,000 households across the country. Smallholder farmers produce most of the crop, but their yields are just about 50% of the potential yield. Fertilizer is known to increase cocoa yield. However, yield response to fertilizer applications varies depending on environmental conditions and management practices. There is limited information on the fertilizer requirement of mature cocoa genotypes commonly used in Indonesia. Therefore, a fertilizer experiment involving nitrogen, phosphorus, and potassium was performed on hybrid cocoa trees in Banyuwangi, East Java, Indonesia. Cocoa trees were planted on brown sandy podsolic soil. Coconut trees were used as a permanent shade with a density of 37 trees per hectare. The trial involved three N levels: 0, 93, and 186 kg/ha/year; three P levels: 0, 80, and 160 kg/ha/year and two levels of K: 0 and 61 kg/ha/year. Treatments were arranged in randomized factorial block design replicated three times. Fertilizer treatments started in 1993, and fertilizer applications were repeated each year. The number of pods produced was counted and used to estimate dry bean yield per hectare. Results over the last nine years of fertilizer application are reported. From 14 to 22 years after planting, a significant effect of N was observed on cocoa yield. N fertilizer applied at 93 and 186 kg/ha/year significantly increased dry bean yield by 16.8 % and 17.1% respectively, relative to control. However, there was no significant difference between the low and high N treatments in their effect on yield. Although P and K fertilizer had been applied for 19 consecutive years, there was no response to these fertilizers over nine years of data, suggesting high P and K availability in the soil. The data suggest that hybrid cocoa planted on brown sandy podsolic soil in Indonesia only required nitrogen to

sustain high productivity. In these soils in Indonesia, P and K fertilizer application are not profitable as it increases production costs in absence of co cocoa yield increases.

Keywords: cocoa, fertilizer, yield

Conservation and use of cacao genetic resources by gene banks and nurseries in six Latin American countries

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ABSTRACT

Cacao (*Theobroma cacao* L.) is among the most important tree cash crops in the tropics. The existing cacao genetic diversity represents a key resource to ensure long-term sustainability of cacao cultivation and diversification but it remains vastly underused. Countries in Latin America offer a great potential for exploiting cacao genetic resources because they integrate both high levels of genetic diversity and quality traits as they occur within the centre of origin (South America) and centres of domestication (Central and South America) of cacao. The objective of this study was to describe the current state of conservation and use of cacao genetic materials in six countries in South (Peru and Ecuador) and Central America (Nicaragua, Honduras, El Salvador, Guatemala), with the aim of identifying the strengths and weakness of each country as well as the most appropriate needs and opportunities for investment. For each country, we reviewed the current regulations for cacao genetic resources, we performed a review of current research on promising varieties, and we carried out a survey covering 176 gene banks and nurseries in the six countries. We found that all countries currently have poor to basic systems of certification, verification and especially traceability. Gene banks conserve many local materials in Peru and Ecuador while they mainly conserve international clones in Central American countries. In all countries except Honduras, more than half of the gene banks do not have any characterization of the conserved materials. Although nurseries in all countries have fair productive capacities, varieties sold are unevenly characterized in Peru, Ecuador and Guatemala, and less than half of the nurseries provide technical assistance to farmers in Ecuador and El Salvador. Based on our results, the main areas for investments in the six countries are: 1) development of a strong system of

certification, verification and especially traceability of cacao genetic material, 2) better characterization of the conserved materials within the gene banks and inclusion of the best materials within breeding programs, 3) better characterization of varieties sold in the nurseries and improvement of infrastructure, maintenance and technical assistance offered to farmers by cacao nurseries, 4) promotion of research on native and fine flavour cacaos in Ecuador and Peru and reactivation of breeding programs using local materials in Central America. A better conservation and use of cacao genetic resources in South and Central America would benefit not only these countries but the whole cacao sector.

Keywords: cacao propagation material, certification and traceability, clonal gardens

Child labor and measurement errors : social desirability bias among Ivorian cocoa farmers

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ABSTRACT

This paper proposes new estimates of the prevalence of child labor in Côte d'Ivoire's cocoa farms that are certified free of child labor. We rely on the list experiment, an indirect survey method, to avoid issues of social desirability bias associated with measures of a sensitive issue, that we implement on a sample of 4 458 Ivorian cocoa farmers. We found that 24% of them were helped by a child under 16 for harvesting and breaking the cocoa pods during the past 12 months, 21% for preparing their farm, and 25% employed and paid a child to perform any task on their cocoa farm. These results are twice as high as those found when directly questioning farmers about their recourse to child labor. Last, using a multivariate analysis, we show that the prevalence of child labor is higher for farms that are more remote, in line with limited school opportunities for children, lower adult labor supply, and weaker law enforcement capacity related to the reliance on children for farm activities. While child labor has been given considerable attention over recent years by most actors of the cocoa value chain, this paper shows that further progress can still be accomplished, particularly amongst the most remote farming communities.

Keywords: child labor, measurement errors, social desirability bias

SESSION 2

SUSTAINABLE COCOA AND CLIMATE CHANGE: THE WAY FORWARD THROUGH MITIGATION AND ADAPTATION



ORAL PRESENTATIONS



Diversity, resilience and market orientation: A private-sector driven approach to cocoa agroforestry in Ghana

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ABSTRACT

Cocoa production in Ghana, the world's second largest cocoa producer, is facing major challenges in terms of its socio-economic and environmental sustainability. Cocoa growing households struggle to make a living income, younger cocoa growers are increasingly opting for non-farm livelihood options, and most of the value added is generated abroad. Expanded cocoa production is linked with deforestation, cocoa trees are overaged, soils are impoverished, and on-farm diversity is reduced. In response to these challenges, chocolate manufacturers and cocoa sourcing companies have launched a series of initiatives in support of the cocoa sector's move toward sustainability. Our study focuses on the sustainability program of a major chocolate manufacturer carried out in collaboration with a licensed buying company (LBC) in Enchi in the Western Region of Ghana. The chocolate company is committed to source cocoa only from agroforestry systems as of 2025. Such systems are expected to have at least 30% shade tree cover, with a minimum of 25 permanent shade trees and of 5 different shade tree species. The LBC has set up nurseries to provide farmers with quality planting material for increasing the number and diversity of shade trees. We carried out key informant interviews, a gender-responsive survey of 129 randomly selected households participating in the agroforestry program, and rapid market assessments in the value chains of associated products (timber, fruits, medicinal plants). Our findings show that, in addition to the timber species which have been the focus of the agroforestry program to date, there is a strong demand also for tree species producing fruits and medicinal plants for household consumption and income generation. Preferences are gender-differentiated, with men prioritizing timber species and women preferring fruit and medicinal plant trees. The timber value chain is well integrated and shows solid demand for the eight tree species prioritized by the program. Tree tenure on farms, however, is subject to cumbersome regulations, requiring simplification to become a secure and viable option for cocoa growers. Value chains of fruits, such as cashew, avocado and coconut, are also well established, with stable or growing market perspectives. The value chain for medicinal plants is comparatively least organized, with a high degree

of informality and numerous small market outlets but options for higher value added. We conclude that a gender-responsive agroforestry program spanning a portfolio of associated value chains can provide attractive options for women and men and the youth, boosting livelihoods and landscape resilience.

Keywords: Agroforestry, Value chain, Inclusion

Implementing agroforestry systems in cocoa production as climate change adaptation methods - Case study from Ivory Coast

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ABSTRACT

Cocoa production in Ivory Coast plays an important role in the country's economy and farmer's livelihood. Traditionally their cocoa plants are cultivated under direct sun. In the last decades, aging of the plantations, climate change, and attacks from pests and disease, have triggered a series of challenges for the Ivorian cocoa production. In 2019, the International Development Research Center (IDRC) funded AdaptCoop, an applied research project whose main objective is to sustainably increase the resilience of cocoa cooperatives and member families when dealing with the impacts of climate change. To alleviate the impact of climate change on Ivorian cocoa production, there is a need to identify the most promising agroecological adaptation practices, for both men and women producers. Therefore, a gender-based analysis was performed interviewing 69 women and 288 men to identify whether there are different tendencies between women and men cocoa farmers, especially with respect to these practices, and the elements that could explain such tendencies. In other words, why women specifically adopt, or not, certain practices and if this is different for men. The results of the gender-based analysis underline very low literacy rates, which are even more pronounced among women, and can limit access to and understanding of information and training. Also, less than half of the women feel they can act on the negative effect of climate change compared to almost three-quarters of men. Such results were then integrated in a multicriteria analysis to identify the most promising agroecological adaptation practices to be supported for implementation by targeted women and men cocoa farmers. The practices that are currently tested include diversifying the plantation by adding shade trees, perennial legumes, bananas, and other edible plants; implement vegetative barrier; use mulching, herb swaths; composting using cocoa residue; scout for disease and pest; use mechanical methods such as pruning or manual removal of insects; use of natural or biological repellent; and store cocoa beans in a weather protected area. Finally, on

top of identifying the constraints faced by cocoa producers in Ivory Coast and its gender-differentiation, this applied research gave us the opportunity to identify and support the implementation of adaptation practices at the cooperatives' level and provide an appreciation of their impact.

Keywords: Gender-based analysis, adaptation practices, Agroforestry

Path Dependency and Cocoa Landscape Dynamics- A Cameroon case study

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ABSTRACT

Current approaches for understanding deforestation and changes in the cocoa landscape suffer from a static rather than a dynamic consideration of the policy and institutional environment governing the sector. The objective of this paper is to use the concept of path dependency to explain the dynamics and resilience of the forest landscape on which cocoa production depends. Using a combination of literature review and historical data on production and area under cocoa cultivation, we illustrate that the forest and cocoa landscapes in Cameroon have been influenced by different agents/actors operating and adjusting to different socio-cultural and institutional contexts (cocoa and market policies). This has led to undesirable outcomes (deforestation) which require new policies and strategies to arrest or reverse the situation (deforestation free cocoa). This path dependency emerged from the fact that the initial government policy was to improve farmers' livelihoods and Government revenue by expanding cocoa production, mainly through clearing of forest land. This path progressed until a critical juncture when deforestation became topical and the official discourse changed into one of promoting more sustainable cocoa production in the late 1990s, and more recently into deforestation-free cocoa. The results further show that over time, the area under cocoa cultivation, cocoa production and productivity aligned with the trends and policies corresponding to various periods in history: (i) Pre-colonial and colonial era; (ii) Post independent, (iii) The structural adjustment and the Post structural adjustment era and (iv) the recovery period till present. Increased production observed in each of these periods has been largely due to increase in area, except during the oil boom period when extension services and inputs provided to farmers allowed significant yield increases. Specifically encouraging policies with positive influence on input and output prices facilitated expansion of cocoa as was the case during the oil boom and post 2000 era. The findings also show that availability and ease of access to forest land with the assistance of village chiefs and autochthones claiming right to land (the first occupant rule) have facilitated expansion of cocoa into the forest. The implications for the future are that to increase the production of cocoa to meet Cameroon's

ambition of 600,000 T per year without deforestation, policies should be put in place to: (i) improve productivity of existing cocoa plantations and (ii) promote the establishment of new cocoa agroforests on non-forest land.

Keywords: Expanding cocoa production, Forests, cocoa production in non forest land

Cocoa and by-crop yields in three organic production systems entering mature stage

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ABSTRACT

Agroforestry systems for cocoa production are commonly promoted for biodiversity conservation, climate change mitigation and adaptation as well as for food security and risk mitigation. Generally, these systems include timber, legume or fruit trees. Successional or dynamic agroforestry systems represent a special type of design and management approach, using high densities and diversity of trees and crops occupying different strata and with varying life cycles. Here we present yields of three organic cocoa production systems entering the mature stage from a long-term trial in Bolivia: A complex successional dynamic agroforestry system (SAFS), a simpler but diversified agroforestry system (AF ORG) and a cocoa monoculture (MONO ORG). Average yearly cocoa yields in the mature phase (9-11 years) were highest in MONO ORG (1520 kg/ha), followed by the AF ORG (910 kg/ha), and lowest in SAFS (790 kg/ha) (yields considering the 8 best yielding clones out of 12). Total system yields in both types of agroforestry systems (dry matter) were 3.5 to 4 times higher than in monocultures over the 11 years. This was mainly due to banana production in AF ORG and from a multitude of by-crops in SAFS. While in young SAFS (until 8 years) crops like cassava, and pineapple were contributing to total yields, peach palm was the most relevant by-crop in the mature phase with around 4 t/ha fresh yields. Additional interesting crops were ginger and curcuma, that growing under the cocoa in SAFS yielded around 1 kg of fresh tubers per m². The results demonstrate how different crops can be associated with cocoa while still reaching elevated cocoa yields. The potential of agroforestry systems to sustainably intensify production on one surface is high and could still be optimised with the use of improved and locally selected varieties of cocoa and by-crops. Different designs of agroforestry systems can contribute to diversification of diets and incomes of producing families and regions.

Keywords: agroforestry, productivity, organic cocoa

Analysis of farmers income on various cocoa intercropping patterns in Indonesia

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ABSTRACT

Cocoa is a national strategic commodity that is a source of income for 1.7 million cocoa farmers in Indonesia. The area of land managed by farmers for cocoa farming ranges from 0.5 - 1.0 ha (average 0.7 ha) with a productivity level of 1.0 ton/ha/year, and cocoa contributes 60% to farmers' household income (Sariningsih, 2020). With this level of productivity, cocoa farming provides farmers with an annual income of around Rp. 7.9 million or still lower than the minimum standard of income according to the poverty line (Rp. 14.6 million/year) and still less than the income of a prosperous life of farmers (Rp. 35 million). ,9 million/year). In an effort to maintain the sustainability of cocoa production, it is necessary to increase the income of cocoa farmer families, among others through intercropping patterns with other commodities that have high economic value but are in line with their function as shade plants. Daymond (2018) reports that there are at least 26 plant species that are integrated with cocoa in Indonesia, especially coconut, Glyricidea, durian, and banana species. This paper reports the results of the analysis of cocoa farmers' income through various intercropping patterns of cocoa with economic commodities, in order to get an overview of the cocoa intercropping pattern that provides maximum income for farmers. Data were processed from various sources regarding the standard of monoculture cocoa cultivation, intercropping cocoa-coconut, cocoa-banana, cocoa-avocado, cocoa-durian, and cocoa-rubber. Assumptions of commodity costs and prices refer to the 2022 reference, with standard management by farming families (minimum labor costs) on a land area of 0.5; 0.75, and 1.0 ha. The results of the analysis using income analysis, R/C ratio analysis, and income contribution analysis, show that the intercropping pattern provides an increase in income of 17.8% compared to the monoculture pattern. The size of the farmer's land also contributes to the feasibility of the farmer's annual income. With the increase in the percentage of farmers' income, it is projected that the intercropping pattern can be a solution to increase farmers' income and become one of the driving factors for the creation of sustainable cocoa production.

Keywords: Intercropping, Farmer's Income, Agribusiness

Deciphering the genetic basis of adaptation to environment in *T. cacao* using resequenced genomes

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ABSTRACT

Theobroma cacao is native to the Upper Amazon. The species has undergone centuries of environmental and human selection and has spread throughout Latin America. The *T. cacao* germplasm is characterized by a high genetic diversity with at least ten major genetically differentiated groups. Little is known about the environmental and climatic drivers, as well as the genomic basis of adaptation in the species. Yet, a better understanding of how plants adapt to their environment is crucial to improve predictions of species' adaptive capacities and to provide accurate conservation strategies of genetic resources in the context of increasing environmental pressure. Environmental changes along altitudinal gradients allow the identification of functionally important genes contributing to the adaptive potential of species at a restricted geographic scale. In this study, using landscape genomics approaches, we deciphered the genomic basis of cocoa tree adaptation to temperature and precipitation from accessions sampled along an altitudinal gradient. A total of 102 geolocalised accessions of cacao trees collected in Ecuador along an altitudinal gradient ranging from 200 to 1000 m above sea level have been re-sequenced to identify genome-wide biallelic single nucleotide polymorphism (SNP) markers and presence/absence gene variation (PAV). The climate variables associated with sampled locations were obtained from the public database WorldClim. Using genome-scan, we detected genes under selection along the altitudinal gradient and potentially involved in trees adaptation to climate. Then, we searched for significant associations between genomic variation and the climate variables by conducting genome-environment association studies. Functional categories of genes associated with adaptation to elevation were investigated. This work will enhance our understanding of *T. cacao* response to continued climatic change. It allows to better characterize the available adaptive genetic diversity, to better understand the mechanisms of adaptation to climate and to apply them to crop breeding.

Keywords: Climate adaptation, Genome sequencing, Genetic diversity

Afforestation of savannah using cocoa agroforestry: impacts on ecosystem services and effects of associated tree species on soil fertility

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ABSTRACT

Past studies showed a gradual expansion of tree cover over savannah in forest-savannah transition zones in Central Africa. While the natural encroachment of savannah by forest is more and more impeded by human activities, farmers in Cameroon have proven that afforestation of savannah is achievable using cocoa and specific techniques to build up an associated tree canopy. Furthermore, mature cocoa agroforestry systems created on savannah (S-cAFS) or in forest (F-cAFS) seem to exhibit comparable multi-strata structures. By combining measurements of cocoa yield, litterfall and cycling, soil quality, carbon storage and tree species diversity along an age gradient (1 to 70 years), we showed that those variables in S- and F-cAFS tended to comparable levels after several decades. Results also emphasized the ability of S-cAFS to increase most of the ecosystem services (including soil carbon and nutrients storage) although the time needed to reach levels found in F-cAFS varied strongly amongst variables. We also compared the impact of five associated shade tree species and unshaded conditions on soil functions and cocoa yield in relation to plant functional traits and leaf litterfall within 8 cocoa farms set up after savannah. Unshaded cocoa conditions showed the lowest soil functions associated with the low leaf litter quality of cocoa plants. Soil functions varied largely among species. Low litter recalcitrance was strongly associated with increases in soil N and P availability, while soil pH, soil C and N contents increased with litter Ca restitution. Improvements of soil functions were the lowest under the fruit trees (*Canarium schweinfurthii* and *Dacryodes edulis*), intermediate under the legume tree *Albizia adianthifolia*, and the highest under the timber trees (*Milicia excelsa* and *Ceiba pentandra*). We detected no change in cocoa yield between the different treatments because of high variability of data but the P nutritional status of cocoa plants was positively related to soil P availability which varied under tree species.

According to the tree species, N, P and K recycling through litterfall was equal to or greater than nutrient removal by cocoa beans and husks. Establishing cAFS in savannah can increase soil fertility, species diversity and carbon storage in biomass and soil over time. Using specific trees for soil quality and compatible with cocoa, and other trees for the provision of goods, can ensure cocoa AFS multifunctionality and sustainability. Future research will need to understand how plant diversity in these cocoa systems, can help to adapt to climate change.

Keywords: Cocoa agroforestry, Ecosystem services, Soil fertility

Leaf density, adult vegetative vigor and flushing intensity as relevant criteria for evaluating drought resistance of cocoa trees (*Theobroma cacao* L.)

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ABSTRACT

In Côte d'Ivoire, one of the most recurrent manifestations of climate change results in long periods of drought lasting more than four consecutive months in the most-affected cocoa production areas. These droughts compromise cacao establishment, productivity and quality, which in turn threaten the longer-term sustainability of Ivorian cocoa farming. To address this constraint, one of the areas of research explored by breeders, is the identification of relevant criteria to assess the resistance of cocoa trees to drought, as a means to developing more climate-resilient genotypes. The purpose of this study is to show how adult vegetative vigor, leaf density and flushing intensity have proven to be relevant criteria for evaluating the resistance of cocoa trees to drought. A trial involving four agro-climatic zones (Bouaflé, Abengourou, Divo and Soubré), two of which experience significant rainfall deficits (Bouaflé and Abengourou), was set up in Côte d'Ivoire. The plant material, planted in two plots per zone, was made up of 15 CNRA families common to each agro-climatic zone and 10 to 15 free progenies, selected in each zone by the cocoa producers for their superior agronomic and technological performance. Eleven criteria were used to evaluate the plant material: i) vegetative vigor measured by the diameter at the collar; ii) trunk circumference at 130 cm above the ground; iii) tree height; iv) foliage density; v) leaf density; vi) flush intensity; vii) drought-sensitivity score ; viii) total number of cherelles per tree; ix) cherelle wilt rate; x) cumulative potential production (2015 to 2018), and xi) bean weight (weight of 100 dry cocoa beans). The results showed a highly significant zone x family interaction (probability < 0.0001) for all the traits studied. In particular, six hybrid families were ranked in the top ten across all study areas, indicating resilience in the more challenging agro-

climatic zones. Of these nine criteria, those having best characterized the six families thus selected are, in decreasing order of importance: 'i) leaf density; ii) vegetative vigor and iii) flush intensity. The use of these three criteria in the selection of drought-resilient plant material is envisaged.

Keywords: drought resistance, cacao breeding, relevant criteria

Agronomic and economic performances of improved cacao clones under different agro-ecological conditions in Costa Rica.

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ABSTRACT

To reactivate cacao production in Mesoamerican countries, in the late 2010s the Tropical Agricultural Research and High Education Center (CATIE) started to disseminate 6 cacao clones (CATIE-R1, CATIE-R4, CATIE-R6, PMCT-58, CC-137 and ICS-95) with high production potential, resistance to diseases and good quality. Ten years later, the agronomic and economic performances of these clones were assessed in three regions of Costa Rica (North, Caribbean and Pacific), in order to identify the factors that influence cacao actual yields and family benefits. The sample of cacao farms was selected from a list of 267 cacao growers provided by the Ministry of Agriculture. From this list, 30 farmers cultivating the clones were selected (10 per region): half with good yields and half with low yields according to producers' perceptions. Visits to the plantations and inquiries allowed characterizing the socio-economic and agronomic context of the farms and households. Agronomic and agroforestry variables, cacao yields, as well as costs and incomes were measured. Statistical analyses focused on differences among yield classes and on the identification of factors that contribute most to the benefits obtained. Farms were grouped into four classes of cacao yield. From the first to the fourth class, the yield increased from 268 to 1770 kg/ha/year, as did the frequency of agronomic practices and application of inputs. Therefore, the production costs also increased according to yield classes but in acceptable levels for smallholders and leading to high cacao yields and incomes (especially classes 2 and 3 with respectively 830 and 1430 kg/ha/year). Class 4 reported the highest yields but not the highest net incomes due to elevated production costs. The two main agronomic factors that led to higher yields and profits were pruning and fertilization. Cacao plantations were between 4 and 10 years old and the shade trees were still in the growth phase. At this age, none of the plantations surpassed 40% of shade cover and other variables of agroforestry structure did not show any influence on clone performance. Another important

finding was that there was no genotype x environment interaction in yield results. The three most promising clones were CATIE-R6, CATIE-R4 and CATIE-R1, in this order. Results reveal that the exploitation of the high productive potential of improved clones must be complemented by an efficient agronomic management. Thus, government agencies and development projects should provide technical support and training to producers in addition to the supply of new varieties, especially clones.

Keywords: Cacao yield, agroforestry, cacao breeding

Using the Cool Farm Tool and Perennial crop model used to benchmark the climate change mitigation potential of cocoa systems

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ABSTRACT

From a climate change perspective, global concerns about emissions associated with tropical commodity production are increasing. Consequently, there is a need to assess the potential to change the present cacao-growing practices into more climate-friendly cultivation systems which emit less greenhouse gases (GHG), store a high amount of carbon in its standing biomass and produce high cacao yields. As part of the NWO-WOTRO project (W08.250.305) we parametrized the Cool Farm Tool and Perennial crop model for cocoa. Subsequently, we calculated the GHG emissions and carbon stocks associated with actual cacao production in 2018 in 509 farmers' fields in Republic of Côte d'Ivoire (Vervuurt et al., 2022). On average, the production of 1 kg cacao beans was associated with an emission of 1.47 kg CO₂eq. Deforestation contributed substantially to GHG emissions, while tree biomass and residue management contributed mainly to carbon storage. Calculated emissions assuming recommended good agricultural practices were 2.29 kg CO₂eq per kg cacao beans. The higher emissions due to the use of more agro-inputs and other residue management practices such as e.g. burning of residues for sanitary reasons, were not compensated for by higher yields. This indicates a need to assess recommended yield increasing practices with respect to climate change mitigation objectives. Comparison with other studies revealed a lack of standardized approaches. We used our method to compare four countries for which data were collected in the same way, and at the same point in time. All systems showed net carbon sequestration per kg of beans, but changes in practices over time led in three countries to slightly higher and in one country to slightly lower GHG emissions per kg of beans. Emissions between countries differed as well. While the tool and harmonised data collection allowed for a fair comparison, more detailed analysis of the actual implementation of the practices will be needed to allow identification of main causes of differences and to propose site specific management practices to increase climate friendliness of systems. For this it is also needed to include disentangled effects of different management practices on yields, currently investigated within the CocoaSoils program (<https://cocoasoils.org>). Furthermore, collection of data on cocoa fields and farming practices need to be better tailored to

the use of assessment tools. Vervuurt, W., Slingerland, M.A., Pronk, A.A. and L. G. J. Van Bussel, 2022. Modelling greenhouse gas emissions of cacao production in the Republic of Côte d'Ivoire. *Agroforest Syst* 96:417–434. <https://doi.org/10.1007/s10457-022-00729-8>

Keywords: Standardized method, Coolfarm Tool, CO₂eq per kg of beans

Variation in environmental risks from cocoa expansion and intensification in West Africa requires context specific responses

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ABSTRACT

Cocoa and other global commodities are important drivers and direct causes of forest loss and degradation in West Africa. To inform efforts to prevent further cocoa-driven deforestation in the West African cocoa zone and support cocoa development planning, this study explored the potential risk from cocoa expansion and intensification in areas that are important for biodiversity and ecosystem services (carbon, water, forest products), based on climatic suitability, a continuation of past deforestation and recent commodity development trends. We found that cocoa expansion and intensification risks further impacting ecologically important areas in West Africa, but that patterns vary in space and demand context specific responses. In countries with high historical deforestation rates, remaining forests should be better protected, degraded forests should be restored, and agroforestry systems should be supported where possible to maintain or enhance biodiversity and ecosystem services provision in cocoa landscapes. Countries with large areas of remaining forest areas that are highly suitable for cocoa and where commodity production is on the rise, any future cocoa production should be planned and incentivised to maximise sustainable cocoa system productivity potential and local to global ecosystem services, whilst avoiding the areas with the highest biodiversity values. The risks to biodiversity and ecosystem services from cocoa expansion and intensification in West Africa are likely to be compounded by climate change which is expected to affect future cocoa production in West Africa. These effects are likely to vary throughout the region as well: some areas will remain or become more suitable for the cultivation of cocoa and other crops, with a risk of continued expansion. Other areas might become less or even unsuitable for cocoa, with a risk of driving a shift in cocoa growing areas, including into the forests of Central Africa. These results highlight that throughout the cocoa growing region of West Africa, sustainable, climate resilient intensification approaches should be promoted to increase and support the productivity of existing cocoa systems on existing land over the longer term, including through agroforestry where appropriate, so that the

historical expansion and associated deforestation seen in some countries in the past are avoided in areas where there are still large amounts of relatively intact forests.

Keywords: deforestation, cocoa development planning, cocoa suitability

Towards a climate-smart dynamic cocoa cropping calendar?

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ABSTRACT

A major cause of low farmer income and widespread deforestation, the vast gap - with estimates ranging from 70% to 80-95% - between potential and actual cocoa yields in West Africa is a well-documented reality impacting over 70% of the world's cocoa production. Because cocoa is a perennial crop and because the vast majority of West African cocoa production is done without the use of irrigation, cocoa farming has long been relatively passive to climate anomalies, despite the sensitivity of the crops to climate variations. Nonetheless, farmers can and do act on the cocoa yields through various farm operations such as replanting of cacao seedlings, pruning, manual pollination, fertilizer application and different pest and disease management strategies. However, these operations are currently carried out either sporadically or following static cropping calendars with monthly precision of the timing of operations, usually based on decades-old practical considerations. Even though the efficiency of many of these field operations is sensitive to the climate conditions before, during and/or following their employment, the static cropping calendars currently used to plan them do not take into account the effects of the observed climatic changes that have been occurring in the African cocoa regions for the past decades, nor the interannual variability in the climate conditions. In this study, we employ a thorough literature review and interviews with African cocoa experts to establish sets of criteria for the ideal climate conditions for each of these field operations. We then carry out an analysis of historical climate data over the African cocoa regions to establish to what extent the ideal timing for each of these operations has changed throughout the past decades and varies from one year to the next, in order to determine if a climate-smart dynamic cocoa cropping calendar could enhance the efficiency of farm management practices in a changing climate.

Keywords: climate-smart, dynamic, farm management

The importance of empirical data in accounting for the long-term and interactive effects of climate change on cocoa.

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ABSTRACT

Cocoa production, like all crop production, will be impacted by climate change. Increasing CO₂ concentration, rising temperatures, unpredictable shifts in rainfall patterns and the increased likelihood of more extreme climatic events predicted in the future are well documented and, in some cases, already evident. Understanding cocoa plant responses to climate change is complex as the simultaneous change in several climate variables at once results in significant interactive effects which may differ from the response to a change in an individual variable in isolation. To capture the complexity of these processes, empirical data is key to developing our understanding of the physiological response of cocoa to these climate variables both individually and simultaneously. Here we present data from a series of controlled environment studies looking at the interactive effects of different climate variables, namely water deficit, high temperature and elevated CO₂. We highlight the importance of considering the interactive nature of these variables and how this differs from single factor variation. Particularly important is the ameliorative role of elevated CO₂ when studied in combination with water deficit stress and high temperature stress. We demonstrate using a JULES land-surface model, parameterised for cocoa, how alteration of single and multiple climate variables alters the predicted response of the crop. Additionally, we provide evidence that, in the absence of other abiotic stresses, cocoa may be more tolerant to higher temperatures than previously reported. We also demonstrate the capacity for thermal acclimation in cocoa when grown at temperatures up to 36°C for a prolonged period (i.e. the photosynthetic performance of plants growing under high temperature conditions now surpasses that of plants growing under “optimal” conditions). These interactive and dynamic responses change our understanding of how cocoa may be affected by climate change. As we attempt to predict cocoa’s response to climate change and develop strategies to future-proof production it is essential that we base

our efforts on empirical data. Cocoa is a perennial crop which will remain productive for prolonged periods during which climate change will be progressing. As such, we need to consider the dynamic nature of the physiological response and consider both the short- and long-term responses of the tree to complex environmental change.

Keywords: physiology, controlled environment, acclimation

Accompanying Research on Strategies for Income Improvement of Farming Families and Sustainable Cocoa Production in Côte d'Ivoire

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ABSTRACT

Plant diversification in cropping systems has often shown the role it can play in regulating crop diseases and pests and in improving producers' income sources. Thus, at the dawn of the 21st century, agriculture must produce more, but above all in a sustainable manner. This "sustainable production" is a multifaceted imperative, each of which can be broken down into several elements, including agroforestry. Taking into account the different cropping practices, the economic profitability of the by-products of agroforestry systems and their usefulness will lead to a fairer and more efficient design of sustainable production systems. However, little is known about their contributions to producers' livelihoods, the quantification of their yields, their profitability and their value for domestic consumption. This study aims to provide information on the profitability of different cocoa production systems, the financial profitability of trees associated with different cocoa production systems, the determinants of adoption of agroforestry practices and the challenges cocoa farmers face in terms of innovation and livelihoods. To this end, floristic inventories of 625 m² in 150 cocoa plots and mapping of different land use systems, as well as socio-economic surveys will be carried out among 150 farmers in five localities in Côte d'Ivoire. Qualitative and quantitative analyses of the variables and statistical tests will be carried out for this purpose using R software as well as cost-benefit analyses. Thus, the financial return and profitability of cocoa trees, agroforestry products and their contributions to socio-economic indicators are known. The determinants of the adoption of agroforestry practices and the challenges faced by cocoa farmers are identified. The results of this study can contribute to better planning of sustainable land use policies. To provide farmers with combinations with better market potential to increase their income by increasing the profitability of the land, when creating

new cocoa farms or renewing existing farms. Finally, to have indicators on the real income and potential of their farms in order to opt for a more profitable diversification. Key words: Cocoa, Sustainable land use, Sustainable production, Yield, Profitability, Impact assessment.

Keywords: Sustainable production, Profitability, Impact assessment

A Physiological Model to Quantify Impacts of Climate Change Variables on Cocoa Productivity

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ABSTRACT

Climate change has the potential to alter cocoa production through, for example, changes in rainfall patterns (more intense droughts and/or more intense wet seasons), higher temperatures and increased carbon dioxide concentrations. A crop modelling approach allows prediction of yield changes in relation to climate events and quantification of interventions designed to ameliorate such changes (e.g. use of overhead shade or planting of different varieties more adapted to climate change). A physiological model is described that is parameterised by experimental data collected under controlled environment conditions. The model is compartmentalised into interacting modules that include assimilation of carbohydrates through canopy photosynthesis, respiration, partitioning of assimilates between vegetative and reproductive growth, partitioning of assimilates within the pod and the dynamics of pod-setting and wilting. Canopy photosynthesis is calculated from the parameters of photosynthetic light responses of clones, specified by the user, and the properties of the canopy (leaf area index and light attenuation through the canopy, quantified as the extinction coefficient). Environmental parameters that can be altered in the model include carbon dioxide concentration, soil water content, air temperature, vapour pressure deficit and solar radiation. These parameters then influence the outputs of the different modules, for example temperature impacts on photosynthetic rate and also on the amount of cherelle wilt. A range of model simulations are presented on the impacts of elevated CO₂ concentration, increases in temperature, drought events and their interaction on yield. The potential impact of interventions such as changing variety and use of overhead shade in ameliorating the effects of climate change is also demonstrated.

Keywords: Climate change, Crop model, Adaptation

Fish farming as a way for diversifying sources of income in the cocoa sector in Ivory Coast

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ABSTRACT

Ivory Coast is the largest producer of cocoa in the world, with production reaching 2 million tonnes in 2016-2017. The South- and Central-West regions are the main cocoa production areas in the country. However, cocoa production faces a significant crisis due to the instability of prices on world markets, land saturation, aging plantations, and climate change. Cocoa farmers have adopted fish farming as an additional production to generate new incomes. The objective of our study was to provide the first description of cocoa production diversification practices in the Ivory Coast through targeted questionnaires. Surveys were conducted from May to September 2021 with cocoa farmers practicing fish farming in two localities of Central-West: Bédiala (n = 21) and Sinfra (n = 12) and one in South-West: Méagui (n = 12). We first used an empirical approach to highlight the farming practices, and then a hierarchical clustering analysis will be applied to identify clusters of sites. Our first results showed that all the cocoa farmers interviewed in Bédiala and 70% of the cocoa farmers in Sinfra practice fish-rice farming in which rice and tilapia (*Oreochromis niloticus*) are cultivated in the same ponds. In addition, the cocoa plantations in Bédiala (85%) and Sinfra (82%) are characterized by the association of cocoa and cashew for shading cocoa plants. Among the cocoa farmers interviewed in the South-West region, 75% of them practice fish-rice farming, with the monoculture of cocoa. With incomes ranging between 400,000 and 3,000,000 FCFA per year, fish farming has become the primary source of revenues for 30%, 40%, and 5% of cocoa farmers in Bédiala, Sinfra, and Méagui, respectively. In such agriculture-aquaculture integrated systems, 51% of the farmers use the periphery of the ponds in the dry season as cacao nurseries, which allows the young crops to benefit from fertilized pond water collected by their roots. Such practices are likely to enhance crop growth while reducing the watering effort. In addition, fish ponds act as a natural barrier against bush fires. These results highlight the positive interactions that exist between

cocoa and fish farming. Nevertheless, the consequences of using phytosanitary products in cacao production near fish ponds remain to be assessed for human consumers and surrounding environments. Based on a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis, we explore the possibilities that may be more promising for cocoa production diversification in Ivory Coast.

Keywords: cocoa farming, aquaculture, diversification

Perception of climate change and adaptations of cocoa producers in the Divo production area

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ABSTRACT

Climate change is one of the major constraints that disrupts the technical route of cocoa production. To ensure the sustainability of cocoa farming in Côte d'Ivoire, one of the challenges for agronomists is to understand producers' perceptions of this phenomenon and how are they adapting? To address these concerns, a study was initiated in Divo, a production area located in the center west of Côte d'Ivoire and increasingly subject to climate change. The objective of this study was to understand, through a survey, the perception of climate change among cocoa producers and the various adaptation measures developed by them in this area. The survey was preceded by the development of a questionnaire and the completion of a pre-survey to refine the survey sheet. It focused on three main areas of the Divo production area (Divo-Lakota; Divo-Hiré; Divo-Tiassalé), i.e. 27 villages and 252 producers. The results showed that 100% of the population surveyed is aware of the phenomenon of climate change. About 85% of growers observed climate change less than 5 years ago and 67% of them noticed the effects of climate change on their own. In addition, according to 51% of them, deforestation was named as the major cause of climate change, followed by intensive and shifting agriculture (29.71% of producers). The producers interviewed perceived the effect of climate change on the soil, on young cocoa trees by high mortalities and on adult cocoa trees by a drop in production and heavy attacks by harmful insects. As adaptation strategies practiced, only 3% of producers said that climatic disturbances led to changes in their farming practices. It is mainly about the modification of the depth of the planting holes, attention placed on the choice of the type of soil (sandy-clayey), the densification of banana trees, the use of cassava as a shade tree, the use of improved plant material and crop diversification. In terms of the socio-economic impact of climate change on households, 81.53% of producers claim to currently invest more financial resources

to establish and maintain their plantations through the purchase of more agricultural inputs compared to previous practices. Climate change is very noticeable by producers but very few take action to adapt. Coping strategies and their use are considered.

Keywords: climate change, cocoa, perception

Combined effects of elevated [CO₂] and increased temperatures on cacao reproductive development

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ABSTRACT

Climate change is leading to increasing temperatures worldwide, however the impact of this on crops needs to be considered in conjunction with an increase in CO₂ concentration ([CO₂]). This study examined the combined effects of elevated [CO₂] and increased temperature on pollen viability, pod set, pod growth and bean yield. All pods were formed by hand pollination. Mature cacao trees of three genotypes (CCN 51, SCA 6, and T85/799) were grown in six controlled environment glasshouses adapted for cacao studies under non-limiting water and nutrient supply. Trees were exposed to three day/night temperatures of 31/22°C (T_c), 33.5/24.5°C (T_c+2.5°C), and 36/27°C (T_c+5.0°C) combined with two [CO₂] treatments, these being ambient (ca. 437 ppm) and elevated (ca. 693 ppm) in a factorial design for 11 months. The control temperature regime (T_c) was based on temperatures that are common for West African cacao regions. Pollen germination and pollen tube length were negatively affected by a 5°C increase in temperature; this was particularly evident for SCA 6 and T85/799. However, elevated [CO₂] largely compensated the negative effect of high temperature in all three genotypes. The proportion of pods set decreased with an increase in temperature, and the highest percentage of wilted pods was observed at 33.5/24.5°C. However, elevated [CO₂] enhanced pollination successful, and pod set, and reduced percentage of wilted pods across all temperatures. At ambient [CO₂] pod size declined with increases in temperatures, whereas at elevated [CO₂] an increase in temperature resulted in larger pods in CCN 51 and little change for SCA 6. A similar trend was observed for pod dry weight. The positive effect of elevated [CO₂] on individual bean dry weight was observed at the higher temperatures for CCN 51, whereas little impact was seen in SCA 6. It can be concluded that for most of the reproductive components studied, elevated [CO₂] mitigates to a greater or lesser extent the negative effect of elevated temperatures. Pod growth and bean yield were more responsive to elevated [CO₂] under warm conditions in CCN 51 than SCA 6 suggesting there is some scope for selecting genotypes better suited to a changing climate.

Keywords: Climate change, Controlled environments, Reproductive components

Dynamic agroforestry – a tool for successful smallholder-grown cocoa in times of climate uncertainty

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ABSTRACT

More than half of the world's cocoa (*Theobroma cacao*) grows in monoculture-like systems in West Africa that are vulnerable to climate change. Dynamic agroforestry (DAF) – an approach developed in Brazil characterized by a high turnover of biomass due to high plant diversity and density, pruning intensity and systematic stratification – has the potential to restore soil fertility, mitigate and adapt to climate change, whilst improving the livelihoods of millions of smallholders. However, we need more knowledge about the acceptance of DAF by West African farmers and about the factors ensuring its socio-economic sustainability. We conducted biophysical and socio-economic research in two DAF projects in the Eastern and Western Regions of Ghana since 2018 and compared the results to traditional cocoa cultivation. We observed a significant improvement of soil fertility under DAF in the first four years after planting. Cocoa vigour and survival rate were significantly higher in DAF, which strongly correlated with lower air temperature amplitude, as well as lower temperature and higher moisture content in the topsoil. 319% higher plant diversity and 98% higher density of shade trees compared to traditional plots demonstrated the high ecological value of DAF. In the first year of establishment, DAF needed substantial investment and labour for by-crops, fruit and timber tree seedlings, which allowed for abundant by-crop harvests and showed that we are indeed in the investment phase of DAF. Data from several years after planting is being put together to get a more comprehensive picture of the productivity and profitability of the systems during the establishment phase. Initial surveys showed that theoretical knowledge of DAF did not correlate with plot performance, indicating that there are factors leading to limited adoption of DAF. We carried out two workshops and a survey with some 600 farmers on the adoption constraints of DAF, and data analysis is on-going. Preliminary results suggest that the main hindrances for large-scale adoption of DAF are financial and logistical challenges

associated with the quantity and diversity of planting materials, stressing that cooperation among value chain actors and an effective incentive scheme are key for successful implementation of DAF on a large scale. Based on our results, a multi-stakeholder workshop in the first half of 2022 will develop local DAF recommendations and elaborate a strategy to incorporate these into national extension programs. If successful, this could lead to the implementation of DAF on a large scale in West African cocoa.

Keywords: Dynamic agroforestry, Climate change mitigation and adaptation, Socio-economic sustainability

Vulnerability of cocoa-based agroforestry systems to climate change in West Africa

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ABSTRACT

The rise in temperature and increasing frequency of severe droughts predicted for the near future will make cocoa plantations more vulnerable, ultimately affecting their vigour, yield and long-term persistence. As a result, some important cocoa cultivation areas in West Africa in the 20th century will have essentially become unsuitable for growing cocoa by the near future. This research work has focused on the vulnerability of cocoa potential distribution under climate change as well as the potential impacts of climate change on the habitat suitability for shade tree species commonly used in cocoa-based agroforestry systems across West Africa (C-AFS). Finally, this information was used to estimate the potential of C-AFS across different scenarios of climate change and discuss opportunities and possible risks of cocoa expansion into climatically less vulnerable areas. To characterize patterns of habitat suitability, we compiled presence location points of selected tree species from the Global Biodiversity information Facility (GBIF). We modelled current and future suitable habitats for 38 tree species (including cocoa). Suitability modelling and mapping of all species were done using a consensus method for Species Distribution Modelling. As environmental predictors in the models, edaphic and climatic variables were used. We considered seven climatic scenarios for 2060 using two contrasting projections of socioeconomic pathways. The prediction accuracy of the species distribution models for cocoa and shade trees showed values between 0.69 and 0.99. The final ensemble model that was built using all the data had an AUC range from 0.84 to 0.99 for the different species, while TSS value range from 0.66 to 0.96 for the ensemble models. The sum of the contribution rate of the climatic variables reached 85% and that of the soil factors reached 15%. The models projected an increase of up to 6% of the potential suitable area for cocoa by 2060 compared to its current suitable area in West Africa. Furthermore, the suitable area was highly reduced once considering only available land-use not contributing to deforestation. Hotspots of species richness overlap the current core cocoa production

areas in Ghana and Côte d'Ivoire, suggesting a potential mismatch for the outer areas in West Africa. Regarding shade trees, the distribution range of 49% of the shade tree species will become unsuitable by 2040 in West Africa, and 60% by 2060. Our results highlight the importance of transforming cocoa-based agroforestry systems by changing shade tree species composition to adapt this production systems for climate change.

Keywords: Habitat suitability, Species richness, Climate change adaptation

Changes in key soil health indicators in cocoa landscapes around Tene Forest Reserve, Middle-West Côte d'Ivoire

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ABSTRACT

The development of sustainable cocoa supply chains built on nature-based agricultural solutions has become a major challenge for major producing countries and private chocolate/cocoa companies. Cocoa farming in the surrounding areas of forest reserves, supported by monitoring of soil health using appropriate parameters, could provide a reliable alternative for an eco-friendly production and a plausible solution against cocoa-led deforestation. The current study was undertaken within and around the Forest Reserve of Tene in the middle-west of Côte d'Ivoire to guide interventions which aim at building up resilient cocoa-forest landscapes. Two landscapes were selected in Mafia and Petit Bouaké, two settlements of cocoa growers in the vicinity of the village Goulikao. They were featured by the presence of similar land-uses namely secondary forest, 26-year-old cocoa plantations, 13-year-old teak plantations and recurrent fallow-maize fields of 5-year-old from which key soil health metrics such as soil organic carbon (SOC), pH-H₂O and Mean Weight Diameter (MWD) were measured at different layers (0-10 cm, 10-20 cm and 20-30 cm). Results revealed that despite the site-specificity of soil health characteristics reflected in higher values in pH and MWD, revealing healthier soils in Petit Bouaké compared to Mafia, similar trends emerged in the effect of land use types on the various parameters studied. Topsoils (0-10 cm layer) of the secondary forest, teak and cocoa plantations have the highest soil organic carbon contents (9.91 – 20.85 g kg⁻¹) and stocks (10.56 – 19.96 Mg C ha⁻¹) as compared to soil layers in other facies. In the same way, SOC sequestration potential rates were promising in Petit Bouaké with values within the range of 0.158 – 0.537 Mg C ha⁻¹ year⁻¹ in the first two soil layers beneath teak and cocoa plantations. This study confirms the followings: (i) recurrent food crop fields are the most degraded land use type in cocoa landscapes with very low SOC stocks and highest MWD values, and (ii) tree-based systems have the potential to replenish SOC, improve SOC sequestration and soil aggregation, thereby contributing to climate change mitigation and adaptation.

The contribution of the findings to devise a sustainable management plan for cocoa-forest landscapes is discussed.

Keywords: Carbon sequestration, resilience, agroforestry

The contribution of cocoa agroforestry on yields, soil, pests, biodiversity and climate change: a multi-dimensional meta-analysis

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ABSTRACT

Scientific knowledge, societal debates, and industry commitments around sustainable cocoa are increasing, thus demonstrating the need to improve cocoa farming strategies. Cocoa agroforestry systems are supposed to improve the sustainability of cocoa production. However, their combined agronomic, ecological, and socio-economic performance compared to monocultures is still largely unknown. Here we present a meta-analysis of 52 articles that directly compared cocoa agroforestry systems and monocultures. Using an inductive, multi-dimensional approach, we analyzed the differences in cocoa and total system yield, economic performance, soil chemical and physical properties, incidence of pests and diseases, potential for climate change mitigation and adaptation, and biodiversity conservation. Cocoa agroforestry systems outcompeted monocultures in most indicators. Cocoa yields in agroforestry systems were 25% lower than in monocultures, but total system yields were more than 10 times higher, contributing to food security and diversified incomes. This finding was supported by a similar profitability of both production systems. Cocoa agroforestry contributed to climate change mitigation by storing 2.5 times more carbon in the biomass and to adaptation by lowering mean temperatures and buffering temperature extremes by the shade tree canopy, thus improving growing conditions for the understory cocoa tree. We found no significant differences in relation to the main soil parameters. The effect of the type of production system on disease incidence depended on the fungal species. Shade management must therefore take the prevalence of main pests and diseases of the region into consideration. The few available studies comparing biodiversity showed a higher biodiversity in cocoa agroforestry systems. The environmental benefits and economic equitability of cocoa agroforestry systems compared to monocultures are shown here: to enhance sustainable cocoa farming, agroforestry systems must be promoted from governments, industry and cooperatives, especially in the combination with rejuvenation techniques of old cocoa plantations and reforestation

of degraded areas. However, the further implementation requires enhanced knowledge on local environmental and cultural conditions as well as tree species-specific traits to develop local agroforestry solutions. A socio-ecological approach must therefore include sustainable farming strategies regarding pollination, weed and shade level management, and livelihood related measures like enabling access to alternative markets and valuation of ecosystem services to promote the further adoption and sustainability of cocoa agroforestry systems.

Keywords: System yield, Sustainability, Agroforestry management

Climate change impact on cultivated and wild cacao in Peru and the search for climate change tolerant propagation material

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ABSTRACT

Cacao (*Theobroma cacao* L.) is expected to be severely impacted by climate change. Using climate change tolerant genotypes represents one of the most promising adaptation options to climate change. Peru has a great potential for cacao genotype selection because it presents high levels of genetic diversity of cacao and is located within the putative centre of origin of this species. The objectives of this study were to (i) assess the future impact of climate change on cacao in Peru, (ii) identify areas where climate change tolerant genotypes are potentially present, and (iii) develop an online tool to help cacao farmers' and practitioners to select appropriate propagation material for climate change adaptation. First, we investigated how climate change is expected to impact the suitability distribution of wild and cultivated cacao in Peru. Drawing on more than 19,700 and 1,200 presence points of cultivated and wild cacao, we modelled their suitable distribution using multiple ensemble models constructed with different methods, we generated future predictions and determined how ecogeographical zones (i.e. zones representative for particular sets of growth conditions) are expected to change. We found that cultivated cacao is expected to experience a contraction in suitable area and a moderate shift towards higher elevations. For wild cacao, most of the current distribution range is likely to remain suitable and expected to further expand. However, in most areas predicted to remain suitable for cacao cultivation in the future, growth conditions are expected to change drastically, requiring the availability of resistant planting stock. Second, we identified areas where climate change tolerant genotypes are potentially present in Peru based on an outlier analysis using the environmental variables most relevant for climate change. The identified areas include for instance genotypes tolerant to drought in Cuzco and Cajamarca and will be later the target of collection missions. Finally, based on these results, we developed an online tool to help cacao farmers' and practitioners to select appropriate propagation material for climate change

adaptation. The tool allows the user to select the coordinates of its cacao farm on the map of Peru. For the selected site, the tool indicates whether the site is predicted to be suitable or unsuitable for cacao cultivation in future, provides some recommendations to mitigate the impact, suggests from which ecogeographical zones to source propagation material and gives a list of gene banks, clonal gardens and nurseries that occurs in these areas.

Keywords: cacao genotypes, habitat suitability modelling, ecogeographical zones

POSTER PRESENTATIONS



Afforestation of savannah with cocoa agroforestry systems: impacts on different soil organic carbon pools, soil carbon stocks and other soil properties

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ABSTRACT

Afforestation of savannah with cocoa agroforestry systems (cAFS) is a common land use change occurring in Cameroon, yet its impacts on soil quality is not well known. Here, we assessed the effect of conversion of savannah to cAFS or other land uses on soil carbon (content and stocks) and different soil properties. Different systems settled on savannah were compared: cropland (≈ 5 years old), cocoa monoculture (≈ 10 years old) and cAFS (20 and 60 years old) including different shade tree species (*Albizia adianthifolia*, *Canarium schweinfurthii*, *Dacryodes edulis*, *Milicia excelsa*, *Ceiba pentandra*). We also used savannah and forest as controls. Soils were orthic ferralsols with 9-15% clay content. Soil analyses were performed on the 0-10 cm layer for C distribution in soil particle-size fractions ($< 20 \mu\text{m}$, $20-50 \mu\text{m}$, and $50-2000 \mu\text{m}$), organic carbon (C) content, and nutrients content. Soil bulk density was measured to calculate soil carbon stocks. The amount of annual litter input and leaves litter nutrient content were also analysed. Soil carbon content was 10.6 g C kg^{-1} in savannah and increased to 17.9 g C kg^{-1} on average in cAFS (13.9 to 23.5 g C kg^{-1}) at the same level of soil C under nearby forest (16.3 g C kg^{-1}). However, we observed a decrease in soil carbon content in annual cropland and cocoa monoculture. Soil carbon stocks showed similar variations as soil carbon contents between land uses: soil C stock in the 0-10 cm layer was 8.5 Mg C ha^{-1} in savannah and significantly increased to $16.3 \text{ Mg C ha}^{-1}$ on average in cAFS (17.9 to $27.8 \text{ Mg C ha}^{-1}$) and decreased to 7.3 Mg C ha^{-1} in annual cropland and 8.4 Mg C ha^{-1} in cocoa monoculture. In comparison to savannah, the different soil properties (soil pH, Olsen P content, exch. Ca^{2+} and sum of bases) were improved in cAFS and were degraded in annual cropland and young cocoa monoculture. Soil carbon was

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positively linked to soil pH, Olsen P content, exch. Ca^{2+} and litter Ca content. The improvement of soil properties including significant increases of carbon in both fine ($<20\ \mu\text{m}$) and coarse ($50\text{--}2000\ \mu\text{m}$) soil particle-size fractions in cAFS was linked to cumulative higher litter inputs in cAFS than in other land uses. Afforestation of degraded savannahs with cAFS appears as a valuable option for soil carbon sequestration and improvement of soil fertility.

Keywords: Soil carbon, Cocoa agroforestry, Savannah afforestation

The effect of water deficit on water relations and chlorophyll fluorescence of rootstock-scion combinations of cacao

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ABSTRACT

Adverse effects caused by drought on cacao seedlings can produce significant yield losses and require a better understanding of plant-tolerance mechanisms in order to overcome them. The selection of a drought-tolerant rootstocks is a key strategy to achieve greater resilience in water-limited environments. This study aimed to assess leaf ecophysiological responses and root growth of four rootstocks and 24 rootstock-scion combinations to water deficit. Leaf stomatal conductance (gs), leaf water potential (wf) and chlorophyll fluorescence (Relative quantum yield of PSII (Φ PSII)) were measured in irrigated and non irrigated seedlings. Data was recorded 14 and 20 days after the irrigation was suspended in the non-irrigated plants. Root volume was determined 24 days after irrigation was withheld. EET-400 rootstock showed significantly higher values of Ψ_f both at 14 and 20 days under water deficit. This rootstock and IMC-67 showed the highest gs after 14 days without irrigation. The relationship between Ψ_f and gs showed that the combinations of rootstock EET-400 with scions EET-575, EET-576 and EETP-800 exhibited the highest gs and Ψ_f . The lower root volumes found under the water deficit condition in EET 400 and IMC 67 demonstrate that tolerance to water deficit by cacao rootstocks is influenced by physiological characteristics of the roots.

Keywords: drought tolerance, water potential., stomatal control

Genetic diversity analysis of a large cocoa trees collection from the Ecuadorian Amazon safeguarded for local and sustainable cocoa production

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ABSTRACT

Ecuador is the top cocoa-producing country in South America and the leading exporter of fine and flavor cocoa worldwide. The production of aromatic cocoa has a direct positive impact on the sustainability of the agricultural sector thanks to a significantly higher producer price paid to the farmer. The aromatic Nacional variety, emblematic of Ecuador, is highly sought after by the chocolate industry. The modern Nacional is a hybrid population resulting from genetic admixture that has lost the specificity of the ancestral variety. In the context of the progressive disappearance of the forests, several collection expeditions (2010 to 2019) have been organized in the Ecuadorian Amazonian provinces of Zamora-Chinchipe, Morona-Santiago and Pastaza, in close collaboration with the local communities, in order to collect and safeguard the maximum number of native aromatic cocoa trees. The objective of our study was to evaluate the genetic diversity of this new collection of cocoa trees previously targeted in the putative area of origin of the Nacional variety and areas further north. A total of 283 native accessions was collected and safeguarded at experimental stations and in local communities. The genetic diversity of the cocoa trees was analyzed by comparison to known genetic groups with a set of 48 SSR markers. This new collection shows that this region is a hotspot of cocoa diversity that clearly enriches the currently known diversity and improves knowledge of the global genetic structure of *T. cacao*. Our results clarify the geographic origin of the Nacional variety in the vicinity of an archaeological site that housed a Maya Chinchipe population that consumed cacao 5000 years ago. The collected cocoa trees were replanted in nearby experimental stations and directly in local communities so that farmers have free access. These new genetic resources will be used in breeding

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programs for the varietal improvement of new aromatic cocoa varieties and more globally for the selection of new varieties adapted to environmental changes.

Keywords: Diversity hotspot, Ecuadorian Amazon, Nacional variety

Monitoring of aerial biomass for reforestation processes in cacao agroforestry systems

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ABSTRACT

High deforestation rates derived from the establishment of crops in Colombia and the importance of the reforestation of agroecosystems for the preservation of biodiversity and carbon sinks, make the constant monitoring of processes that support the conformation of natural spaces immersed in agricultural matrices a necessity. With this in mind, PlanT project has specialized in the reforestation of areas where cocoa cultivation has been established intensively and unsustainably, helping to mitigate the negative effects on the landscape and contributing to the conservation of the existing fauna. Obtaining real data, based on reliable and comparable measurements, makes it feasible for projects such as PlanT to continue, therefore, it is necessary to implement and use precision agricultural technologies that allow results to be evaluated. Satellite techniques, especially the use of vegetation indexes, are presented as a low-cost alternative that allows calculating and monitoring forest coverage over time, which will show the impact that reforestation has on the connectivity of some previously deforested areas. In the specific case of PlanT project, changes in the aerial biomass of the reforested areas before and after the establishment of the plantations were monitored using Landsat 8 images, which served as input to determine the NDVI index (Normalized Difference Vegetation Index). For the calculation of the biomass, the diameter and height of the tree, tree cover percentage, and soil inclination were measured. Analyzing the correlation between the invested costs and the obtained results from the field measurements vs the remote sensing processes used, it could be concluded that the use of technology, especially sensors, has a high utility for monitoring coverage changes over time and at a lower cost.

Keywords: Reforestation, NDVI, PlanT

Organically managed cacao agroforestry systems increase soil organic carbon and nitrogen stocks and microbial biomass concentration within six years after establishment

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ABSTRACT

Agroforestry and organic agriculture pursue largely the same goals and methods. The accumulation of biomass to improve soil structure and fertility as a basis for agricultural production and the avoidance of agrochemicals to preserve biodiversity. Nevertheless, there are still many gaps of knowledge about agroforestry systems and organic agriculture, especially about the long-term effects. To address the topics of long-term economic and environmental viability, a long-term trial was set up in Sara Ana, Bolivia. In this study, conventional and organically managed cacao monocultures (MCS) and agroforestry systems (AFS) were compared in terms of soil organic carbon (SOC) and nitrogen (N), microbial biomass, and litter decomposition. SOC and N stocks in the topsoil under cacao trees were significantly higher under organic compared to conventional management practices, while there were no differences between the MCS and AFS with the same management practices. A change between the cultivation systems with increasing soil depth was not found. Microbial biomass strongly decreased from the organic surface layer to the subsoil in all systems. Close to cacao trees, differences in microbial C concentrations became apparent between the four different production systems. Within A and B horizons, there were no differences between the systems. In the organic surface layer microbial N concentration under cacao trees was four times higher in the organically managed systems than in conventional systems. The organically managed AFS had the highest concentrations of microbial N. The annual decomposition rates of cacao and *Erythrina* spp. leaves were not different between the systems, but half-life of cacao leaves litter was almost twice that of *erythrina* leaves. Organically managed cacao agroforestry systems lead to healthier soils and should therefore form the basis for

production that is not only designed for short-term profit, but also preserves soil ecosystem services in the long-term.

Keywords: Agroforestry, Organic agriculture, Soil stocks

Participatory agroforestry design – a flexible approach for locally adapted agroforestry systems

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ABSTRACT

Cocoa agroforestry systems are broadly promoted, with varying guidelines for their implementation. In cases, where projects merely distribute tree seedlings, guidelines on planting patterns and management of the systems are often missing. Different methodologies are proposed to plan agroforestry systems. Here we present a process for participatory design of agroforestry systems, based on a process of sharing experiences, visiting inspiring models of agroforestry and then define individual goals, assess resources and evaluate the opportunities in each individual situation for diversifying production. In the design process, species and crops for combination with cocoa are evaluated in a participatory manner between farmers and technicians, based on different criteria like market possibilities, preferences for subsistence production, strata, life cycle etc. The process can be supported by different visualization tools and feedback from technicians or consultants on the design is important. Locally available data on yields, prices and labour time needed for different crops can further refine the species and their numbers to be planted. We have applied this approach for the design of demo plots in Peru, as well as a part of a training of trainers, with high rate of engagement and adoption. Inspiration, peers' experience sharing and visual tools were extremely important in the process. The fact that the farmers design their agroforestry farm by themselves with just a guidance of technicians, make the system more approachable, holistic and sustainable compared to traditional agroforestry projects. Nevertheless, as each of the cases is individual, the time spent on such design makes it challenging to be applied in large scale at the moment.

Keywords: Co-design, Holistic approach, Capacity building

Understanding the micro-ecosystem of wild cacao in Colombia: the case study of the Cacao Colombia BIO expeditions

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ABSTRACT

The genetic diversity of a crop species such as *Theobroma cacao* is probably too narrow to respond to new adaptations required for the rapid environmental changes occurring in forested regions worldwide. To improve future crop resistance and productivity, it is necessary to widen the gene pool of cultivated species. Using crop wild relatives could be an option to increase the genetic base of a crop such as cacao because they contain unique alleles adapted to a wide range of environments. Colombia is part of the center of origin of cacao, and many cacao crop wild relatives from the genera *Theobroma* and *Herrania* are distributed in Colombia. Two expeditions were conducted in the Amazon region of the Caguan-Caqueta and the Pacific Central Choco region in 2018 and 2019 to explore the ecosystem of Colombian wild populations of *T. cacao* and its wild relatives. We collected 174 samples of *Theobroma* and 37 of *Herrania* species. We also collected samples from species trees located in radio up to ten meters from a *Theobroma* tree, to study the plant species diversity associated with the cacao crop wild relatives' ecosystem. Biogeographical analyses were conducted at the national and regional levels using the species distributions and climate. Species were identified using taxonomic classification and confirmed with a DNA barcoding approach using two chloroplast regions, *rbcL* and the spacer between genes *trnH-psbA*. The distribution, composition, and genetic diversity of tree species that coexist with *Theobroma* and *Herrania* species were analyzed. The bacterial endophytic population isolated from leaves was identified using the sequence RNA 16S to compare the diversity of the endophytic community associated with cacao and its crop wild relatives. The multi-level and inter-disciplinary approach to studying the micro-ecosystem of cacao in the wild is novel and helped to improve the underst

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Keywords: Crop wild relatives, endophytes, plant interactions

Diversity and Uses of Non-Timber Forest Products in Organic Cocoa base Agroforests in the South-East of Côte d'Ivoire.

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ABSTRACT

In the South-East of Côte d'Ivoire, through the Project REDD+, the NGO NITIDÆ has certified as organic some agroforestry farms according to a strict base among which the presence of NTFPs. The current study highlighted the diversity and importance of the uses of those NTFPs in the Region of La Mé. The main question of the study is to record the NTFPs present in these organic cocoa farms and the diversity of their uses. To answer the question, an assessment of the NTFPs and their importance have been carried out in 50 organic cocoa plots in three sites. Ethnobotanical surveys among 50 producers and 75 stakeholders involved in the valorization of NTFPs with economic potential were conducted through a questionnaire. The perceptions of these people have also been investigated to know how and why they keep trees in their farms. In each selected farm, botanical inventories have been conducted to record, identify, and measure the tree species diameters. Data collected were analysed by using ethnological, botanical, economical, and statistical methods through the Software R. The quantities and qualities of sold NTFPs have been evaluated. The study revealed a great diversity of spontaneous species linked to the biological richness of cocoa agroforests. From our surveys, 48 species among those inventoried were used diversely by local populations for food, medicinal, cultural, aromatic and others (crafts, packaging) purposes for diverse reasons. The fruits and barks of these trees were the most used organs. The study allowed to identify the distribution channel of the most used NTFPs from locally to neighbouring countries. The total income from the sale of these NTFPs was around 2.154 million FCFA (3,597 million \$ US) varying from one actor of the chain to another. Some challenges remain to make the value chain sustainable.

Keywords: NTFPs, Agroforestry, Organic cocoa

Economic profitability of cocoa-based agroforestry systems in the transition zone in central Côte d'Ivoire

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ABSTRACT

Cocoa production in Côte d'Ivoire is generally based on "full sun" crops. However, the presence of traditional Agroforestry Systems based on cocoa (AFSc) has been highlighted in several regions including the Centre and the Centre-West. This study was carried out in the centre of Côte d'Ivoire, in a forest-savannah transition zone considered unfavorable to cocoa cultivation because of the low rainfall and the long dry season observed. Small producers have nevertheless managed to circumvent these obstacles by adopting agroforestry systems. This study therefore aimed to provide information on the financial profitability and potential economic value of simple, mixed and complex AFSc types identified in central Côte d'Ivoire. A socio-economic survey and direct observation of farmers with these types of AFSc, revealed an average annual cocoa production of 207.7 kg ha⁻¹ (i.e., 323.9 USD). This income does not vary significantly from one type to another. The fruit species associated with cocoa trees bring in an average of 32.39 USD ha⁻¹ yr⁻¹. This fruit intake is greater in simple AFSc than in the other two types. Given the profitability of cocoa trees and associated species, no system is more profitable than another. However, the potential economic value of the stored carbon and the other benefits that the complex AFSc type offers to farmers make this type more efficient and sustainable than the other two, considering ecosystem services. We therefore recommend considering payment for ecosystem services if one wishes to promote complex cocoa agroforestry systems in the study areas.

Keywords: Cocoa agroforestry systems, Ecosystem services, Côte d'Ivoire

Improving Access to Information on Cocoa Planting Material to Benefit Farmers: An Introduction to the Updated International Cocoa Germplasm Database

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ABSTRACT

Getting the right planting materials to farmers, now and in the future, is a key component of sustainable cocoa production. The International Cocoa Germplasm Database (ICGD) is the primary source of information on the characteristics, origin and location of cocoa clones worldwide and has long been a tool for breeders to identify and locate new genetic resources for breeding improved, resilient cocoa plants. However, the inclusion of ‘Recommended Planting Materials’ for different regions, as defined by national cocoa organisations, means that ICGD can help the decision-making of cocoa farmers and organisations involved in growing cocoa. This paper explores the new features available to users of ICGD and illustrates how to best access the wealth of information that the database contains. It explains how searches for multiple traits can be easily combined to form complex queries, describes how the search results are presented in a way that reflects the search inputs, and demonstrates how additional information can be accessed. ICGD is made available free of charge via the website ‘www.icgd.reading.ac.uk’ and the website has been redesigned to allow improved access via mobile devices and with better integration with the International Cocoa Quarantine Centre at Reading (ICQC,R) to allow quick access to up-to-date information on the clones available for distribution. Search options have been updated to be more dynamic (based on available data) and expanded to incorporate new data recently added to ICGD, including recommended planting material, details on available genomic data, and climate change-related physiological traits. Improved access to genetic fingerprints, including reference genotypes, helps breeders and researchers confirm the identity of the plants they are using. Clone lists generated by any search (including group names, such as ‘ICS’) can be submitted to further searches (e.g. locations holding the clones). All information in ICGD is referenced to its original source and has been obtained from a wide range of publications, proceedings and reports, as well as directly from International Symposium on Cocoa Research, 5-7 December 2022, Montpellier, France

individuals from research institutions and genebanks. With information on around twelve thousand cocoa clones, including yield components, quality attributes and disease reactions, ICGD aims to support the continuing conservation and breeding efforts required to maintain sustainable cocoa production in the face of increasing pressures from pests and diseases, current low yields, and the uncertainties posed by global climate change.

Keywords: Information, Planting material, Breeding

Rootstocks: A key tool in adapting to climate change

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ABSTRACT

Cocoa farming is currently facing scenarios that compromise the sustainability of the crop, both agronomically and commercially, a determining factor is climate change, which can provide conditions such as increased incidence of pests and diseases, climatic disorders, among others. In Colombia, the production chain has been growing, responding to national policies, in this sense, during the year 2021 Colombia obtained a production of 69,040 tons, thus achieving a record production figure; Colombian cocoa has been recognized by the ICCO as fine cocoa flavor and aroma. However, the high demand imposes the need to constantly address challenges and challenges in terms of material management, selection of new genotypes with favorable attributes in terms of production, health, adaptation, evaluation of rootstock materials, evaluation of abiotic factors that limit agricultural production and can generate negative effects on growth, productivity, and can cause damage to cell walls and membranes, stressing the root, restricting the absorption of water and nutrients, such as: drought, salinity, pH, high and low temperatures. Given this background, the National Federation of Cocoa Growers, with resources from the National Cocoa Fund through the Research Program, has been working on the search for new rootstock materials tolerant to water deficit that help genetic improvement and contribute to the expansion and conservation of the genetic base of cocoa. Thus, the evaluation of materials began, where from an initial preliminary selection, 4 materials were prioritized, which demonstrated adaptation to abiotic stress conditions, water deficit. This activity was carried out in the nursery with treatments of 0% (without water application), 25%, 50%, 75% and 100% water, applied at the beginning of the evaluation, the materials that performed best were FBO 1, FSV 80, EET 96 and FSA 20; with these evaluations it is expected to expand the proposal of graft carrier type materials that are becoming widespread in the country, adapting to current demands such as climate change.

Keywords: graft carrier, abiotic, cocoa

Standardisation of physiological trait measurement protocols for identifying cacao climate resilience

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ABSTRACT

Traditional cacao breeders have largely omitted integrating physiological traits within their breeding programmes, and yet this is critical for building climate-resilient cacao. The Collaborative Framework for Cacao Evaluation- Climate Change (CFCE-CC) project aimed to help fill this gap and respond to predicted climate change in Brazil, Colombia, and Costa Rica (funded by WCF), and Côte d'Ivoire (funded by the ECA-Caobisco Joint Cocoa Research Fund). Its overall goal is to help increase sustainability and climate resilience of cocoa productivity and quality with better information on improved, diverse and locally-adapted cocoa varieties based on a set of combined physiological, agronomic and production traits. In the context of challenges to worldwide cacao production (e.g. low yields; high pest and disease pressure, increasingly longer droughts) this first phase' CFCE-CC project has delivered: i) a set of criteria for cacao breeding for resilience on climate change; ii) a platform for scientists to share data, knowledge and experiences, and iii) a set of relevant elements to define suitable growing systems for cacao production. This project team proposed innovative methods and standardized protocols for measurement of physiological traits to enable comparison of germplasm at different locations. Key traits were sorted by category and existing protocols for their measurement were documented, compiling both 'low-' and 'high-tech' options along with their measurement methodologies and equipment requirements. Twenty-eight traits were linked to an existing cacao ontology and grouped for i) Growth (13 traits - leaf, root, biomass etc.); ii) Yield/ quality (4 traits - pod, cherelle), and iii) Physiological responses (12 traits - photosynthesis, gas/water use). Ultimately this rationalized list of traits will facilitate integrating key physiological parameters within cacao breeding programs for drought tolerance, high temperature resilience

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and water-use efficiency. Through a nascent project platform, scientists will be able to share data, knowledge and experiences in the CFCE-CC context. As an evolving shared space, the Platform presents the CFCE-CC project work in progress, aiming at boosting cocoa productivity, quality and climate resilience via optimizing genetic diversity to develop drought- and high temperature-tolerant cocoa varieties. The Platform will facilitate: i) monitoring and documenting development of common protocols; ii) catalysing interactions between key project stakeholders through access to methodologies and project results; and iii) discussions on climate change and cocoa. To consolidate this work, a second phase is proposed, including more producing countries, where selection criteria for climate-resilient germplasm would be validated and information on the resilience of germplasm shared.

Keywords: climate-resilient cacao, physiological traits measurement, cacao-knowledge platform

Conservation and introduction of woody species into cocoa-based agroforestry systems for biodiversity conservation, production diversification and climate change mitigation in Cameroon

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ABSTRACT

Often practiced to the detriment of natural forest vegetation, cocoa cultivation is among the most important factors of deforestation. In Cameroon, in an effort to diversify crops and production, farmers cultivate cocoa in agroforestry systems by conserving or introducing useful woody species. Our studies were carried out in the Center, East and Littoral, regions with the objective of analyzing the contribution of cocoa agroforestry systems (AFS) to biodiversity conservation, carbon storage and production diversification. Floristic inventories were carried out in agroforestry plots and surveys were conducted among farmers to identify the origin, and the uses of trees. In all three regions, the density of cocoa is on average lower than the agronomic recommendations of one thousand one hundred stems/ha. As for the number of associated species per hectare, it was higher in the East region (9.16 species/ha). Shannon diversity indices in Center and Littoral regions were low, less than 3. In these two regions, the low diversity of AFS ($H' < 3$) characterizes the dominance of a group of species, most often introduced and fruits trees (*Cola acuminata*, *Elaeis guineensis*, *Carica papaya*, *Persea americana* and *Dacryodes edulis*). The associated trees are mostly multi-purpose trees with at least two uses and can have up to five. Food is the first use represented much more by fruit trees. Wood is also one of the main products of the trees, as well as medicine, the improvement of soil fertility and providing shade to cocoa. Associated trees also contributed to climate change mitigation through their carbon storage potential. This potential was estimated between 88 and 121 tCO₂ h⁻¹. A large number of species with a conservation issue according to the status of the International Union for the conservation of nature (IUCN) red list have been identified in cocoa AFS. However, the conservation of trees in cocoa farms also has constraints, the most important of which are excess shade, which also leads to high maintenance costs through pruning of trees. The lack of seedlings and land tenure are also constraints to tree conservation. Strategies to improve the cocoa based AFS must take into account the

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tree species needed by farmers and support these farmers in their search for the best trade-offs between cocoa production and biodiversity conservation.

Keywords: associated trees, cocoa agroforestry system, tree uses

Agroforestry systems and the incidence on water status of cacao trees

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ABSTRACT

The world scenario of the cocoa sector faces challenges for bean production, due to prolonged periods of global events, which increase temperature, generate changes in rainfall patterns, precipitation regimes, and reduced productivity. Climate alterations will be critical in production areas with water availability restrictions that can affect the cocoa plant, as it is sensitive to drought, water limitations, and have a direct negative effect on leaf physiology, fruit, and bean size. Colombia called cocoa the "crop of peace" because of its contribution to post-conflict in the substitution of illicit crops. Under this scenario, some producing areas have been established in regions with severe restrictions (rainfall < 1500 mm/year) that limit the development of the crop and its production. The research was focused on agroforestry systems (AFS) with cocoa established in dry tropical zones (Department of Huila, Colombia), where the influence of tree cover on the water status (sap flow and water potential) of cocoa trees was studied. Cacao trees of genotype CCN51, established in free solar exposure (SLE) and SAF systems, were used in a productive state. Climate and soil conditions were homogeneous in the plots, since they were located on the same farm. To measure sap flow and water potential, SFM1 type sensors and PSY stem psychrometers were used, respectively, both installed on the main trunk of 3 cocoa trees in each plot ($n=9$). Data were scheduled to be stored every ten minutes and downloaded weekly. Sap flow and water potential data were obtained at 2 precipitation epochs, maximum (March and April 2017) and minimum (September and October 2017). Data were analyzed by fitting linear mixed models. An effect of the production system and monitoring season on sap flow and water potential in cocoa plants was found. Water potential was higher in SLE in both seasons, but it was more accentuated in the season of minimum rainfall. The opposite behavior of sap flow was found since this variable was higher in SAF during minimum rainfall. The management of shade canopies in cocoa crops under suboptimal climates has a positive impact on water status and is an alternative for the adaptation of cocoa to climate changes.

Keywords: Sap flow, Water potential;, Agroforestry

Osmotic adjustment of cocoa genotypes (*Theobroma cacao* L.) of Ecuador's national variety in an environment with drought seasonal

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ABSTRACT

Almost all the world cocoa supply comes from rainfed production systems affected by different degrees of drought, an aspect that underlines the importance of genetic improvement for cocoa tolerance to water deficit. In this context, an investigation was carried out in the main cocoa producing area of Ecuador to identify genotypes with this attribute. The study included the determination of the hydric (Ψ_f) and osmotic ($\Psi\pi$) potentials, osmotic adjustment (Δo) and modulus of elasticity (ϵ), in 10 genotypes of the National and CCN 51 varieties, and analysis of their relationships with N-foliar, specific leaf area (AFE), stomatal density (DE) and yield. The complete randomized design was used, the t 0.05 test to separate the effect of the rainy and dry periods and the Duncan 0.05 test to differentiate between genotypes. Rain periodicity affected significantly the behavior of Ψ_f and Δo . The differences between genotypes allowed discriminating the L12H27 with tolerance to water deficit. Regressions to model significant and highly significant correlations revealed the capacity of $\Psi\pi_{100}$ and $\Psi\pi_0$ in the rainy period to predict $\Psi\pi_0$ and ϵ in the dry period; Δo at maximum turgor to predict Δo at minimum turgor; Ψ_f in the rainy season to predict N-foliar; and N-foliar for predicting yield. The curvilinear relationship between Ψ_f and DE underlines the usefulness of DE as a criterion to identify cocoa parents for genetic improvement of drought tolerance.

Keywords: Cocoa, Water deficit, Osmotic adjustment

Genomic insights into the origin, evolution, and local adaptation of cacao populations

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ABSTRACT

Global environmental changes will likely strongly impact the phenology and yield of crops. There is an urgent need to harness the genetic variability of crops ensuring that they adapt to new conditions in response to climate challenges. Climate change is affecting the yield of cacao due to the increase in the variability of rainfall and temperature. Here, we integrate genomic data of more than 350 genotypes of cacao to assess potential adaptive genetic variation that may allow us to predict vulnerability and biogeographical shifts under future climate change scenarios. The cacao genomic data was generated from a sample of individuals found throughout the geographical range of the species permitting identification of genotypes associated with particular climatic regimes. This large genomic dataset also identified novel genotypes, especially in Colombia, that may also be a source of superior traits to address the challenges of changing patterns of abiotic and biotic stress.

Keywords: Genomic, Origin, adaptation

Selection of new varieties of cocoa (*Theobroma cacao* L.) adapted to the effects of climate change in Côte d'Ivoire

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ABSTRACT

In Côte d'Ivoire, climate change is particularly evident in the lengthening of drought periods, which seriously affects the establishment and productivity of cocoa orchards. In addressing this challenge, breeders must maintain or improve tree productivity and bean technological quality. The objective of this work is to select new varieties of high-performance cocoa trees adapted to different agro-climatic zones. The experimental design, which is based on the previous achievements of the CFC/ICCO/Bioversity (2004-2009) and FIRCA (2008-2011) projects, includes four agro-climatic zones (Bouaflé, Abengourou, Divo and Soubré) including two with rainfall deficit (Bouaflé and Abengourou). The planting material, planted in two plots per zone, is made up of 15 CNRA families common to each agro-climatic zone and 10 to 15 free progenies, selected in each zone by the cocoa producers for their superior agronomic and technological performance. The traits studied concerned i) the production potential, ii) the adult vegetative vigor measured by the diameter at the collar of the trees, iii) the grain size evaluated by the weight of 100 dry cocoa beans, and iv) the field resistance to black pod-rot (caused by *Phytophthora* spp.), evaluated by the percentage of rotten pods. The results showed that with the exception of field resistance to black pod-rot, a highly significant zone x family interaction (probability < 0.0001) was observed for the studied traits. In particular, the negative impact of drought on the weight of dry bean size has been highlighted. The study also allowed the selection of four families of promising hybrids for resistance to black pod disease in the field, and nine remarkable farmer-selected progenies for bean size. For most of the traits studied, six families of hybrids were ranked among the ten best families in all the study areas, thus highlighting the stability of these families for these traits, regardless of the water regime of the area.

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The interest of releasing these varieties of selected cocoa trees in production areas with low rainfall in Côte d'Ivoire was considered and discussed.

Keywords: climate change, agro-climatic zone, breeding

Fairtrade and Climate Change: Analyzing impacts on cocoa producers in Ghana

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ABSTRACT

Climate change is expected to severely impact agricultural production in the future. Identifying future climate change impacts on certified agricultural producers remains a challenging task. On the one side, there is numerous case-study evidence on past climate change impacts for different regions and crops. Such knowledge is however not always transferrable to other regions. On the other side, global studies on potential climate change impacts on main agricultural products present an overview of potential future impacts, while neglecting regional economic, cultural, and biophysical contexts. The aim of this study was to understand climate change impacts on farmers and cooperatives and how well climate change projects are addressing the farmers and the cooperative's needs. A combination of different methods including a systematic review of the documentation and a hotspot analysis was key to generate a deep understanding on the impacts of climate change on Fairtrade cocoa producers in Ghana. By synthesizing spatially explicit data from global climate change models for a world-wide analysis of climate change impacts on different crops, a pattern is observed, where most locations of current cocoa production will experience more days with extreme temperatures under a low emission scenario. Under a high-emission scenario, all cocoa producing locations will experience considerably more heat stress. Fairtrade production regions seem to be less affected by climate change indicators (consecutive dry days, warm spell duration index, extreme rainfall events) compared to other, non-Fairtrade production regions for the same crops. Results of interviews with Fairtrade Producers Organization Managers and a standardized producer survey indicate that farmers are aware of severe changes which demand a shift in their agricultural practices and livelihoods. In comparison to other crops in the identified hotspot areas, cocoa farmers reported the severest climate change impacts, particularly a negative effect on yields. Mitigation strategies include planting shade trees and implementing improved agricultural practices. Overall responses and the degree of changes in practices vary considerably between producers. Nevertheless, the need for further farmer-inclusive trials and further adaptations of agricultural practices come alongside economic needs intensified by the unstable context related to Covid-19, which fall disproportionately onto disadvantaged producers.

Keywords: Climate change, Fairtrade, adaptation

How to boost cocoa yield in Ghana? – quantifying the cocoa yield gap and identifying its drivers (CocoaSoils project)

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ABSTRACT

Globally, cocoa production is largely concentrated in West Africa where over 70% of cocoa is produced. In this region, cocoa farming is largely a rain-fed, low-input system with low average yields, which are expected to reduce due to climate change. With increasing demand, there is a need to increase global cocoa production whilst avoiding deforestation and expansion to croplands. Thus, it is important to know how much additional cocoa can be produced on existing farmland, and what factors determine this potential for increased yield. In our study, we estimate the cocoa yield gap by calculating water-limited potential yields for cocoa as the upper limit that can be achieved on existing land in a rain-fed system using a physiological crop growth and production model for cocoa (CASE2) and comparing this with achieved yields by farmers across 93 cocoa farms in Ghana. We then related the estimated absolute and relative cocoa yield gaps to environmental and management factors using mixed-effects models to identify potential causes of yield gaps and opportunities and entry points for sustainable intensification. We found considerable yield gaps on all cocoa farms. Absolute yield gaps ranged from 2,223 to 6,071 kg/ha across sites (mean=4,577 kg/ha) and relative yield gaps from 49 to 98% (mean= 86%). Thus, current farmer yields are only 14% of the potential under rain-fed conditions. Mixed-effects models showed that the absolute yield gaps were larger at sites with higher precipitation in the minor wet season and higher minimum temperature in the minor dry season. This model explained 22% of the variability in the yield gaps. In contrast, variation in the relative yield gaps was driven by management factors only, as normalizing water-limited yields results in a weak climate signal. The mixed-effect model showed that the relative yield gaps were reduced by increasing cocoa planting density and the application of fungicide against black pod, explaining 33%

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of the variability. In conclusion, the absolute cocoa yield gaps in Ghana are determined by climate with larger yield gaps in humid areas, whereas the relative yield gaps can be reduced by agronomic management practices. This suggests that improved practices offer opportunities to substantially increase cocoa production and close yield gaps without increasing planted area, regardless of current climate conditions.

Keywords: crop model, water-limited yield, cocoa yield gap

From living wage to living income: economic analysis of the cocoa value chain in Ghana

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ABSTRACT

What is the impact of living income concept implementation in Ghana on small-scale farmer's livelihood? How does productivity of farmers increase related to technic of farming improvement? And much more, what is the difference between farmers involved in this concept and those who are not? To answer these questions, we addressed a semi-structured questionnaire to 120 farmers in Kumasi region in Ghana. The data collection took place inside communities in Kumasi between October and November 2020. The analysis with R-studio helps to demonstrate 3 main categories of results. The first category, which is descriptive, is based on the socio-economic analysis of the group of people interviewed. It shown that there is no big difference between owners of farm. Most of the person living in each household depend on the income from cocoa production and other activities as trading and commerce. Against all expectations, women have a larger plot of land at their disposal and their production is therefore higher. This is followed by the statistical analysis of the data on annual yield, income, certification and all the activities in which the producers are involved and that punctuate their lifestyle. To increase productivity, farmers use pesticides, followed by fertilizers, but also practice agroforestry. They are not benefiting from financial institution loans, but 50% of them are certified through Cocoa life institution and assumed that they are not meeting living income expectations however there is a positive change of income. Finally, the third part is based on a comparative analysis of living standards over a period of time and the level of influence of financial institutions and cooperatives on production and recreation activities. Food, school fees and transportation are the most costing services to farmers. However, they are involved in majority in cooperative, they find credit from the cooperative and have a basic recreative activity. We assume that the proximity of schools in most of the case, could be one of reason of resilience of children in schools. The question on women leadership is nevertheless, mitigated. Women are strongly involved in the production activities but their encountering or segregation inside the community is mainly doubted. In spite of belonging to

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certification structures, farmers are entirely part of cooperatives and it would seem that they have a great preference and faith in cooperatives.

Keywords: Cocoa certification, Value chain, Poverty reduction

Structure and composition of cocoa agroforests in the Yangambi biosphere reserve in the Democratic Republic of Congo (DRC)

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ABSTRACT

Cocoa agroforests (C-AFS) can help developing sustainable land use. Those with forest-like structures are of particular interest since they are able to support a large array of ecosystem services while theoretically providing rural households with income and contribute to food security. This study describes the typologies of cocoa agroforests in the landscape of the Yangambi reserve, located in the northeast of the DRC. A botanical inventory was carried out on 55 C-AFS, both from smallholder farmers (n=33) and from the National Institute for Agronomic Studies and Research demonstration plots (INERA; n=22). We measured associated perennials and cocoa trees diameter at breast height and height. Using surveys and bibliography, we also documented associated perennials succession guild, leaf-life span, farmer use and IUCN status. We then performed a Principal Component Analysis followed by a hierarchical ascending classification. We finally discriminated between the groups obtained using an ANCOVA using age of the C-AFS as a covariate. Our results underline that, while studied C-AFS showed equivalent densities of associated perennials, 3 groups could be distinguished. Group 1 (n=20) comprised of a majority of INERA plots and were characterized by the lowest density and basal area of cocoa trees and highest proportion of timber species. Group 2 (n=16) comprised plots with the highest basal area of cocoa trees, lowest height and highest proportion of pioneering and medicinal perennials. Group 3 (n=19) distinguished from others by its highest proportion of palms and lowest associated species diversity. Finally, none of the C-AFS studied comprised associated perennials with significant conservation concerns. Thus, our study highlights the three main types of objectives given by (or corresponding to the need of) local farmers to C-AFS: (i) production of cocoa and timber – at the expenses of cocoa; (ii) production cocoa and traditional/multiple use of their associated perennials; (iii) production of cocoa and food. The composition

and structure of C-AFS in the study area are determined also by the history of the plot and the proximity of mature forest. Indeed, while keeping approximately 89 associated trees per hectare (excluding palms), these C-AFS can't participate to species conservation at an interesting level. This may be due to selective logging undertaken before people install cocoa. Yet, their diversity level is worth mentioning since they seem to both provide direct multiple services to the farmers cultivating them while probably supporting indirect forest-like ecosystem services compared to very simple of full sun systems.

Keywords: cocoa agroforestry, biodiversity conservation, Congo basin

Physiological, productive and health performance of regional cocoa genotypes with tropical fine woods, Agrosavia model.

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ABSTRACT

In Colombia there are about 178,000 ha of cocoa cultivated in association with fruit and timber species, with a production of 64,281 tons year⁻¹ and an average yield of 0.34 ton ha⁻¹. Because of its growth habit, cocoa is grown in agroforestry systems, in association with other plant species, which provide shade and allow the farmer to obtain alternative income. In this sense, the interaction between the genotypic characteristics of the cocoa plant and its agroecological environment (e.g. agroforestry system, altitudinal gradient) promote the variable expression or not of its production attributes and resistance to natural enemies. The objective of this research was to evaluate the physiological, sanitary and productive behavior of outstanding cocoa genotypes associated with different planting designs and environmental conditions. For this research, nine cocoa clones (SCC 13, 19, 53, 82, 83, CCS 73, 77, 80 and ICS 95) were established under an agroforestry system with Abarco (*Cariniana piryformis*), Teca (*Tectona grandis*) and Caucho (*Hevea brasiliensis*) shades established in two locations (El Carmen and Rionegro), corresponding to two agroecological zones (Santander Mountain and Middle Magdalena) in Santander. The photosynthesis rate and light saturation curves (A/Q) per cocoa genotype under agroforestry arrangements (Abarco - Caucho in El Carmen and Abarco - Teca in Rionegro) were evaluated with the ADC Lc Pro plus photosynthesis measuring equipment. The results showed no significant effects of shade systems on the photosynthesis rates exhibited by the cocoa clones. However, the wet season showed higher photosynthetic activity (4.94 $\mu\text{moles CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) than the dry season (4.3 $\mu\text{moles CO}_2 \text{ m}^{-2} \text{ s}^{-1}$). SCC 19 showed the highest photosynthetic rate with average values of 5.63 $\mu\text{moles CO}_2 \text{ m}^{-2} \text{ s}^{-1}$. Regarding the light curves, the photosynthetic rate increased with increasing light intensity, reaching a maximum inhibition of 1000 μmoles of photons $\text{m}^{-2} \text{ s}^{-1}$. Regarding productivity, the clones expressing the highest yield were SCC 19 with 1.8 kg ha⁻¹ and SCC 13 with 1.6 kg ha⁻¹ under Abarco shade, with *Monilia* losses of 5 and 8%, respectively; productivity is related to the higher photosynthetic rates of the clones. In conclusion, the regional clones should be planted in agroforestry arrangements

that provide between 40 and 50% shade. Light intensities above 1000 μmoles of photons $\text{m}^{-2} \text{s}^{-1}$ can cause a reduction in photosynthesis levels, so shading that reduces light to these levels is recommended.

Keywords: Theobroma cacao, Physiology, Agroforestry

Effect of Climate Change on the Management of Phytophthora Pod rot of Cacao in Nigeria

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ABSTRACT

Cocoa production is an important economic activity in growing ecologies of Nigeria. *Theobroma cacao* is prone to diseases, among which pod rot caused by *Phytophthora megakarya* and *P. palmivora* is endemic with economic crop losses if not managed. Despite regular application of fungicide every rainy season coupled with regular farm sanitation, there are still regular outbreak of the disease every year. Without protection, cocoa pod can easily succumb to infection caused by *P. megakarya* and *P. palmivora*. Effect of climate change on the management of *Phytophthora* pod rot was conducted in 2014, 2015 and 2016 at Onigambari Experimental Station, Ibadan- Lat. 7.216°N, Long. 3.852°E by application of copper-1-oxide 60% + metalaxyl 12% WP between May and October each year. Three spray regimes (fortnight-spray, monthly-spray and no spray application) were adopted. The regression analysis of weather parameters (relative humidity, temperature and rainfall) with black pod disease incidence indicate strong relationship and high R-square value. Weather significantly affect the black pod incidence: positive correlation between black pod incidence and relative humidity ($r = 0.19, 0.53$) except in year 2016 which recorded a negative linear correlation ($r = -0.19$). Negative correlation ($r = -0.54$) was recorded between black pod incidence and temperature in year 2014 and 2015 but positive ($r = 0.53$) in 2016. The linear relationship between black pod disease and rainfall showed a negative correlation ($r = -0.42$). Effect of weather was established both in temporal and spatial distribution of pod rot incidence in cocoa production and environmental factors influencing development of *Phytophthora* pod rot were both positively and negatively correlated.

Keywords: Cacao, *Phytophthora* pod rot, climate change

Sustainable Cocoa and Climate change: Impact on farmers in Costa Rica and the Dominican Republic.

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ABSTRACT

Even after the damages caused by monilia in the 1980's, production in Costa Rica remains a 100 % Fine or Flavor Cocoa. Both countries are often used as successful examples of sustainable quality cocoa in different ways, Costa Rica being the country where the renowned Tropical Agricultural Research and Higher Education Center (CATIE) is located, and the Dominican Republic having experienced a great paradigmatic shift regarding its production, placing it now as a premier organic cocoa exporter in the world, with 40 % of its production classified as Fine and Flavor Cocoa when it was known in the 1980's as a bulk and cheap cocoa producer. Many interventions, originating from international organizations, from state administrations and from the private sector take place in the cocoa sector. Analyzing how farmers are impacted by these external interventions will be the main goal of this presentation. Using field work realized since 2011 and doctoral research data collected during the past three years, I am mobilizing tools from my two educational backgrounds (Engineer in agro-development at ISTOM and Ph. D. candidate in economic geography at Sorbonne Nouvelle) in the fields of comparative agriculture, territorial analysis and cartography. I also approach my subject from the points of view of the global value chain and political ecology theory in order to investigate the value chain of the cocoa sector in both countries, the interactions between the economic actors, and to analyze the projects that have been carried out, the discourses that are used regarding sustainability and climate change, and finally the national governance in both countries. Proposals would point to agroforestry practices, improvement of productivity and to diversification techniques, using tourism as an economic perspective. The presentation will show how, sometimes, projects are disconnected from farmers' economic and social realities and how cocoa has been a crop subject to a constant flow of social, environmental, and economic initiatives that have transformed ways of life and agricultural practices. In that sense, cocoa is a fascinating crop that reveals the "colonial" status of a globalized product of great international importance, through the circulation of knowledge, this circulation highlighting relations of power and forms of control.

Keywords: cacao, sustainability, farmer

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SESSION 3

INNOVATIONS TO SUPPORT THE COCOA PROCESSING AND MARKET DEVELOPMENT



ORAL PRESENTATIONS



Decoding the fine flavour properties of dark chocolates

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ABSTRACT

The demand of consumers for high quality chocolate, organic cocoa and bean-to-bar products is increasing. Bean-to-bar chocolates are made of cocoa beans of defined variety and origin and differentiate themselves by its unique flavour properties in contrast to products from the mass market. In the past, a lot of research has been done in defining the flavour properties of cocoa and chocolate intermediates as well as their off-flavours. This research has been mostly conducted on products produced on high industrial scale, deriving from blends of cocoa beans from different origins to achieve a consistent standard quality. However, the specific fine flavour attributes of cocoa liquors or the dark chocolates produced thereof deriving from defined origins and varieties have been scarcely investigated on molecular level. Therefore, the aim of this investigation was to decode the fine flavour properties of chocolates with specific flavour attributes produced of reference liquors of the Cocoa of Excellence Programme. For this reason, reference liquors with distinct fruity, floral or cocoa-like flavour profiles were selected and the corresponding chocolates were analysed for their molecular flavour composition. After the screening for odour-active molecules by means of aroma extract dilution analysis (AEDA), selected key flavour compounds have been quantified in the chocolates with the overall aim to decode the fine flavour properties on molecular level. This way it could be observed that fruity and acidic flavour attributes were linked to high odour activity values (OAVs) of acetic acid and fruity smelling esters. Chocolates with intense cocoa-like and roasty flavour attributes showed high OAVs for the odorants 2- and 3-methylbutanal as well as for furaneol and dimethyl trisulfide. The flavour attributes floral and astringent were characterised by high dose over threshold values (DoTs) of epicatechin, procyanidin B2 and high OAV of 2-phenylethan-1-ol. The acquired knowledge of the molecular composition of selected cocoa fine flavour attributes provides a basis for future quality assessment of cocoa and chocolate and the

development of standardised training samples for sensory evaluation of cocoa products.

Keywords: dark chocolates, flavour-active compounds, sensory references

Characterisation of the digital divide and assessment of the impact of the use and non-use of digital tools in the Ivorian cocoa sector

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ABSTRACT

Digital tools have changed our daily lives, both in our personal and professional environment, over the last few decades. This is also the true for the agricultural sector, especially in the North where these uses and their relevance are documented and studied. On the other hand, in countries where agriculture is not subsidised and where farm incomes are low, few studies have looked into the use or non-use of digital tools and their impacts on the various actors in the agricultural sector. To address this shortcoming, we conducted a study to characterise the different uses of information and communication technologies (ICTs) among the different actors in the cocoa production chain in Côte d'Ivoire. This work makes it possible to evaluate the level of the digital divide that exists at the inter- and intra-actor category level and to understand the socio-eco-geographical determinants of this divide. In addition, a qualitative analysis of the impact of the use and non-use of ICTs allowed us to determine under what conditions ICTs have a beneficial effect on the well-being and living conditions of agricultural households. Our results clearly indicate a significant digital divide between the farmer population and the actors who gravitate around them. In other words, there is a digital data gap between those who produce the data, i.e. the farmers, and those who use it. Indeed, less than 5% of cocoa farmers use digital tools such as online payment services to sell their cocoa or agricultural messaging services to know the weather and the selling prices of agricultural products. In contrast, the other entities that structure the upstream part of the sector use many useful ICTs to optimise the management of their activities and thus maximise their profits. Focus groups were used to assess the positive and negative impacts of the emergence of digital tools on farm households. Participatory work between the various actors in the cocoa sector, digital entrepreneurs and policy makers has highlighted original digital development orientations. These should lead to the emergence of digital tools that are more relevant because more inclusive and more useful than those that exist today.

Keywords: digital divide, cocoa sector, ICTs

Metal Transporters involved in Cd uptake and distribution in cacao: gene function, evolution, and expression

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ABSTRACT

The tropical tree *Theobroma cacao*, the source of cacao beans, accumulates the harmful heavy metal cadmium (Cd) in its tissues when grown in soils that contain this element. Regulations that limit the amount allowed in chocolate and other cacao derived products have prompted research to develop mitigation solutions. Cd uptake and accumulation share many molecular and physiological pathways used by plants to manage other elements. Several classes of proteins have diverse roles in the transport of metal ions in plants, including Cd. This work investigates one of the main families of Zinc (Zn) and Cd transporters in cacao and its evolution. The HMA family of proteins from cacao, a class of P-type ATPases that plays an important role in Cd redistribution and storage, was identified, and characterized. The work includes characterization of the members of the gene family and their evolution in cacao. Functional characterization of candidate HMA genes was conducted using a yeast expression system and transgenic *Arabidopsis thaliana* complementation to establish the capacity of the encoded proteins to transport Cd and Zn in planta. To gain a more comprehensive understanding of Cd uptake and transport in cacao, the transcriptional response of cacao was evaluated using RNA-Seq in collaboration with the Corporation of Agricultural Development of Colombia (AGROSAVIA), the results of which will be described in another presentation in this symposium (Delgadillo et al).

Keywords: Cadmium, Heavy metals, P-type ATPases

Ureolytic bacteria that induce carbonate precipitation from cocoa farms in Santander, Colombia: cadmium distribution, isolation and application of rhizobacteria

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ABSTRACT

The content of cadmium (Cd), a toxic metal, in cocoa beans with concentrations that exceed the limits established by international regulations is a problem that affects cocoa farmers in various countries. A possible strategy to mitigate the presence of the metal in *Theobroma cacao* L. is the use of ureolytic rhizobacteria (UR) that induce carbonate precipitation (MICP), which alter the Cd fractionation in the soil, reducing its availability and absorption by plants. In this first stage of research, rhizospheric and non-rhizospheric soils and cocoa beans (51 samples of each), were collected in two cocoa farms at Santander, Colombia. Urease activity and Cd content was quantified in soils, and Cd concentration was determined in cocoa beans. Rhizospheric soils were also used to isolate ureolytic rhizobacteria (UR-MICP). Soil urease activity was determined by ammonium production. The quantification of Cd was carried out by atomic absorption spectroscopy with electrothermal atomization, with digestion of soils in a block digester and of plant material in a microwave digester. Cd availability was evaluated with DTPA. The isolation of the UR-MICP was carried out in culture medium supplemented with urea, Cd and/or calcium. In rhizospheric soils, pseudo-total Cd and available Cd concentrations varied from 1.16 to 21.28 mg/kg and 0.72 to 12.16 mg/kg, respectively, and urease activity was between 45.71 and 345.67 mg/kg*2h. On the other hand, non-rhizospheric soils presented pseudo-total Cd concentrations from 0.49 to 3.57 mg/kg, available Cd concentration from 0.23 to 1.83 mg/kg, and urease activity from 11.08 to 146.15 mg/kg* 2h. Results show that the two types of soils have differences in Cd distribution and the presence of hotspots within the farms. These sites should be avoided by cocoa farmers for planting, and could serve as target for UR-MICP application for Cd bioremediation/mitigation. Furthermore, the higher urease activity of rhizospheric soils suggest their functionality and potential for application of the MICP process. Currently, Cd quantification analysis in cocoa beans is ongoing. Finally, from the rhizosphere soil samples, 60 Cd-tolerant UR-MICP bacteria were

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isolated, demonstrating that cocoa soils are niches for this type of microorganisms. The application of UR-MICP bacteria in Cd precipitation assays have a high potential to alter Cd availability in soils and contribute to mitigate this toxic metal in cocoa beans.

Keywords: availability, MICP, *Theobroma cacao* L.

Juicy beans: an integrated concept towards cocoa pulp use and living income

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ABSTRACT

This paper shares an innovative and integrated concept called ‘juicy beans’, which was piloted in the Cocoa Fruit Lab in 2021. Juicy beans are cocoa beans from which a percentage of the cocoa pulp is extracted before 4 day fermentation in a wooden box. The Cocoa Fruit Lab was set up in Bouaflé, by the female-led cocoa cooperative COVIMA, Beyond Beans Foundation/ETG, Döhler, Kumasi Drinks, Anna Laven and Alexandre Bellion, and was co-funded by the Sustainable Trade Initiative (IDH). The aim of the lab was empowering women to become the producers and marketers of their own cocoa products, shifting value-addition processes to origin countries. This micro-factory is ready to produce sustainable and quality cocoa (box-fermented and solar-dried) for export and cocoa juice and specialty chocolate for the local market. Before the Cocoa Fruit Lab came into existence, the COVIMA cooperative and their members proceeded to post-harvest in a traditional way by operating the fermentation in the plantation. During the harvest, the wet cocoa beans are semi-buried and protected by banana leaves for 6 to 7 days without real attention to the lactic and acetic fermentation stages. The juice, a by-product of this wet cocoa mass, was not valued. Moreover the fermented bean was popularized by only these physical aspects, without interest for a taste value. The multi-stakeholder partnership that came together in the micro-lab created momentum and the infrastructure for testing a circular approach and centralize post-harvest work in the Fruit Lab location, as well as the transformation of cocoa into chocolate. Furthermore it allowed to assess the difference between fermentation methods and the valorization of quality attributes, as taste impact, and to explore ways for further optimization of value creation in by-products of the pulp and the beans during the post-harvest. Such an approach potentially brings more value to cocoa farming families by providing them with an outlet for their wet beans (saving labor costs for fermentation and drying the beans) but also by turning cocoa pulp (usually an overlooked waste product) into fruit juice, raising incomes by up to 30% per kilo of

cocoa beans. In addition, the premium quality of the juicy beans might generate an additional premium as it allows for making premium chocolate. Very recently we made the first batch of Ivorian chocolate with ‘juicy beans’ as ingredient. The first tastings seem to confirm our hypothesis that juicy beans translate in very tasty bars.

Keywords: juicy beans, cocoa pulp, living income

Virgin Cocoa Butter from Modified Cocoa Bean Processing

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ABSTRACT

The quality of cocoa butter is determined by the solid fat content, the free fatty acid concentration and the triacylglycerol composition. In addition to the features of the raw material, these parameters are controlled by the process design. To elucidate these impacts, a systematic modification of processing steps was conducted. In this study, cocoa butter and cake were produced in pilot scale with or without bean fermentation, deshelling and roasting followed by hydraulic or expeller pressing of cocoa mass or nibs, respectively. The conventional cocoa bean processing employing fermentation, deshelling, roasting and hydraulic pressing, was found to be superior for the production of cocoa butter at the highest yield. However, the resulting butter was attributed with a lower solid fat content and a higher concentration of free fatty acids compared to other processing methods. Alternatively, the cocoa beans that have been treated without fermentation and roasting, continued with expeller pressing are resulting in cocoa butter with increased solid fat content and decreased free fatty acids compared to conventional processed butter. The proportions of the triacylglycerols SOS (C18:0–C18:1–C18:0) and POS (C16:0–C18:1–C16:0) compared with POP (C16:0–C18:1–C16:0) were found to be higher in cocoa butter from expeller pressing, than from hydraulic pressing, which may contribute to the higher melting temperature. Less free fatty acids in butter of unfermented beans, is possibly because the obstruction of enzymatic hydrolysis occurring during fermentation. Furthermore, omission of the roasting step might protect the cocoa butter from thermal damage. The application of expeller pressing, instead of hydraulic pressing, might expose cocoa beans with less pressure and thus prevent lipid hydrolysis. The term ‘virgin cocoa butter’ is proposed to refer to cocoa butter that obtain minimal effects from enzymatic and thermal reactions, produced from unfermented and unroasted cocoa beans. For chocolate industry, this virgin cocoa butter has potential use as a seed material for fat crystallization or as the additional fat to improve the melting property of the chocolate. Production of virgin cocoa butter could also serve as a strategy to utilize unfermented cocoa beans that are already in the market. Compared to conventional processing, the cocoa cake from

unfermented and unroasted cocoa beans was characterized with higher concentrations of polyphenols, which carry bitter and astringent notes, but are associated with health benefits, particularly cardioprotective effects. The use of the press cake beyond classic chocolate production is therefore currently under study.

Keywords: Cocoa butter, Quality, Processing

Is chocolate consumption truly enhancing dietary cadmium intake in the general population? A Belgian consumption survey.

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ABSTRACT

The main cadmium (Cd) exposure route in the non-smoking population is the diet. Large contributors to the diet are staple foods such as grain products. However, luxury products such as chocolate and other cacao-derived products can also be relevant due to potentially high Cd concentrations. Tolerable weekly and monthly dietary intakes were established by jurisdictions such as EFSA (equivalent to 0.36 µg Cd/kg body weight (BW)/day) and JECFA (≈ 0.83 µg Cd/kg BW/day). The large contrast between these guidelines results in conflicting dietary recommendations for the consumer. Furthermore, current dietary exposure studies result in non-detailed consumption data based on broad food categories and do thus not succeed in quantifying the dietary intake from cacao-derived products. Included categories are for example dark and milk chocolate, while it is crucial to have more detailed information concerning cacao concentration and origin. Such low resolution in consumption data can lead to over- or underestimation of cacao-related Cd exposure, especially for individuals with high exposure consumption patterns that include, for example, high cacao content single origin dark chocolates. The objectives of this research are (i) to accurately quantify the consumption of cacao-derived products in the Belgian population and (ii) to use those consumption data to calculate the resulting Cd intake. First, an online- consumption survey was conducted in a sample (N = 1530; age 3 – 85) of the Belgian population, in which respondents were asked to report their consumption of all cacao-derived products (i.e. bread toppings, chocolate bars, desserts, snacks...) in two non-consecutive 24-hour recalls. Second, Cd concentrations were determined in a range of cacao-derived products (N = 488) identified in the survey, using microwave-assisted digestion followed by ICP-MS analysis. The data were combined to obtain a distribution of the Cd intake resulting from cacao consumption in Belgium. The median Cd exposure (P50) related to cacao-derived products was 0.009 µg Cd/kg BW/day, while highly exposed individuals (P95) consumed 0.071 µg Cd/kg BW/day. These intakes account for about 0.5% (P50) and 4% (for P95) of the mean total daily Cd intake, indicating low

importance of cacao-derived products for dietary Cd intake. A small fraction of the subjects (0.14%) exceeded the EFSA tolerable Cd intake guideline through cacao consumption. That fraction increased to 2.45% when including the mean Cd exposure from the remainder of the diet. This research is the first step towards more refined Cd risk assessment related to cacao.

Keywords: Consumption survey, Cadmium intake, Exposure study

The effect of soil and foliar Zn and Mn application on the uptake of Cd levels in cacao grown on Cd-rich soils.

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ABSTRACT

Global regulatory bodies have implemented stringent regulations for Cd in chocolates and cocoa-based products to protect their consumers against any potential negative effects. Many countries particularly within the Latin American and Caribbean region are currently faced with the challenge of ensuring that their cocoa beans can meet these maximum allowable Cd limits. Scientific researchers have explored different ways by which Cd may be mitigated at the pre-harvest cacao phase, targeting different soil-plant relationships. One such relationship highlighted in past studies is the negative correlation that exists between Zn and Mn soil concentrations and the levels of Cd accumulated in cacao tissues. In order to determine if there was a direct effect for this relationship, a greenhouse experiment was established to evaluate the effectiveness of soil and foliar applications of Zn and Mn at a single recommended application rate, on Cd bioaccumulation in *Theobroma cacao* L. This experiment was conducted in a completely randomized block design using rooted cacao cuttings of a single variety planted in Cd-rich soil and monitored over a 12-month period. To validate the outcome of the greenhouse study, a subsequent field trial was carried out in a similar randomized complete block design on a site of TSH cacao trees for another 12-month period. The results demonstrate that this approach could be used to reduce Cd levels in cacao tissues and should be explored as an alternative mitigation strategy.

Keywords: Cacao, Cadmium, Mitigation

Agronomic countermeasures for reducing cadmium (Cd) uptake in cacao plantations in Ecuador

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ABSTRACT

Cadmium contamination is reported in beans from Latin America and the Caribbean regions. Soil properties such as soil pH and organic matter are key drivers in Cd uptake by cacao plants. Thus the modification of these properties can impact Cd accumulation in cacao beans. Agronomic countermeasures, i.e., application of soil amendments, has been proposed to mitigate the contamination. In this study, soil amendments were applied at six demonstrative farms localized in distinctive edaphic-climatic conditions. In these farms, Cd in cacao beans were above 1 mg/kg which is considered excessive for export. Treatments included the application of organic matter (compost and biochar), calcium carbonate, and calcium sulfate. The amendments were applied on the top layer of the soil every six months for 24 months. Soil and plant samples were taken periodically to conduct laboratory analysis. Soil amendments affected the targeted properties. Soil organic matter increased between 10 to 90% with the application of 8.6 kg/tree/year, no statistical difference was observed in the lower rate. In average, a difference of 1.53 units was observed when comparing control vs highest rate (2.8 kg/tree/year) of calcium carbonate. This change was observed in the first 15 cm of soil surface. Soil pH was increased in limed soils up to 25 cm depth, then, there was no difference with control. Contrary, calcium sulfate did not alter soil properties. Phytoavailable soil Cd was significantly decreased ($p < 0.05$) in two farms when calcium carbonate or compost were applied. Despite these positive and significant changes in soils, the effect on Cd concentration in leaves or beans was not always observed. For instance, calcium carbonate achieved a Cd decrease ($p < 0.05$) in cacao beans of 50% as compared to control, 22 months after the application. Six months later, this treatment showed 20% higher Cd as compared to the control. Similarly, the application of compost showed a 50% lower ($p < 0.05$) Cd in beans as compared to untreated plants. Again, six months later there was no difference between treatments. Calcium sulfate showed variable results with up to 20% less Cd compared to control. Soil

properties were affected on the surface layer (< 15 cm) only, however, cacao roots penetrate up to 2 m thus Cd could be absorbed deeper in soils. Additionally, Cd concentration varies significantly between replicates which obscures true effect of the treatments. Soil amendment application should be monitored for longer period.

Keywords: soil amendments, contamination, heavy metals

Physical, aromatic and sensory evaluation of cocoa beans developed by agricultural research in Côte d'Ivoire and improvement of harvesting activities and quality of cocoa beans during primary processing activities

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ABSTRACT

In Côte d'Ivoire, most of the cocoa varieties developed by the CNRA are known for their early production, yield, susceptibility to diseases and insect pests and for the physical quality of the beans. The initial properties of these plant materials, characterized by high cocoa intensity and woody flavors, are inhibited by poor harvesting and post-harvest practices. The objectives of this study are, on the one hand, to identify the aromatic profile of the plant material exploited in Côte d'Ivoire and, on the other hand, to raise awareness, in close collaboration with the Conseil Café Cacao and ANADER, of good harvest and post-harvest practices to preserve the traditional flavor of cocoa in Côte d'Ivoire. It is in this context that the WCF African Cocoa Initiative II program supports through USAID, the governments of Côte d'Ivoire, Ghana, Cameroon and Nigeria to preserve the traditional flavor of West African cocoa. This program allowed the establishment of a cocoa sensory analysis laboratory in 2018 at the CNRA and the training of a technical staff and twenty panelists according to the ISCQF International Standards used by Cocoa of Excellence. The evaluations included 133 samples consisting of beans from the MOCA/CNFA project, independent producers, exporters and 16 clone samples also developed in Côte d'Ivoire. The results of the analyses revealed cocoa-intensive samples for some and complementary attributes of floral and fresh fruit notes for others. Producers selected according to their motivation and commitment to improving the quality of Ivorian cocoa and producers involved in the MOCA / CNFA project, were trained and then followed by the regular collection and analysis

of their samples. The results indicate an improvement in the quality of cocoa beans characterized by high cocoa intensity, low acidity, a good balance between bitterness and astringency and light woody and spicy notes. In total, 1200 people including producers, trainers of trainers, ANADER trainers and agent of CNRA involved in cocoa research sector were trained in good harvesting and post-harvest practices.

Keywords: Cocoa, sensory analysis, Côte d'Ivoire

Development of cocoa physical reference samples for training and calibration of sensory evaluation panels: perspectives from a range of food products

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ABSTRACT

A number of food products such as olive oil, wine and coffee have developed standard procedures for sensory evaluation. These include glossaries of terms, physical reference samples for odours and flavours, and evaluation forms. These provide useful models to promote science-based approaches to assessing cocoa quality. The objective of this research is to review the use of physical reference samples of different food products, to guide the development of such references for training and calibration of sensory evaluation panels for cocoa products. A review of literature of 149 articles was carried out, comparing and analysing the following: method and purpose of descriptive sensory analysis, panel size, initial level of training and training duration, number and complexity of sensory attributes, selection and screening of panellists, establishment of physical references, and intensity scales. The analysis resulted in recommendations for the development of cocoa-specific physical references, including the following: standardized procedures for selecting, screening, training, and managing the panel; a universal sensory glossary for cocoa products; standard procedures for selecting, preparing, presenting, and storing physical references; creation of several physical references for flavour attributes, focusing on those correlated to global quality; and a system of certifying descriptive sensory panels focused on the process and not on the training materials. There is an urgent need in cocoa producing countries to build capacity of national sensory panels for the assessment of cocoa quality and flavour, for a better understanding cocoa quality and flavour potential for increased value and profitable production. Physical references are critical for training sensory evaluation panels; and generating a commonly agreed glossary of terms and establishing physical references for cocoa products are essential to ensure panel's performance in terms of repeatability, discrimination and alignment.

Keywords: Physical reference samples, Sensory panels, Training and calibration

Applying computer vision to cocoa bean cut test images: towards an efficient and accessible tool for evaluating physical quality

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ABSTRACT

A cut test is done on fermented and dried beans as the most commonly used method to visually assess bean quality for trading and before it is further processed. It provides information on the internal colour, any signs of diseases and pests and the degree of fissuring. This information is used to select the optimum roasting conditions to process into liquor and sensory evaluations of cocoa liquor and chocolate. The steps involved in cutting the beans for analysis are easily implemented, however the visual assessment requires experience to yield reliable results, and a significant amount of time to process. The objective of this research is to develop a tool by applying deep learning models and to read images of these cut tests to classify them quickly and reliably. This first step involved selecting a variety of cut test images from the extensive library of over 1,000 cocoa beans samples from more than 55 origins of producers participating in the Cocoa of Excellence Programme. A neural network model for semantic segmentation to identify the cut beans within these images was created. The next step involved using cut test images of recently submitted bean samples, along with a number of other bean samples of lower quality to broaden the scope of the attributes used in the network training. From these images, each cut bean was isolated and labelled by an experienced evaluator for each property, providing over 20,000 labelled sub-images. The segmentation model was then applied along with the labelled data to train models each on colour, fissuring, and defects. The segmentation model works well for cut test images, as these are of a relatively consistent type regarding their shapes and background. The deep learning models for colour, fissuring, and defects on these segmented cut bean sub-images were able to reasonably approach the classifications identified by the experienced evaluator, with probabilities approximately increasing with the intensity/clarity of a sample's class. The results of this research demonstrate a proof of concept for providing a digital tool to evaluate cut test images of

fermented and dried cocoa beans. Such a tool would increase capacity of cocoa producers to get immediate feedback on the characteristics of their beans.

Keywords: Cut tests, Cocoa bean quality, Deep learning

First Sensory Map of Cocoa Almonds in the State of Pará, Brazil.

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ABSTRACT

Currently, in the state of Pará, there is an area of approximately 201,000 hectares of cocoa plantations in Agroforest System (147,000 hectares are in production), cultivated by 28,000 farmers and, in year 2021, 133,000 tons of this commodity were produced. This area of cocoa trees is established in 30 municipalities, distributed in five production zones: Southwest Pará, Southeast Pará, Northeast Pará, Tocantins River (island region) and Middle Amazon. These regions, because they have some climatic and soil differences, as well as their planting propagation materials maintain the genetic diversity of the plants, provide interesting differences in their aromas and flavors, opening opportunities for aggregation of values. Thus, knowing the organoleptic constitution of cocoa beans produced in the state of Pará is of fundamental importance for placing them on the international market, especially when it is intended to produce special chocolates. Therefore, obtaining a sensory map of these cocoa beans by region of production will enable a marketing structure capable of positioning the product in a more demanding market. Based on the condition that, in order to produce a quality chocolate, it is necessary that the raw material has good genetics (diversity), proximity to the place of origin of the culture and in the production process, the primary processing of the cocoa beans contemplates the technical rigor in its main stages (fruits at the point of harvest, good fermentation and natural drying), the first “Sensory Map” (figure below) of cocoa beans in the state of Pará was established, based on samples that competed for the award for the best beans for chocolate from the state of Pará, during the International Chocolate and Cocoa Festival of the Amazon in 2019, whose responsibility for the evaluations and results was the experts from Ceplac (Neide Alice B M Perira) and the Cocoa Innovation Center (Adriana Cristina R Ferreira).

Keywords: COCOA, Sensorial Analysis, AMAZON

Influence of Origin and Thermal Processing on the Aroma Quality of Cocoa Fruit Pulp for its Use as a Food Ingredient

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ABSTRACT

By-products of the cocoa supply chain represent together about 70-80% of the fruit's weight and comprise the pod husk, the bean shells and the cocoa fruit pulp. Their disposal raises several social and environmental concerns. Therefore, their use as novel ingredients might increase the sustainability of the cocoa industry. Due to its pleasant flavor, cocoa pulp has gained the attention of European food producers. As large scale processing of the pulp still poses challenges regarding its quality and shelf-life, it has been mainly commercialized within producing countries so far. The influence of the fruit's origin on the aroma composition was analyzed by aroma extract dilution analyses using gas chromatography-mass spectrometry/olfactometry for cocoa pulps from Vietnam, Indonesia, Cameroon and Nicaragua. Altogether, 65 aroma-active regions were determined. Of these, 36 were perceived in all pulps. Odorants with high dilution factors expressed fatty, green and smoky notes in Vietnamese pulp. In Indonesian pulp, intense odorants smelled predominantly fatty, cheese-like and phenolic. Cameroonian pulp exhibited intense butter-like, popcorn-like, flowery and fruity attributes, whereas fruity, flowery, but also clove-like and vanilla-like notes were dominating in Nicaraguan pulp. Thus, the origin determines the aroma properties of cocoa pulp and influences its suitability for various foods. The high moisture and sugar contents of cocoa pulp make it prone to microbial growth. Therefore, we investigated the effect of pasteurization and ultra-high temperature (UHT) treatment on the microbial stability, color and aroma properties of Cameroonian pulp. Both treatments were effective in the inactivation of aerobic mesophilic bacteria, yeasts and molds, with UHT showing over 99% efficacy. During storage at 4°C and 23°C, a significant microbial growth couldn't be observed for 24 weeks. Compared to fresh pulp, thermally treated as well as stored samples exhibited browning, with more pronounced changes in color when kept at 23°C. The choice of technology affected the diversity and intensity of aroma-active regions.

For example, the perceived intensities of acetic acid and linalool were reduced in both treated pulps. As aroma impressions result from complex interactions between many odorants, correlations between single volatiles and an olfactory perception are often inconclusive. For instance, some floral and fruity attributes were better preserved in UHT pulp, yet the overall sensory profile of the pulp changed due to the formation of thermally induced compounds. The suitability of thermal treatments as preservation technology was demonstrated, whereby minimal thermal input and cold storage are recommended to maintain pulp quality.

Keywords: Cocoa Pulp, Thermal stabilization, Aroma composition

Understanding cadmium accumulation in cacao and its implications for developing tools for mitigation of cadmium in cocoa beans

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ABSTRACT

For many cacao farmers, particularly in the Latin American and Caribbean regions, Cd accumulation in cacao beans represents a significant threat to the economic viability of their produce on the international market. Several strategies are being developed to mitigate this threat, but knowledge of Cd transport in cacao is largely based on studies in other crops and model plants. Additionally, an understanding of Cd transport to the beans of the plant is currently non-existent. Three studies were conducted with the objective of understanding Cd bioaccumulation and partitioning in young clonal cacao accessions grown in a drip irrigation system and field grown adult cocoa accessions. The first study investigated Cd bioaccumulation and partitioning in six, 9-month-old cacao clones (low and high Cd accumulator genotypes as determined from a field study) in a drip irrigation system under high and low Cd treatments (0.2 μ M vs 20 μ M). The plants harvested were separated into leaf, stem and roots and analysed for Cd, Mn, Ni and Zn. The second field study investigated the bioaccumulation of Cd, Mn, Ni and Zn in leaves over the flushing cycle and over the year in five 40-year-old cocoa clones. The third study assessed the partitioning of Cd, Mn, Ni, and Zn in pods of 12 varieties. There were significant ($P < 0.05$) differences in the uptake and partitioning of Cd between varieties with significant differences in Cd uptake between high and low Cd accumulators in the drip irrigation study. The plant stem was found to be the most important sink for Cd accumulation under high Cd conditions. In the field study significant differences in metal concentrations were identified between leaf flush phases with levels increasing as the leaves matured. The period at which metal loading into the fruit was likely highest was determined. The study also identified the main pod factors that influence variations in cotyledon Cd concentration. The implications of the findings on selecting the appropriate rootstock for high cadmium areas, on the timing of application of soil amendments for Cd mitigation and leaf stage to be used as an indicator are discussed.

Keywords: Cd fruit loading, metal accumulation over time, genetic variation

Consumer perceptions of the circular economy and the Ivorian cocoa value chain

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ABSTRACT

Purpose of the paper: We determine how consumers perceive the Ivorian cocoa value chain (CVC). In particular, we examine how inequalities are reduced through the theoretical lens of the circular economy (CE). Design/methodology/approach: The approach in terms of method is a traditional literature review followed by a survey. Findings: Circular business models are in operation throughout the chocolate sector at different levels: the farmer level by improving soil health through agroforestry, the transporter level by accounting for transport costs to make the model profitable, the grinder level by utilizing polyphenols drawn from cocoa bean shells and cocoa pod husks, the manufacturer level by using previously wasted fruit pulp to produce a beverage, the trader level by governing the value chain according to the CE framework, the retailer level by improving traceability systems with Internet-of-Things -based logistics systems, and finally at the consumer level by slowly but surely adapting towards circular purchasing behaviour. The CE is defined as a socio-economic business eco-system that efficiently uses materials through the optimisation of waste and disposal, which enables sustainable development using business models and innovation. Measurement of circularity along the CVC should be conducted using the Organisation for Economic Co-operation and Development's (OECD) six-point scale, which covers more than ten defined sectors including Financing, Co-ordination and Innovation. According to the OECD, people, places and policies are essential components of the CE framework. Research limitations/implications: This research considers cocoa exported from Ivory Coast only and excludes other producing countries. In addition, there is a paucity of government data on the living income of Ivorian cocoa farms, which could impede the representativeness of the secondary data used. As a result, this could limit the paper's accuracy in determining the potential effect of implementing circularity on living income levels. Practical implications: This paper, which identifies problems in the CVC, can be a useful tool for policymakers and analysts. Social implications: The circular economy is an effective way of achieving living income for Ivorian

cocoa farmers. To achieve circularity throughout the cocoa sector, stakeholders should measure progress using verified tools. Originality/value of paper: This research responds to a call in the literature for empirical analysis of consumer views on the CE. Furthermore, this study contextualises the CE along the CVC in Ivory Coast. Paper type: Theoretical and empirical.

Keywords: Consumer Perception, Circular Economy, Cocoa Value Chain

Quality of traded raw cocoa: origin specific variation, correlations of quality determining factors and development of a “cocoa quality system”

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ABSTRACT

Cocoa farms around the world export close to 4 million metric tons of fermented and dried cocoa beans (raw cocoa) annually, worth nearly 10 Billion US\$. Around 60 countries produce and export cocoa beans. However, differences in quality and quantity of this commodity are immense due to a vast variety of e.g. agricultural practices and post-harvest management. Changes of the market usually occur slowly and are to some extent predictable, since the cocoa tree is a perennial crop. However, quality studies suveying and comparing traded cocoa beans from various countries are rare. In order to display the typical cocoa trade situation two studies, both called “Cocoa Bean Atlas” were carried out, comprising the results of 265 traded, raw cocoa samples from 32 different countries [2]. The sampleset represents bulk and fine/flavour cacao, different regions (e.g. Bali, Sulawesi, Sumatra), special traded qualities and provenances (e.g. Arriba, Maracaibo, Java “A”) as well as 5 monoclonal fermentations (e.g. varieties EET 95, EET 103, EET 48, CCN 51, CCN 31) and samples of the close related species *Theobroma grandiflorum*. Around 15 analytical parameters such as content and composition of fat and fatty acids, free amino acids, polyphenols, acetic and lactic acid, methylxanthines etc., as well as physico-chemical attributes (e.g. bean weight) and cut test were analysed. The results from these parameters were correlated within samples from one country, but also between countries using Principal Component Analysis. In order to interpret these correlations the factors “fermentation process” and “origin” were looked at in a separate study [3]. Therefor, different fermentation stages (single cocoa beans) were collected from the sampleset (e.g. from Ghana, Ecuador, Haiti, Indonesia). Polyphenols (epicatechin, catechin, anthocyan), pH and enzymatic activity (aspartic proteinase, polyphenoloxidase) were analysed. Also free amino acids were analysed in special fermentation and incubation tests. Using all four data sets, a typical processing related biochemistry pattern could be detected (“cocoa quality system“). It provides the possibility to rank even unknown samples from which just a few

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analytical or cut test results are known. The fermentation status of the cocoa bean could be identified as the most important, but not the only driving factor for the main differences between samples. The variation of the main characteristics of traded raw cocoa quality is described, possible interactions of biochemical changes along the processing steps are captured and presented as “cocoa quality schemes”. 2 Rohsius, Elwers, Lieberei, (2010): Cocoa atlas. DVD 3 Rohsius (2007): Dissertation.

Keywords: traded raw cocoa, cocoa quality system, Theobroma cacao L.

POSTER PRESENTATIONS



Revaluation of cocoa cultivation: physicochemical characterization of the pod and mucilage of three main types of cocoa in Chiapas

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ABSTRACT

Of the approximately 28,000 tons produced during 2019 in Mexico, less what is exported, cocoa (*Theobroma cacao* L.) is sold in the national market in the form of grain or giving added value; producing mainly chocolate, butter and sweets. In smaller amounts it has medicinal and cosmetic use. To obtain the above products, the cocoa bean is usually used as raw material (which represents only 20% of the weight of the fresh fruit), obtaining the mucilage and pod of this fruit as a by-product or residue. Cocoa mucilage is the white pulp that is found covering the seeds. The mucilage contains between 5 to 11% of total sugars depending on the variety and stage of maturation. Unlike mucilage, the cocoa pod contains between 2 to 3%. The physical-chemical composition of both mucilage and cocoa pods makes them an excellent raw material from which various by-products can be obtained in the food and non-food industry. Ignorance of the nutritional value and the usefulness of the "residues" that are generated after obtaining the cocoa bean, cause millionaire losses. With the purpose of detonating the agroindustry in the Soconusco Zone in Chiapa and motivating producers to continue with the production of this crop, which provides unique flavors and aromas in the world, a characterization of the physicochemical composition of three types of cocoa: Criollo (Carmel), Trinitario (Regalode Dios) and Forastero (PMCT-58). The biological material was provided by the INIFAP experimental field Rosario Izapa, Chiapas. These cacaos have been distributed in the region for being high quality materials and resistant to pests and diseases. The objective was to evaluate the proximal chemical composition, pH, humidity, ashes and total sugars of the pod and mucilage of a group of healthy ripe fruits collected in the Rosario Izapa experimental field. A proximal chemical analysis of the flour obtained from the pod by the methods proposed and accepted for food analysis and quality control by the AOAC. The composition of the cob,

having low concentrations of sugars and a slightly acid pH, could be used as a nutrient in the culture medium for the growth of *Trichoderma*, being a sustainable option for the production of the fungus that is used as biological control in plantations. of cocoa. Although the mucilage has a higher concentration of sugar, it has an acidic pH, which could benefit the growth of the fungus when mixed with the shell of the cocoa pod.

Keywords: Carmelo, Regalo de Dios, Cocoa Pod and Mucilage

Rapid characterization of the chemical profiles of cocoa beans fermented with anti-fungal co-cultures

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ABSTRACT

Fermentation of cocoa beans with microbial co-cultures has been shown to enhance quality. However, the metabolites responsible for the improved cocoa characteristics and their transformation pathway are still partially unknown. This study was conducted to facilitate the selection process of a functional co-culture of yeasts and lactic acid bacteria with primarily anti-fungal properties. An innovative approach of microbial selection is offered by characterizing the metabolic profiles of cocoa beans using an untargeted rapid mass spectrometry method, REIMS (rapid evaporative ionization mass spectrometry). Controlled fermentations were conducted by inoculating cocoa beans with different microbial co-cultures previously identified for their anti-fungal properties. The chemical fingerprints of the cocoa beans were screened using the untargeted rapid evaporative ionization mass spectrometry (REIMS) combined with multivariate data analysis. Statistical models were built based on the chemical fingerprints acquired by REIMS. Therefore, unsupervised component analyses were performed, followed by supervised linear discriminant analyses. These models allowed us to visualize the differences and similarities between samples by clustering them according to the resemblances of their metabolite profiles. In our models, the cocoa beans fermented with co-cultures were gathered and separated from those fermented without co-culture, highlighting the similar metabolite profiles of beans fermented with co-culture. The models also permit the detection of the chemical compounds which differentiate the samples. The mass spectra of these key quality markers were obtained by supplementary REIMS

analyses for further identification. Extensive screening of cocoa metabolite profiles will be conducted with additional anti-fungal yeast and lactic acid bacteria strains to strengthen the models and identify other quality markers. Thereby, these models aim to rapidly recognize cocoa beans fermented with anti-fungal co-cultures facilitating microbial strain selection. This selection approach could be extended targeting other quality parameters which enhance cocoa bean quality, such as improving taste and aroma. Models could be built to discriminate beans with and without the targeted features. Then, unknown samples could rapidly characterize, determining whether they are conformed to expectations.

Keywords: Cocoa bean fermentation, Rapid evaporative ionization mass spectrometry, Anti-fungal microbial cultures

Breaking Off a Piece of Cadmium Uptake in T. Cacao

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ABSTRACT

Cadmium accumulation in *Theobroma cacao* poses a threat to the health of the consumers of cacao products and an economic challenge to its producers. The selection and breeding of low-Cd accumulating varieties of *T. cacao* is hindered by a lack of knowledge regarding the mechanisms and underlying genetics of Cd accumulation in this species. We used a reverse genetic approach to identify and characterize *T. cacao* homologs of the Zrt-/Irt-like protein (ZIP) family. ZIPs transport biologically important divalent metals like iron, zinc, and manganese, as well as non-essential metals like cadmium, across lipid bilayers. We identified a *T. cacao* ZIP, which is expressed almost exclusively in roots and has the highest molecular sequence homology to the *Arabidopsis thaliana* IRON-REGULATED TRANSPORTER 1 (IRT1), a high-affinity Fe transporter involved in Cd accumulation for several plant species. The *T. cacao* IRT1 homolog mediates the transport of Fe, Mn, Zn, and Cd in yeast heterologous expression experiments and rescues the *A. thaliana* irt1-1 mutant phenotype. Functional analyses of TcIRT1 are ongoing as are attempts to modify its selectivity to reduce Cd uptake.

Keywords: Cadmium, Rhizogenes, Metal transporters

Metagenomics and expression analysis reveals that members of the Erwiniaceae and Enterobacteriaceae are active players in the initial steps of cocoa fermentation

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ABSTRACT

Cocoa fermentation is one of the fundamental processes for the generation of chocolate flavor and aroma, followed by drying and roasting. Currently, there is a large amount of information related to the role of yeast, lactic acid bacteria, and acetic acid bacteria in cocoa fermentation which contrasts with the limited information available for the bacteria belonging to the Erwiniaceae and Enterobacteriaceae family. These microbes might be capable of metabolizing the cocoa pulp-bean mass and therefore they might have a more key role in the metabolic processes of cocoa bean fermentation. Elucidating the role of these families is fundamental to improving the process either by favoring conditions that modulate the spontaneous colonization and activity of the microbial community or by formulating consortia that guarantee the fermentation efficiency and quality. Here we described the first approach to determine the relevance (presence, distribution, and gene expression rates) of these families during the fermentation process in several farms around Colombia, where we coupled the use of gene marker (16S rRNA) community profiling, with metagenomics, gene expression analysis, and metatranscriptomics. Our results show that the genera *Tatumella* and *Pantoea* have a higher gene expression activity during the first 24 hours than previously anticipated (higher than yeast). Metagenomic assembly and binning of the communities involved in the fermentation at 24 and 48 hours, allowed us to reconstruct Metagenome-Assembly genomes (MAGs) of the dominant microorganisms, which allowed us to identify which bacteria carried genes involved in the initial steps of the fermentation. Several genes involved in depectinization were identified, suggesting that the first degradation starting with the transformation of pectin (Poly 1,4 α – D-galacturonate) to pectate (Poly 1,4 α – D-galacturonate) by the enzyme

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"Pectinesterase" (EC 3.1.11). Our metagenomic analysis identified this enzyme in associated contigs, mainly to bacteria of the *Frutera* and the *Enterobacter* genus. The second step involves the enzyme "Polygalacturonase" (E.C. 3.2.1.15), which catalyzes pectate to Digalacturonate, and was found in more significant numbers in contigs associated with the taxonomic group of the genus *Tatumella*. To validate the expression of these genes during fermentation, sets of primers were designed and validated, and tested for the initial 24 hours of cocoa fermentation using RT-qPCR. In summary, our results show that bacteria from the *Erwiniaceae* and *Enterobacteriaceae* families have a significant role in the initial steps of fermentation and that using their pectinolytic activity might be relevant to improve fermentation efficiency and quality.

Keywords: Metagenomics, Fermentation, *Erwiniaceae*

The Global Cocoa and Chocolate Value Chain: Key Players and Opportunities for Developing Countries

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ABSTRACT

The location of economic activities in specific locations and the rearrangement of industries into global value chains have transformed the analysis about regional and country competitiveness in the last decades. The global value chain approach helps us better understand how industries transition to greater value activities in a process known as scaling and how this value is captured and distributed among the different economic players with heavy implications on the improvement perspectives of countries, companies and the cacao and chocolate industry producers. This study allowed us to observe how the reduction of cocoa bean production and grindings was affected by the COVID-19 pandemic having an impact on global market prices that also influence the efficiency of the circular economy. Through our findings we realized that the cocoa and chocolate industry moves in a global landscape where the production system arises in underdeveloped countries and its consumption is localized in first world countries, which refers to localization decisions. Industries in developed countries, mainly the United States and the European continent, have been taking all or part of their production process to countries with low labor, raw material or resource costs in order to increase margins and improve productivity. Other important reasons for offshoring have been the fiscal advantages of some countries or the access to available skills or technology conditions; creating some kind of specialized ecosystem (cluster). The information used came from an intensive documentary review and an exploratory analysis of global industry structures and trends with interviews with different actors in the global cocoa and chocolate value chain, as well as a contextualization of cocoa bean and cocoa by-product exports and imports in the world. This study was able to diagnose the configuration of the global cocoa and chocolate value chain as a fundamental element to interpret the business of this industry and to propose an innovative strategy for the development of the world market.

Keywords: Global value chain, Cocoa, Upgrading

Organoleptic quality assessment of *Theobroma cacao* L. in cocoa farms in northern Huila, Colombia

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ABSTRACT

Cocoa is a food with sensory and organoleptic attributes that depend on postharvest processes such as fermentation. This process, in addition to affecting the sensory profile, affects chemical reactions and consequently the quality of the final product. This is why the Agroindustrial Training Center "La Angostura" has been developing different strategies to support the production of high quality cocoa in the north of the department of Huila, Colombia. In this context, a chemical and sensory characterization of cocoa (*Theobroma cacao* L.) samples from different cocoa farms in the municipalities of Algeciras, Campoalegre and Rivera was carried out. Bromatological analyses were developed, secondary metabolites (caffeine and theobromine) and total polyphenols as well as compounds of the volatile fraction were determined using gas chromatography by solid phase microextraction in headspace mode (HS-SPME), finally, a classification of the sample (acceptable, unpalatable and contaminated) resulting from a tasting panel was performed. In general, cocoa samples were rated as acceptable with sensory attributes such as (nutty, floral, fruity) that were related to adequate levels of caffeine and theobromine. Likewise, a relationship was found between the bromatological characteristics with the contents reported for pH and acetic acid, as well as between fat content and volatile compounds of the functional group of terpenes (Linalool and Linalool Oxide), these compounds related to sensory attributes such as Floral. It is concluded that the postharvest practices carried out in cocoa farms in the north of the department of Huila had an impact on the quality of the product. It is important to perform this type of characterization because in the department of Huila cocoa production has been characterized by having excellent attributes in flavor and aroma cataloged as fine aroma cocoa, making the cocoa bean a high quality product, so this research will be a tool that will contribute to the impact of the cocoa sector in the northern part of the department.

Keywords: sensory analysis., secondary metabolites, bromatological analysis

Digital QR classification system for cocoa trees

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ABSTRACT

The Agroindustrial Training Center "La Angostura" as an educational institution, has been working on the development of the production of fine and aromatic cocoa, high quality in the department of Huila-Colombia, it is important to highlight this initiative encourages the participation of young people, children of cocoa producers, appropriating new technologies for the development of the sector, generating a generational link, in addition to impacting areas that have been affected by the armed conflict in this way generating development opportunities in the territory. In this context and seeking to include concepts of industry 4.0, internet of things, cloud technologies, Big Data, to these production processes, and in order to include improvements in the processes of information management and traceability of cocoa, we propose the development of a computer system that allows the characterization of plant species of importance, in this particular case, cocoa trees, and that through QR codes can obtain the specific data of this characterization, which provides species data, atmospheric conditions, soil, production rates, fermentation variables, analysis, bromatological, physical and sensory. The system consists of two elements, a web software, which serves as the system administrator, this allows the administration of users, the management of species information, in text and images, the registration of owners, farms and their location, as well as facilitating the entry of documents, links and studies of interest that will be displayed in the mobile application. On the other hand, a native mobile application on the Android platform, which facilitates users to scan QR codes to view the stored information of the species, also has a crop management section (phytosanitary management, irrigation and fertilization) and a module for viewing documents, articles and links of interest, the mobile application allows downloading data from the cloud to be used in non-interconnection area working offline. This digital QR classification system of cocoa trees for the selection of nuts with special properties for high-value commercialization is a model that constitutes a reference for the management of cocoa crops in the region that serves as a guide for cocoa producers to improve their agroecological and agroindustrial processes with specialized genotypes in flavor and aroma.

Keywords: Digital QR, COCOA, education

Effect of soil characteristics on cadmium absorption and plant growth of *Theobroma cacao* L. seedlings

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ABSTRACT

Cadmium uptake by cacao plants can affect plant growth, consumer health and commercialization. To develop mitigation strategies, it is essential to identify the soil characteristics that could influence this absorption. To determine the relationships between cadmium absorption and the soil characteristics of cacao areas, the responses at concentrations of 0, 2, 5, 10, and 20 $\mu\text{g g}^{-1}$ of cadmium in three soils of these areas and an andisol were evaluated, using 120-day-old seedlings of four cultivars of *Theobroma cacao* L. In the present study, several relationships were found between chemical and physical soil characteristics and available cadmium, such as real and bulk densities, as well as contents of iron, sand, magnesium, potassium, sodium, and copper. Additionally, moderate to strong correlations between potassium ($r^2 = -0.56$) and real density ($r^2 = 0.42$), with foliar cadmium, were found. Moreover, a differential deleterious effect on cacao growth in variables such as biomass was corroborated in cadmium concentrations from 5 $\mu\text{g g}^{-1}$ in soils. There were no statistical differences between cultivars with respect to cadmium uptake or plant growth. Finally, a multiple linear regression model is proposed to estimate the foliar cadmium content ($r^2 = 0.878$). Some soil characteristics such as density, as well as sand, clay, aluminum, potassium, and iron contents, should be considered before establishing cacao crops to avoid cadmium accumulation. The correlation between potassium with foliar cadmium indicated that potassium could be significant in cadmium uptake mitigation strategies. The high correlation between available cadmium and foliar cadmium indicates that the quantification methodology developed using ethylenediaminetetraacetic acid extractant may be a useful diagnostic tool.

Keywords: cadmium uptake, heavy metal, phytoavailability

Link between volatile composition of cocoa beans and the use of yeast starter culture during fermentation

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ABSTRACT

Cocoa quality derives strongly from its flavor and its flavor precursor composition. Cocoa flavor may be seen as the result of the chemical and biochemical reactions that take place during the cultivation, harvest and post-harvest processing of the cocoa beans, which are all at the same time heavily dependent on the cocoa variety and origin. Subject to all these conditions is the final chemical composition of the cocoa beans, which is highly complex. Both, volatile and non-volatile compounds contribute to the final flavor perception of cocoa. Around 600 volatile compounds have been reportedly found present in cocoa beans. Among post-harvest processes, fermentation has arguably the most significant impact on the formation of volatiles (mainly alcohols, esters, and carboxylic acids), as well as their precursors. Some of these precursors and intermediates will then be further transformed during roasting by means of Maillard reactions and Strecker degradation (producing pyrazines, aldehydes and ketones, among others). Fermentation of cocoa beans involves an initial anaerobic phase (driven by yeasts and lactic acid bacteria), followed by an aerobic phase (where acetic acid bacteria are predominant). Varied factors influence cocoa fermentation and the products resulting thereof. This work focused on the study of the impact of fermentation time and of the use of yeast starter cultures on the final volatile composition of the cocoa beans, which would translate into differences in their consequent perceived flavor profiles. Large-scale fermentation trials of Trinitario beans were carried out in wooden boxes (600kg) in Dominican Republic in April 2020. Three different fermentation techniques were carried out: one spontaneous, and two inoculated with different *Saccharomyces cerevisiae* strains. Beans were collected and dried after 4, 5, and 6 fermentation days, for them to be later roasted under the same conditions. A SPME-HS extraction (using a

DVB/CAR/PDMS fiber) and GC/MS analysis of volatiles compounds was performed on dried raw beans and on their roasted counterparts, which ultimately allowed to showcase the impact of time and of the addition of yeasts during fermentation on cocoa bean composition and on its flavor potential.

Keywords: cocoa fermentation, flavor formation, volatiles

Organizational innovations along Ghana's Cocoa Value Chain

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ABSTRACT

Cocoa production in Côte d'Ivoire and Ghana accounts for at least 60% of global production. Ghana's cocoa sector, which contributes about 10% of agricultural GDP (which is 30% of overall GDP), is challenged with several sustainability issues linked to low farmers' income, child labour, and deforestation. Stakeholders in the cocoa sector in Côte d'Ivoire and Ghana are developing new forms of coordination (organizational innovations) to meet the challenge of producing sustainable and traceable cocoa. These may be driven by cocoa traders and processors (chocolate companies) in collaboration with both governmental and non-governmental institutions. These innovative forms of coordination are linked to the management of a specific quality and can prompt cocoa farmers to adopt more sustainable practices, strengthen their bargaining power in the sector and/or improve their livelihoods (income, food security, etc.). However, information about these organizational innovations remains scanty. This study seeks to outline and examine the organizational innovations employed by stakeholder within Ghana's cocoa value chain, particularly, towards addressing the key sustainability issues. It follows the conceptual framework of transaction cost economics (Williamson, 1998), with an organizational innovation being a new form of governance structure implemented by a value chain actor to reduce transaction costs. The study method follows a qualitative design and uses data obtained through desk reviews and key informant interviews of value chain actors to analyse the various innovations capable of contributing to better sustainability within Ghana's cocoa sector. While cocoa value chain can boast of many innovations, this study identified only a handful of organizational innovations (i.e., Living Income Differential (LID); Virtual Mode of Payment; and Certification Schemes and Sustainability programmes). Other technical and institutional innovations identified include Rural Service Centres, Cocoa Farm Rehabilitation and Intensification Programme, Cocoa Farm Irrigation System, as well as introduction of the cooperative system to cocoa farmers. The results also show the emergence of a new certification scheme, the African Regional Standard, that seeks to harmonize other schemes. Most of these innovations are government-led with support from chocolate companies, ensuring a somewhat strict

top-down management where the regulator is prominent at every stage of the value chain. Thus, facilitating partnerships of private/research institutions and the public sector (the regulator) could be leveraged to address barriers to developing and/or implementing organizational innovations and other sustainable cocoa management issues.

Keywords: Organizational Innovation, Cocoa, Value Chain

Improving the institutional capacity of Colombia and Ecuador to mitigate trade barriers due the high cadmium levels in cacao

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ABSTRACT

Since the implementation of new European limits on cadmium (Cd) in cacao-derived products, research on reducing Cd in cacao has been at an all-time high. Research focuses on different mitigation strategies such as the application of soil amendments, the effect of genetics on Cd uptake in cacao trees and post-harvest strategies. This is most relevant for the cacao industry in the Andes region, because the soils in this region are naturally more enriched in Cd compared to soils in other cacao producing regions across the world. However, local institutions are not fully prepared to cope with the new limits, neither regarding surveillance nor implementation of good agricultural practices. This project, funded by the Standards and Trade Development Facility (STDF), addresses these issues through a coordinated regional approach with participation of Colombia and Ecuador. The first objective of this research is improving harmonization and quality control in laboratory procedures. A proficiency test with 6 cacao samples was conducted in collaboration with the Clima-LoCa project and more than 25 Ecuadorian and Colombian laboratories. This test gathered information on inter-laboratory variation. A detailed questionnaire was then used to get information on used protocols for common lab practices and quality control. The coefficients of variation (CV) of the Cd concentrations in the cacao samples among participants ranged between 32 and 76 % for the different samples, which indicates a low consistency between laboratories. Participants willing to improve were helped to identify sources through individual performance reports. A written guideline for laboratory quality control was also written and distributed. Secondly, the sample heterogeneity of bagged beans ready for sale was analyzed. Four bean mixtures from different locations across Ecuador were sampled. Additionally, the cacao distribution chain was interviewed to identify common sampling strategies used to evaluate bean quality per selling lot. The variability of bean Cd content was analyzed on three different levels: (1) the variability in one bag, (2) the variability among bags of one pallet and (3) the variability between among pallets in one shipping container. Finally, a consensus sampling strategy for industrial aliquots was written based on the measured variability and the existing sampling strategies. The final strategy,

which will be presented at the symposium, is a trade-off between feasibility (time and cost) and accuracy.

Keywords: Cadmium, Quality control, Variability

Cash transfers to increase cocoa farmer resilience and protect children – Evidence from Ghana

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ABSTRACT

Persistent poverty among cocoa farmers is a root cause of unsustainable practices in cocoa farming, including child labour. Many attempts to address poverty among cocoa farmers tie income gains to production volumes: price regulation, certification premiums, or programmes aiming to increase productivity. However, there is growing recognition that incentivising farmers to produce larger cocoa volumes may increase certain risks, such as deforestation and child labour. Cash transfer programmes, based on factors such as family size or the number of school-age children, are a commonly used tool by governments to reduce poverty. But their use in the private sector is rare. The International Cocoa Initiative evaluated the impact of unconditional cash transfers given to members of a cocoa cooperative in Ghana on socio-economic outcomes, including child labour. In a randomized experiment involving 644 cocoa producing households, farmers allocated to the treatment group received mobile money payments over a 6-month period, followed by an endline survey collected in April 2021. The cash amount corresponded to 28% of average monthly household expenditure at baseline. The study showed that cash transfers reduced the likelihood of children doing hazardous work during a 6-month recall period by 9.3 percentage points (a 16% decrease from the sample mean). The cash experiment coincided with the outbreak of the Covid-19 pandemic, which resulted in income losses for 46% of participating households. In addition, 66% reported some unexpected negative income shock, unrelated to the pandemic. While cash recipient and control households were equally affected by these events, cash recipients were significantly more resilient: the cash transfers decreased the likelihood that a family had to reduce food consumption after an adverse event by 21 percentage points (a 31% decrease from the sample mean). In line with previous research that shows that child labour is often used as a buffer to cope with shocks, households in the control group increased their use of child labour in response to an adverse event, but households in the treatment group did not. This finding reinforces the conclusion that by increasing households' resilience to shocks, cash transfers also helped to protect children. Overall, the results show that unconditional cash transfers paid to cocoa farmers can be an effective poverty reduction strategy, while also avoiding some of the negative consequences of interventions tied to increased production, such as child labour.

Keywords: financial risk management, child labour, cash transfers

Impact of cocoa pod maturity and storage on cocoa quality

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ABSTRACT

Pod maturity determination is mainly done by the farmers and this is based on the intuition and the experience of the farmer, with little knowledge on the impact on the quality of cocoa beans. Studies have found that the quality of cocoa beans is affected by pod maturity, pod storage, drying and roasting of the cocoa beans. However, many have emphasized post-harvest practices such as pod storage, fermentation and drying as the major influencers of cocoa quality, with little to no consideration of the maturity stage of the pods used. This study looked at the impact of different maturity stages of pods on the biochemical quality and sensory characteristics of cocoa beans, considering pod storage and fermentation time as the other factors. The experimental design used was 3×3×2 full factorial design with the following experimental factors: pod maturity (immature pods, mature pods, and ripe pods), pod storage (3, 7 and 10 days) and fermentation time (4 and 6 days). Biochemical characteristics of the cocoa beans considered were fat content, acid content, bean count, total phenolic, theobromine, and caffeine content. The sensory profile of cocoa liquors produced from fermented, dried and roasted cocoa beans included the cocoa, nutty, bitter, roasty, spicy, acidic, and astringent attributes. It was found that pod maturity had a significant impact on the bean count, fat content and total phenolic content. Cocoa beans from immature pods had the highest fat and acidic content but were found to be lower in total phenolic content. In the sensory profiling, the cocoa liquors obtained were more acidic, less cocoa, and less nutty and had the most sensory defects among the maturity stages. Cocoa beans from mature pods were characterised by high total phenolic, theobromine and caffeine content. Cocoa liquors produced tend to be more cocoa, bitter, roasty and nutty. Cocoa beans from ripe pods were found to deliver more floral, fruity, and cocoa notes with the least acidity. It was also observed that increased pod storage for all the maturity stage reduced the acids, fat, and total phenolic content. Increasing pod storage is also correlated with increase in cocoa, spicy, roasty and nutty attributes and reduced the bitterness of the cocoa liquors. Increased fermentation time coupled with pod storage significantly

reduced acids and bitterness while increasing the nutty attributes. In conclusion, pod maturity tends to have significant impact on the quality of cocoa beans and hence cannot be ignored.

Keywords: pod maturity, pod storage, cocoa

Manufacture of Craft chocolate using local technological innovations and supportive Cocoa Regulation

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ABSTRACT

Cocoa is the main cash crop in Bougainville (Papua New Guinea), generating income for 70% of rural household. Dried, fermented beans are usually exported to the commodity market and downstream processing remains undeveloped. In Bougainville we first introduced small scale chocolate making as a tool to assess bean quality and improve grower awareness of faults in badly processed beans. Because of the interest we then assessed the commercial viability of local small scale chocolate production. A locally made press extracted 35-37% oil (cocoa butter) and cocoa powder from cocoa liquor. With an optimal grinding time of 8 hours the simple gross margin was estimated to be K19.25 (\$US4)/kg dry beans, providing a valuable source of family income. In order to monitor and regulate the production, quality, marketing and consumption of craft chocolate and other cocoa products the Bougainville Government developed and incorporated schedules on the Specification of chocolates, Specification of cocoa powder and Specification of cocoa butter. The construction, availability and adoption of local chocolate making by many hundreds of individuals and Cooperative society groups could increase local production and household income, promoting local consumption and the sustainability of cocoa farming

Keywords: Income diversification, Living incomes, smallholder farmers

Innovative fine cocoa fermentation system by means of vertical stirring integrated into a stainless steel tank.

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ABSTRACT

The fermentation of fine cocoa is generally carried out using traditional methods in which the contents of wooden boxes are decanted daily. However, this approach has been little optimized relative to the key role of fermentation in the development of cocoa flavors. Here, we present an innovative fermenter design to enhance the reproducibility in the fermentation of cocoa beans, a crucial step in the production of chocolate flavors. In this design we integrate a mixing system into a vertically oriented stainless steel tank capable of handling volumes containing approximately 250 kg, a weight comparable to that handled by traditional fermentation systems. This stainless steel fermenter, which has only limited cost, will accommodate both the lactic and acetic phases of cocoa fermentation within the same tank. Its design further allows the accommodation of different monitoring instruments within the interior without disrupting the process of fermentation. In this way, it is possible to continuously read out the temperature and pH and monitor the critical steps in the phases of fermentation. The lactic phase of fermentation will be realized in an anaerobic environment. During this phase, the cocoa mass is homogenized through mashing to facilitate the fermentation by yeast in this closed environment. After a timing controlled by measurement outcomes, the acetic fermentation can undergo oxygenation of the beans by stirring the cocoa mass from bottom to top and by removing the lid of the tank. This novel fermenter facilitates the optimization of fermentation protocols for the particular conditions that surround any harvest of cocoa beans, e.g. sugar content, water content in the mass of humid cocoa beans, growth season, or variability related to particular genetics of the cocoa bean strain. Its stainless steel design is robust in the context of the production of acetic acid, guaranteeing an excellent durability, and brings ease of cleaning and thus hygienic control. Furthermore, it limits the introduction of contaminants that can perturb the yeast at the start of fermentation. The different aspects of this stainless steel cocoa bean fermenter are together innovative as they guarantee the means to ensure reproducible production, and permit straightforward parametric readout and

subsequent analysis. Thus, this stainless steel fermenter will facilitate the unparalleled production of high-quality organoleptic chocolate.

Keywords: tank stainless steel, integrated process, innovation

Strengthening Cacao Market Development through Added Value Innovation (fermentation) for Cocoa Farmers in Jembrana - Bali - Indonesia

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ABSTRACT

Mapping of cocoa in Indonesia, states that currently the area of cocoa plantations reaches around 1.5 million hectares with 75% of Indonesia's cocoa production located in Sulawesi. Most of them are smallholder plantations (97.29%). The data above confirms that cocoa is about people's lives. Jembrana - Bali, one of which has placed cocoa as a source of livelihood with a total area of 6,258.64 hectares. According to the Bureau Central of Statistics data in 2018, 14,350 people in Jembrana were living below the poverty line. Cocoa has been the main commodity supporting 610 farmers since 2011. NGO Kalimajari initiated a Cocoa Sustainable Program to produce high quality fermented beans. It has doubled the income of 610 smallholders, 40% of which are women and young farmers. Kalimajari have been closely working with Kerta Semaya Samaniya Cooperative (KSS), which holds the Rainforest Alliance Certification since 2011 as well as Organic EU and USDA certification since 2017. Currently the Cooperative is able to produce around 75.000 kg high quality fermented beans per annum. Farm productivity reaches 800 to 1,000 kgs of dry cocoa beans per hectare per annum, with 610 farmers as cooperative members covering an area of 800 hectares. With unique flavours: honey, brown sugar, fresh tamarind, KSS has brought Jembrana cocoa to the global market and was selected as "Cocoa of Excellence" among other 50 types of cocoa by the Salon du Chocolate in Paris October 2017. KSS was declared the sole holder of the Organic Certificate in Indonesia. The main focus of program: 1. Innovation program to support the fermentation processing as a form of technological transformation. Research on mapping clones to provide accurate information to farmers. This study is in collaboration with the Indonesian Coffee and Cocoa Research Institute in 2020. 2. Innovation program through Market Development. The target market is the local and export premium/fermented market. France is the first destination, collaborating with Valrhona in 2015 and producing 68% Single Origin Bali Sakanti chocolate. Dutch Heinde & Verre Chocolate with Single Origin Kerta Semaya Samaniya Mylk 55%, won the Academy of Chocolate category Silver in 2021. This strong collaboration was also fully assisted by the Biji Kakao Trading Company. 3. This program encourages women and youth farmers to have equal access in program implementation. Currently, Kalimajari is scaling up in other areas, to carry out a transformation in improving the quality of Indonesian cocoa.

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Keywords: fermentation, women and youth, cooperative

The quest for quality of Ecuadorian cocoa: Certification and traceability

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ABSTRACT

There are two main global strategies applied by cocoa value chains actors, namely one based on volume (cocoa as a commodity) and another which privileges quality to obtain Premium prices. Quality of cocoa beans and its products is determined by both intrinsic and extrinsic factors. Intrinsic factors include the genotype, climatic conditions, soil, and agronomic management; external factors involve the post-harvest process (fermentation, drying, storage), roasting and transformation. Chocolate companies are increasingly demanding certified cocoa to add distinction and value to the final product. Third Party Certifications (TPC) include organic, fair trade, origin certification and, more generally, sustainability. These certifications facilitate i) CFA differentiation strategies and its positioning as a Premium quality product, and ii) the communication of industrial quality driven by external factors. Certification relies on the existence and correct performance of traceability systems. Nevertheless, small producers (the vast majority of Ecuadorian producers) lack access to financing for certification and traceability, resorting, in many cases, to external financing, even though certification does not guarantee sales at Premium prices. The few producer associations that export cocoa directly have gained access to market niches through TPC certifications, but most lack an internal control system to maintain certifications, and such priorities are not reflected in or supported by public policy. Participatory Guarantee Systems (PGS) constitute an alternative certification scheme to TPC. The management of the PGS involves approaches of good governance, gender equality, quality, healthy nutrition, ancestral knowledge, agro-ecosystems, ecosystem services and climate resilience. In parallel, the industry considers the dimensions of quality in detail: performance, properties, reliability, product conformity, durability, ease, aesthetics and perceived quality; through continuous improvement processes for quality and traceability standards. In the context of a study of the cocoa sector in Ecuador, which mobilised dozens of actors, we analysed the institutional and organisational conditions for the implementation of the various forms of certification in Ecuador, and we qualified their impact on the competitiveness of Ecuadorian production. The study produced an exhaustive review

of the secondary documentation and collected data via face-to-face surveys. This follow-up work, explores questions on certification and traceability as a means to guarantee and communicate cocoa quality in the Ecuadorian context: What is needed to strengthen standard certifications and enable the emergence of PGS initiatives? How could producers and/or associations participate more directly in the different public policy plans that respond, for instance, to certification systems more adapted to local conditions?

Keywords: traceability, certification, Ecuador

Impact of pollen genetic origin on compatibility agronomic traits and content of bioactive compounds in cocoa

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ABSTRACT

International Symposium on Cocoa Research (ISCR 2022) Abstract Incompatibility within and between cocoa trees or cocoa clones is incontestably one of those factors which reduce cocoa yield in fields. Indeed, the traceability of raw materials is one of the major challenges that agro-industries face today. Increase of cocoa production and improvement and cocoa products' quality passe through the identification of cocoa genetic and geographic origin as well as the farm where cocoa is produced and harvested. Hand-pollination was used to assess compatibility between clones, to select interested agronomic traits (pod length, pod cortex thickness, average beans number, average beans weight, average weight of fresh or dry beans) and to improve specific cocoa beans quality through bioactive compounds (polyphenols and purine alkaloids) content. Four different parents were used as female-clones: ICS40 (higher Trinitario), SNK16, SNK10 (Local Cameroonian Trinitario), SCA12 (Lower Amazon Forastero) and four clones added to the female ones as pollen donors: SNK16, SNK13, (Local Cameroonian Trinitarios), UPA134 (Upper Amazon Forastero), T79/467 (Amelonado, Forastero), T60/877 (Amelonado, Forastero), ICS40 and SCA12. Crosses within Trinitario clones showed a low level of compatibility (0–18%) whereas the general combination ability between Trinitario×Forastero (59–81%) and within Forastero (84–88%) and between Forastero×Trinitario (78–88%) was very promising. SCA12 clone showed a high level of compatibility efficiency compared to the two Trinitario female-clones studied. The pollen grains from SCA12 increased the pod length and average weight of fresh beans in ICS40 female-clone meanwhile those of T60/877 also increased the pod cortex thickness and average weight of fresh/dry beans in SNK16 female-clone. The genetic description of each pollen clone donor played a key role in the resulting hybrids. Beans from the hybrid (♀)SNK10×(♂)IMC67 recorded the highest polyphenol content (49.18±1.55mg CatE/g). The highest concentration of condensed

tannins (22.81 ± 0.69 mgCatE/g) was recorded in beans obtained from the hybrid (♀)ICS40 \times (♂)UPA134. The content of caffeine differed ICS40 hybrids ((♀)ICS40 \times (♂)UPA134 and (♀)ICS40 \times (♂)SCA12) to other hybrids (Local Cameroonian Trinitario or Upper/Lower Forastero). The results highlighted that the genetic origin of pollen grains could increase compatibility between clones, agronomic traits and consequently the bioactive compounds content of beans.

Keywords: Hybrid, Incompatibility, Bioactive compounds

Novel Time- and Location-Independent Postharvest Treatment of Cocoa Beans: “Moist Incubation” of Unfermented and Dried Cocoa Nibs

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ABSTRACT

Post-harvest processing of cocoa beans is a crucial step for the formation of cocoa flavour. Spontaneous microbiological fermentation is not easy to control due to several variable factors such as weather conditions, ripeness of the fruits as well as the batch-size, leading to quality variations of the resulting cocoa beans. In previous research on fermentation-like incubations of cocoa beans in aqueous solutions under controlled temperature regimes, it could be shown that not microorganisms themselves, but their metabolites are necessary for the flavour precursor formation and the desired biochemical changes within the bean. Therefore, it was concluded that an application of this technique in the cocoa growing area may permit standardisation and mechanisation of cocoa fermentation. However, implementing this process on a farm requires expensive infrastructure or transportation to locations with existing infrastructure. To overcome this, an alternative time- and location independent approach of post-harvest processing, the so-called “moist incubation” has been established. For this reason, unfermented and dried cocoa nibs, which are storable and easy to transport, were treated with a solution containing lactic acid and ethanol and incubated at 45 °C for 72 h under aerobic conditions to induce the desired changes within the cocoa material before drying. The resulting raw material of this process and the model chocolate produced thereof were analysed in comparison to the fermented and unfermented raw cocoa beans as well as their corresponding model chocolates by sensory evaluation, gas chromatography-olfactometry and the quantification of selected flavour-active compounds and their respective precursors by gas chromatography mass spectrometry and high performance liquid chromatography mass spectrometry. The outcome of this investigation shows that moist-incubation constitutes an alternative cocoa post-harvest treatment, resulting in chocolates of desired flavour properties.

Keywords: cocoa incubation, cocoa flavour, post-harvest treatment

Yeasts potential interactions influencing the formation of fine aromas during cocoa fermentation process

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ABSTRACT

The first post-harvest treatment of cocoa beans relies on the appropriate fermentation of the cocoa pulp. This process is now considered as a key step in the quality of the final chocolate. Recent researches showed that aromas of fine chocolate involving fruity and/or floral notes might be partly linked to the surrounding environment of cocoa beans. Among microorganisms involved in the fermentation process, yeasts represent the most interesting producer of aroma compounds, either by specific enzymatic, or by their own metabolism with the production of higher alcohols, and esters. Some researchers showed that specific aroma from cocoa fruit introduced into the fermentation process could be further recovered in the cocoa liquor, supporting the idea that aroma production in the surrounding environment of cocoa bean could help in adding beneficial traits to the final product. These findings show the significance of an efficient yeast starters selection strategy able to enhance and harmonize the production of fine chocolate. To date, the interactions between indigenous yeasts of cocoa fermentation have been poorly investigated. Studying these interactions could help understand why fermentation leads to higher or lower quality chocolate. In this study, 90 strains were isolated from fermentation batches which gave chocolate of standard and high quality. Among these strains, 56 different species were identified by sequencing ITS region. The majority of isolates were identified as *Saccharomyces cerevisiae* (22), and *Pichia kudriavzevii* (20), the others being shared within other genera such as *Candida*, *Pichia Hanseniaspora*, or *Torulaspora*. Intraspecific variability within the two major species (i.e. *S. cerevisiae* and *P. kudriavzevii*) was performed using GTG-5 fingerprinting and a minimal medium relevant for cocoa pulp environment was designed to screen fermentation performances (sugar consumption/ethanol production) and aroma production

profiles. *S. cerevisiae* strains exhibited faster fermentation kinetics than *P. kudriavzevii*. Yeast species were typically clustered according to their aroma profile, with some intraspecific variability regarding their production capacities. Killer phenotypes of all strains were screened against main isolates and were subsequently cocultured with their target to evaluate the impact on aroma production. When grown with indigenous killer species, fine aroma compound production by high producers like *P. kudriavzevii* was drastically limited. These findings showed that fine cocoa harmonization process not only relies on the presence of beneficial yeasts but can also be influenced by the presence of competitors that could decrease the production of fine aroma during the fermentation process.

Keywords: Cocoa beans, fermentation, Aroma compounds

Is transfer of precursors and aroma compounds produced by yeast during cocoa bean fermentation influenced by the tissue bean structure?

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ABSTRACT

Chocolate is obtained thanks to a large number of unit operations, including cocoa beans fermentation, their drying, roasting and processing into cocoa liquor. Fermentation is the first operation in chocolate processing. Without yeasts, lactic acid and acetic acid bacteria fermentative activity, a large part of aroma compounds would not be found in chocolate. In literature, there is a general consensus that fermentation is an important factor which influences chocolate flavor quality. These observations have led researcher to identify solutions to optimize the fermentation step, especially to control chocolate flavor. As for most of the fermented food or beverages, a solution aims to use starters in order to manage the biochemical transformation of cocoa beans. One focus has been done on starters ability to produce specific aroma compounds that could then be found in chocolate, and thus induce specific flavor qualities. However, there is still a lake of information regards to the transfer of precursor and aroma compounds produced by yeasts and their diffusion into the cocoa seed. Thus, this work was done to first prove whether precursors and aroma compounds, that could be produced by yeast during cocoa bean fermentation, were diffused from the pulp to the seed. For this purpose, labelled molecules, which constituted aroma precursors and key aroma compounds in chocolate, were chosen to follow their transfer into cocoa beans during simulated fermentation. Molecules transfer was studied in 4 media following a progressive experimental approach to evaluate the tissue layers impact. First medium contained cocoa seeds, without the pulp and tegument, a second medium contained cocoa seeds with the tegument, the third contained the whole cocoa beans constituted of the pulp, tegument and seed, and the fourth contained the whole cocoa beans and yeast. Cocoa beans samples were submerged in distilled water concentrated in labelled molecules; and maintained at 35°C for 6 days. Then, the labelled volatiles were analyzed by SPME-GCMS, and the labelled aroma precursors were analyzed by GC-MS after extraction and derivation. Analyses are underway: initial indications are that all

studied compounds (i.e. volatiles and precursors) could diffuse from media to the cocoa seed and that the transfer speed is dependant of the nature compounds, with differences depending on media analysed.

Keywords: Cacao fermentation, Labelled aroma compounds, Transfers

Improving the wellbeing of Congolese by promoting cocoa made in Congo: assessing challenges limiting good market access of its cocoa beans

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ABSTRACT

At the beginning of the year 2025, cocoa beans without the respect of some standards will no longer be exported in EU. Therefore, it will be highly difficult for Congo to export the high quantity of cocoa that government is intended to produce because of diversifying its sources of income and increasing its Gross Domestic Product (GDP) (current 7%). Before this measure, the good price of certified cocoa was already attractive such the way that, the Congolese government had concluded in 2021 a Public-Private Partnership (PPP) with the French Development Alliance four years support to promote the “cocoa made in Congo” via “Project d’Appui à la Relance du Secteur Agricole (PARSA)”. The project aims at the emergence of sustainable and quality cocoa production with a limitation of the negative impacts of the sector on the environment. The current study, which aims to identify key challenges in the different chain links in post-harvest, was defined as one of the key starting points. It was carry-out between November 2021 and January 2022 mainly in the Sangha division, which produces about 70% of Congolese cocoa beans. Firstly, a field visit (40 people met) followed by a face-to-face meeting with three divisional key informants helped to identify specific challenges. Then, group discussions with 35 people from the agricultural direction, NGOs, farmers organizations, and other ongoing programs were organized. Three categories of people have then interviewed: authorities, extensionists, and farmers. The long list of challenges obtained was subjected to problem trees for grouping. Data were subjected to descriptive statistical analysis using SPSS to estimate the relative frequency of appearance of different challenges. The results highlighted different challenges defined as followed: individualism (95%, mentioned by all categories), Multiplication of illegal buyers (90%, equality mentioned by all), bits poor

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knowledge on post-harvest techniques (70%, mostly presented by extensionists), a weak link between producers and micro-finances (75%, mostly mentioned by farmers), insufficient of quality control posts (50%, mostly mentioned by extensionists), poor statistics in Congolese production (40%, equally mentioned by extensionists and authorities), poor market information system (30%, mostly mentioned by extensionists), poor knowledges and application of standards (80%). It can be concluded that several challenges limiting the commercialization with good price of Congolese cocoa. Also, the study highlighted key interventions, not yet analyzed, able to be carried out to alleviate those challenges in view of improving the wellbeing of Congolese via increasing of their Gross Domestic Product.

Keywords: Commercialization, Post-harvest, Standards

Transparent and collective-voices in modelling a a nation-wide cocoa traceability system for Cameroon, from farmgate to port of exit

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ABSTRACT

This paper details the innovative bottom up process and outcomes of designing a national model for a cocoa traceability system (from farmgate to port) in Cameroon. The traceability system is oriented towards delivering the outcomes described in the Roadmap to Deforestation-free Cocoa in Cameroon, in which the Ministry of Trade committed to putting a national cocoa traceability system in place with 100% traceability of Cameroon cocoa by 2025 from farmgate to port of exit. Such as system needs to take into account multiple demands and objectives of such a system, including cocoa production and trade quality standards superimposed with voluntary sustainability standards certification used in Cameroon, corporate programs and practices, and proposed EU directives on human rights and environmental due diligence for EU-based companies and on minimizing risks of deforestation and forest degradation of commodities imported in the EU. Learning from experiences in West Africa, the system design builds on secondary evidence presented in a review of the current state of traceability systems in Cameroon and uses a participative approach to offer especially farmers but also other actors a transparent and collective voice on the definitions inherent, needs of, and approach used to elaborate a model for a national cocoa traceability system. The result is a visual overview of a national cocoa traceability system which can aggregate farm level data, mobility and trade data for cocoa at a national scale, precisising the intervention of different actors and the possibility of a blueprint. The operability of this system is critically assessed. The tools and technologies recommended to be employed by the system and the feasibility its operation in the national context is assessed, taking into consideration the setting of Cameroon and international policies and practices regarding cocoa, trade and forests. Alignment with multiple local and international requirements for a cocoa traceability and transparency are clarified. The interoperability with other

existing individual and national systems is detailed and the cost of a system (technologies, setting up, human resources equipment and maintenance (per year) are estimated.

Keywords: traceability, deforestation-free forest friendly, policy

Cocoa quality and flavour: Towards a common language for increased value and market access.

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ABSTRACT

There is an urgent need for accepted, credible and verifiable protocols for the assessment of quality and flavour of cocoa beans to facilitate feedback and enable farmers to present the best value proposition to buyers. Between 2015 and 2022, the Alliance of Bioversity International and CIAT and its Cocoa of Excellence Programme lead the development of the International Standards for the Assessment of Cocoa Quality and Flavour (ISCQF); describing step-by-step how to: (1) sample the cocoa beans to be evaluated, (2) assess its physical quality, (3) process it into coarse powder, liquor and chocolate for (4) sensory evaluation of the flavours expressed in these 3 products. Their application results in a complete description of the cocoa bean quality and flavour expressed in coarse powder, cocoa liquor and chocolate to be communicated along the cocoa value chain. The methodology to develop these standards started in 2015 with the setting up of a Working Group of 20 members representatives of the value chain. A detailed review of practices in cocoa and other crops such as coffee, olive oil, and wine was carried out and a first proposal developed in 2016 reviewed in 2017 by over 150 individuals. This led to the development of a series of protocols published between 2020 and 2021 consulted by over 1,500 individuals from 99 countries and public review. The revised protocols are compiled into the first manual on cocoa quality and flavour assessment. The objectives of these protocols are to: (1) identify the intrinsic flavour attributes and characteristics of the beans when converted into a finished product such as chocolate, (2) unlock the value of the evaluated cocoa and empower producers and buyers to target specific markets, and (3) facilitate targeted marketing flavour customization to meet consumers' needs. Clear communication using a common language is essential throughout the value chain, from producers, buyers/traders, chocolate makers to consumers. These protocols are the result of an extensive consultative process. They support the efforts of cocoa origins to increase their capacity to better understand the quality and diversity demanded by the market. They are intended to be used by national food quality labs, standardisation

organisations, national research institutes, and cocoa producers' cooperatives and associations.

Keywords: Flavour quality attributes, Market differentiation, Increased value

Physiological traits, Yield, Yield components and bean dynamics relationship of different cocoa genotypes under Drought

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ABSTRACT

Climate change scenarios predict more intensified droughts, which may threaten crop yield. In cocoa, yield variability depends on climatic variability and the soil moisture regime. Predictions of yield responses to climatic variation require a basic understanding of cocoa yield components under environmental stress. This study aimed to establish this understanding by quantifying relationships between physiological, morphological, yield and bean traits of different cocoa genotypes. We conducted an experiment with six genotypes, of which four genotypes are considered drought-tolerant, in Ivory Coast to test the effect of irrigation in the dry period. The analysis revealed significant effects of irrigation on leaf physiology, yield and bean traits. Responses to drought were genotype-specific. Moreover, we found effects of irrigation on leaf morphology and crown traits. Water stress negatively influenced the number of pods, bean shape and size. The resistant-genotypes had their leaf physiology less affected by drought thus were able to produce maximum yield with high bean quality. We also found that leaf water potential, and stomatal conductance had a positive influence on yield and bean traits under severe water stress, but that LAI and SLA had a negative influence on yield and the number of pod to get 1kg of bean. These results suggest that high physiological rates are critical for optimum growth during pod formation and filling. All the traits were inter-correlated and correlated to yield, thus the included traits can be considered for screening cocoa genotypes on drought tolerance for breeding purposes. We found that the most commonly used cocoa genotypes in Ivory Coast are high susceptible to experimental drought. Our results suggest that climate change may strongly influence cocoa physiology and yield.

Keywords: Bean physical properties and Yield, Cocoa physiology, Water stress

Utilization of cocoa genetic resources in Peru from university research (2016-2021)

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ABSTRACT

In a scenario of increasing relevance of the cocoa value chain in Peru (Arévalo et al. 2016), a country that the evidence points to this being one of its center of origin (Lanaud et al. 2012, Olivera 2013, Zarrillo et al. 2018), a reflection is proposed about the importance of the genetic resources of this crop from the perspective of its conservation and utilization, in the academic field. A sample of 45 academic theses that had cocoa as the object of study was analyzed, corresponding 44 of them to 21 Peruvian universities and the rest to a Spanish one. These investigations on cocoa were carried out in 13 regions of Peru, Lima concentrating 12 of them while the remaining 33 were distributed in the rest of regions, drawing attention that two of these regions, Lima and Tacna, are not cocoa producers. Likewise, it is worth mentioning that 91% (42) of these theses were for professional degrees, 6% (2) for master's degrees and only 3% (1) for doctor's degrees. It was found that 10 theses covered germplasm research activities aimed at the transformation and/or innovation of cocoa, thereby conferring added value with potential commercial utilization. These investigations were related to four productive sectors, classified according to Laird & Wynberg (2012). Four investigations are located in the Food and Beverage sector (Bobadilla Jiménez 2016, Loza de la Cruz and Inga Orihuela 2018, Rojas Sosa and Rojas Manayay 2017, Gonzáles Ramírez 2019), three in the Pharmaceutical Industry (Orihuela Gutiérrez 2016, Poma Choque 2018, Montenegro Maldonado 2021), two in Cosmetics (Limas Pino 2018, Nunjar Aliana 2020) and one in Industrial Biotechnology (Del Águila Flores and Zegarra Jumanga 2016). These would constitute cases in which knowledge has been released without due and possible precaution, outside the national system of access to genetic resources and those will probably end up in the numerous patents processed in many other countries (INDECOPI 2015; Pastor-Soplín 2008), which value formality and intellectual property rights. The cocoa resource carries an intangible aggregate associated with its genetics, history and culture, intangible values that can be useful for claiming various available intellectual property rights, such as trademarks,

geographical indications, and denominations of origin, among others, that properly used can increase market opportunities.

Keywords: cocoa, innovation, genetic resources

Official Rural Credit for Cacao in the Amazon: problem or solution?

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ABSTRACT

The use of public policies with the objective of promoting the development of cacao cultivation in the Amazon and, especially in the state of Pará, must be considered as the starting point in the change of paradigms in this matter, and rural credit was decisive in the establishment of plantations of cocoa trees in their first 15 years of their technological phase. Until the beginning of the 1970s, cacao in the Amazon was considered an extractive crop. It was with the advent of the Initial Cocoa Project, created by the Secretary of Agriculture of the State of Pará, that the cocoa tree entered its technological phase. CEPLAC, considering its expertise in cocoa cultivation, was invited to be the technological advisor for the Project, implementing the technology that was already being implemented in the cocoa trees deployed in Bahia. To support the actions of new cocoa plantations, subsidized rural credit was one of the main elements to support those producers who were motivated to participate in the Project. Thus, from the mid-1970s with the advent of PROCACAU until its end in 1985, development programs such as PROTERRA and POLOAMAZÔNIA, among other things, entered as providers of financial resources for rural credit. These incentives had a small stoppage between 1985 and 1989, being resumed at the end of 1989 with the implementation of the credit program called Constitutional Funds (North, Northeast and Midwest of Brazil). However, an issue that has been established for some time is that, even with the availability of financial resources to finance cocoa farming, curiously, what has been seen is the return of these resources to the source of the National Treasury, as farmers apparently, they do not feel encouraged to seek these resources. In order to try to understand the reasons for such events, a field survey was carried out in some municipalities of the Transamazonica, a region that represents almost 80% of all the movement of production and planted area of cocoa trees in the state of Pará, where farmers report that excessive bureaucracy, lack of information about credit programs and private financing on the part of cocoa buyers are the main reasons for their choice not to seek official credit.

Keywords: COCOA, FINANCE, AMAZON

The Dynamics of Sustainability and Traceability of Cocoa production in Ghana: Inventory and Analysis

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ABSTRACT

The global chocolate and chocolate confections worth US\$ 103.28 billion are projected to increase to US\$ 161.56 billion by 2024. Ghana is the second-largest producer of cocoa in the world. In 2019/2020, Ghana contributed 18% (850 thousand metric tons) of the global cocoa bean production. Demand for cocoa is on the rise this will change the structure of cocoa markets, affects cocoa production, and might undermine possibilities for sustainable cocoa supply chains. The global cocoa consumers and the chocolate confections are rapidly demanding sustainable and traceable cocoa. Knowledge on the progress of sustainability in the cocoa supply chain in Ghana is, however, limited and scanty. Such knowledge is needed to inform dialogue and raise public awareness and advocate for policy reforms in the management of a sustainable cocoa economy. This paper outlines progress made by the cocoa supply chain in Ghana to supply sustainable and traceable cocoa to cocoa buying companies (CBC). It does so by identifying, characterizing, and locating farms supplying cocoa beans to CBC. Then, it assesses the risks and opportunities of halting the sale of cocoa from uncertified sources on farmers and their communities. Further, it identifies challenges hindering effective cocoa traceability and transparency. The paper synthesizes results of desk study, literature review, participatory rural appraisal methods, interviews, and farm inspections in 18 cocoa-producing communities in the Atiwa East, Asunafo North, Assin North, Adansi South, and Juaboso/Sefwi-Wiawso of Ghana. The research areas are key cocoa production areas. Forest reserves—including Krokosua Hills, Sui River, Kakum National Park, Numia, and Atiwa Range with Globally Significant Biodiversity Area (GSBA), Wildlife Conservation, and Guineo-Congolian ecoregion under IUCN Category II status fall directly within the study areas. Based on synthesized information 76% of farmers have their farms certified and thus practicing sustainable production, 93% of cocoa buying companies have excluded uncertified cocoa farms from their supply chain. Of the 234 farms visited, 3.4% of cocoa farms were located in forest reserves. The study shows that 82% of farmers do not belong to any cocoa

cooperative. The study concludes that although sustainability within the cocoa sector is achievable a lot of challenges still persist, including capacity building, poor yields, cost of mapping farms, and information asymmetry in the sustainability practices.

Keywords: traceability, sustainability, cocoa

Cartographic Strategy of Traceability

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ABSTRACT

As part of the REDD+ Ecuador Action Plan, the Ministry of Environment and Water, and the Agriculture and Livestock aim to create a national framework for the certification of deforestation free agricultural and livestock production. Contributing to this effort, we designed a Cartographic Strategy of Traceability (CST) for this certification which was implemented in a pilot study in five Organic Cacao Associations in the Ecuadorian Amazon. The CST has six phases: i) Farms limits mapping. - using smartphones GPS and the open source applicative Qfield done by mapping teams in each Cacao Association. ii) Data mapping processing. - done by a GIS specialist who received the data collected by the mapping iii) Data analysis.- done by a GIS technician who identifies the forest in farms through GIS analysis using the national land cover map (MAAE, 2018) iiiii) Remote forest conservation monitoring.- through GIS analysis of Global Land Analysis & Discovery (GLAD) Data. For the pilot study, we identified Cacao Associations which officially expressed their will for the implementation of deforestation free production, where we created a mapping team integrated by young active members. These teams were trained to use their own smartphones GPS to map the associations member's farms using the applicative Qfield and to send the data to the GIS technician directly from their phones for the systematization and validation process. Next, the GIS technician uses the official land cover map that identifies forests (updated to 2018) and confirms whether there is forest in the farms. In the case that forest cover is identified within the farms, this area is extracted and analyzed with GIS technics to identify forest change using GLAD forest change data during 2019 and to identify forest change alerts during 2020 and 2021 using GLAD Forest Alerts data. The implementation of CST showed that the tools proposed to collect cartographic information of the associations allowed us to map 611 farms that summed 8758.67 ha. We found that 269 of these farms had 2768.67 ha of forest according to the 2018 land cover national map. After the GIS analysis of the GLAD forest change data of 2019, we found that only 36 farms presented forest loss (19.55 ha - Min 0.001 ha, Max 2.16 ha). On 2020, 39 farms presented GLAD forest change alarms of

confirmed category, whether on 2021 we did not find any forest change alarm of same category until February 30th.

Keywords: traceability, deforestation, monitoring

Detection and analysis of Cacao Swollen Shoot Virus by Capture Sequencing – a universal method

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ABSTRACT

The Cacao Swollen Shoot disease (CSSD) is the major viral disease on cacao, impacting cacao production. The disease is endemic in West Africa and causes the death of cacao trees within few years. The infectious agent is a virus from the family Caulimoviridae, member of the genus Badnavirus, and composed of a 7 kbp DNA genome. The most common method for CSSV diagnosis is based on visual inspection of plants to look for symptoms. While this method is reliable to detect the presence of the disease, it is inadequate for detecting latent infections in asymptomatic cocoa trees. Recently, new molecular methods based on PCR, qPCR or immune-capture-PCR have become available for the detection of the viruses in plants. However, they do not meet the expected requirements, mostly because of the difficulty to design universal primer and probes covering the genetic diversity of CSSV (qPCR and PCR), or the difficulty to establish (immune-capture-PCR). In order to circumvent these limitations and in the goal of obtaining a universal assay that would allow the detection of all strains of CSSV, we have established a capture-based approach to enrich specifically CSSV DNA from whole leaf DNA extracts, followed by sequencing. To this end, we have generated probes covering the entire CSSV genome of pathotypes B and CD. Following the capture, the enriched DNA was sequenced on Illumina MiSeq, followed by mapping on the corresponding CSSV genomes. We show that our approach allows to enrich efficiently the targeted pathotypes, as well as to identify mutations (e.g. SNPs). Owing to the flexibility provided by the hybridization conditions, we demonstrate that the approach allows to capture other CSSV genomes that diverge up to 70% from the genome of the viruses used to design the probes. The method we have developed is therefore universal in its ability to detect of CSSV infection without a priori knowledge of the pathotype or strain. In addition, thanks to the complete coverage of the CSSV genome, the

method allows to assemble de novo the full genome of the virus. Applying the method to a large number of pathotypes would rapidly allow the establishment of a compendium of the CSSV genomic sequences to support epidemiology studies. This would significantly contribute to the understanding the biology of CSSV. Similarly, population genetics would allow the tracking back of the origin of infection outbreaks and the setup of good practices to contain and avoid them.

Keywords: CSSV, Detection, DNA Sequencing

Cocoa price forecasting as a tool to increase future contracts potential in managing farmers' price volatility risk.

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ABSTRACT

Agricultural commodity markets have always been affected by a significant price volatility. Unanticipated changes in supply and demand often result in large price fluctuations. This is mainly due to the inelasticity of market fundamentals in the agricultural sector. Price volatility is one of the main sources of farmers financial risks and leads to a certain level of uncertainty about their income. Cocoa prices are no exception. In the last decade, London cocoa prices ranged in between a maximum of around 2.600 £/t and a minimum of around 1.300 £/t, with huge fluctuations either within a marketing year or across marketing years. This volatility makes cocoa farmers — especially in the developing countries, where this commodity mainly comes from — highly susceptible to poverty. Among other instruments, agricultural futures can be used by farmers in order to avoid the consequences of price volatility on income and investments decisions. Future contracts can allow farmers to “fix” a certain price for their production, thus excluding the possibility that their selling prices will fall in the future. This method is known as hedging. However, taken individually, hedging would result in farmers risk of losing higher profit potential. We identify cocoa price forecasting as a possible tool to increase the potential of future contracts in managing farmers' financial risk. After a brief introduction on the cocoa market, we show how fundamentals analysis can be used to achieve price forecasting. In particular, we empirically prove that a statistically significant relationship between cocoa fundamentals and cocoa prices exists; then, we exploit such relationship to forecast London Cocoa future prices. In our analysis, the quality of fundamentals data and the price forecasting accuracy are positively correlated; hence, we support the importance of the ICCO supply and demand data and forecasts. Finally, we indeed show how price forecasting could represent an instrument for farmers to better take advantage of the use of futures in financial risk management. Price forecasts can provide a reference point they can use to optimize hedging strategies in terms of timing and volume and serve in limiting the loss of higher profit advantages and, ultimately, improving farmers' income.

Keywords: Price Forecasting, Risk Management, Futures

Farmer segmentation: An approach to find aspiring cacao intercroppers from a population of coconut farmers

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ABSTRACT

The world demand for cocoa and chocolate is increasing, which in turn fuels demand for expansion of cacao growing areas. However, such expansions also have to be done in a climate-friendly way, as carbon neutral and deforestation-free cacao commitments are made across the industry (Kroeger, A. et al, 2017, IDH, n.d.) Intercropping cacao with an existing crop could be the answer to this paradox. Historically, cacao has been known to be compatible as intercrop with timber trees, shade loving crops (pineapple, pepper, cocoyam, etc), food crops (cassava, maize, etc) or with shade trees as fruit crops (coconut, banana, durian, etc) and other perennial crops (cola, oil palm, cashew, etc) (Adeyemi, 1999, Bentley, Boa, & Stonehouse, 2004). Our project evaluated possible pathways for cacao integration into an existing cropping system – coconut in Davao Oriental, Philippines. Farmer acceptance of cacao and interest to invest in cultivation of the more sensitive trees within their existing farms, serves as a helpful case study that can be applied to other cacao intercropping systems. The feasibility of coconut-cacao intercropping was assessed through farmer segmentation using hierarchical clustering and random forest classification of 425 farmers in Davao Oriental, Philippines. Based on a typology which matched the profiles of self-reported ‘satisfied’ cacao farmers to similar profiles of monocrop coconut farmers, we provide evidence that a minority of coconut farmers will likely convert into early cacao adopters. These potential early adopters are characterized by presence of at least one other intercrop in their coconut farms (e.g. banana), perception about suitable soil type, higher likert scores on attitudes towards entrepreneurship and risk, capital, and labor resources. However, lack of financial, land and labor capacity, climate shocks such as drought and typhoon are the major barriers for the farmers’ willingness to start or continue

investing in cacao. Support to farmers to access credits, high quality seedlings, improvement in post-harvesting services, and provision of extension services to increase farmer's capacity to cope with extreme events, as well as pests and diseases, could be beneficial to both coconut farmers and chocolate producing companies for sustainable sourcing in the promotion of cacao as intercrop. The result of this study will further support the investments of Barry Callebaut and USAID's in Mindanao towards adoption of sustainable cacao agroforestry systems for raw material production. This work highlights the importance of pre-investment study for more effectively cacao expansion strategies.

Keywords: cacao, farmer segmentation, cacao-coconut intercropping

A direct sourcing model based on key quality metrics for Costa Rican cocoa

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ABSTRACT

Heightened customer awareness and demand for sustainable chocolate has led to an increase in bean-to-bar chocolate producers and benefitted the market segment of fine flavour cocoa. However, although the sector is growing, the market remains a niche and is currently suffering from a massive oversupply of fine flavour cocoa. Costa Rica, a world leader in high-quality cocoa, is only one of many countries struggling with this issue. More innovative business solutions are necessary to help smallholders cultivating premium cocoa access markets and find buyers. The goal of this study was to establish a quality-based direct sourcing model in Costa Rica based on a multi-stakeholder approach. First, exploratory research was conducted in the form of interviews with cocoa producers, farm visits and written interviews with bean-to-bar chocolate manufacturers to help provide a more in-depth understanding of current challenges. To provide a set of key metrics to assess cocoa bean quality on a quantitative scale, data was collected by means of a literature review and protocols for chemical, physical and biochemical analyses were identified and summarized to create one standardized test protocol. 18 different cocoa bean samples were collected from lots of smallholders and processors in different regions throughout the country and analysed. Last, an online platform was established in the form of a direct sourcing map, linking interested cocoa farmers to potential buyers. Results showed high quality performances for all samples tested, indicating that biochemical aspects of cocoa bean quality could be assessed in a reliable manner with the methods provided and adapted. Flavour profiles of the beans could be established by means of new promising technologies, such as GC/MS headspace or HPLC. Interview results showed that many smallholders struggle to access markets and often lack the right knowledge on subjects such as the importance of quality control in post-harvesting practices. The study's results illustrate the often-neglected struggle of high-quality cocoa producers and the prevailing disconnect between different actors along the value chain. Furthermore, it highlights the need for more participatory and applied research. While research has made tremendous advance in optimizing and assessing

cocoa bean quality and good flavour notes, the knowledge often cannot be accessed by producers. Digitization offers tools to connect stakeholders, consolidate the supply chain and increase transparency, traceability and market access. By linking the efforts of research institutions, policy makers and actors from the industry, multi-stakeholder cooperation is enhanced.

Keywords: Cocoa quality, Direct sourcing, Costa Rica

Guiana (amazonian endemic cocoa) : Chemical composition and biological potential

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ABSTRACT

According to Motamayor et al., 2008, Guiana is one of the ten fundamental genetic groups in the world. It is native of French Guiana and differs by a very rough yellow pod and small beans. Although cocoa is well-known to have health benefits mainly due to its polyphenol composition, no studies of Guiana were led on its chemical and pharmaceutical aspects. To go further in order to expand the market, one way of valuing cocoa was the chocolate factory. Fermentation is a necessary key-step resulting in typical chocolate colour/taste and causing alteration in beans composition. Fermentation is known to generate a 70% decrease in Forastero polyphenol contents (most world produced cocoa reference), but no data were available on this impact on Guiana. Therefore, our objectives in this study were: (1) to outline chemical composition and biological (antioxidative and anti-inflammatory) potential of Guiana, (2) to determine the impact of fermentation on these parameters. Unfermented and fermented cocoa beans from Guiana and Forastero were performed. To assess Guiana chemical composition, total polyphenol contents were quantified using Folin-ciocalteu method and theobromine, flavonols and procyanidins contents were carried out by HPLC-DAD. Antioxidant activity was evaluated using 2,2-diphenyl-1-picrylhydrazyl (DPPH) and Oxygen Radical Absorbance Capacity (ORAC) assays. The anti-inflammatory activity was studied on macrophages pretreated with Guiana extracts, whose inflammatory process was subsequently initiated by gamma interferon and lipopolysaccharides. Measurements of the production of inflammatory markers such as interleukin-6 (IL-6) and tumor necrosis alpha (TNF-α) determined the anti-inflammatory potential of cocoa. Comparing to Forastero, Guiana showed higher theobromine and lower caffeine contents. Moreover, Guiana and Forastero had similar “total polyphenol”,

epicatechin, B2, C1 and A1 procyanidins contents. Antioxidant capacity was equivalent for both varieties in DPPH assay but was higher for Guiana in ORAC assay. Stimulating and inhibiting actions on TNF- α and IL-6, respectively were also evidenced in Guiana. Fermentation modulated both cocoa compositions by decreasing methylxanthine and polyphenol contents. This process also reduced antioxidant and immunomodulatory activities. Indeed, 6-day fermented Guiana showed higher stimulation on TNF- α production and lower inhibition on IL-6 production than unfermented Guiana. In conclusion, equivalent compositions of polyphenol and methylxanthine were demonstrated between Forastero and Guiana. A 6-day fermentation modulated the antioxidant and immunomodulatory potentials, and Guiana could be less affected by fermentation than Forastero.

Keywords: Amazonia, Fermentation process, Health

New smells and flavours of Venezuelan cocoa (*Theobroma cacao* L.)

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ABSTRACT

The sensory evaluation of cocoa has become increasingly important, both at the research and production levels. In the present work, a series of cocoa liquors of different origins has been evaluated, coming from the main producing areas of Venezuela, using a trained cupping panel for this purpose. The objective of this research was to update the wheels of aromas and flavours of Venezuelan cocoa previously published in 2013, including producing areas with new types of cocoa. The samples of the producers from all over the country fulfilled the following stages: selection, reception, and coding, physical analysis of the grains, liquor elaboration and sensory analysis. The panellists identified typical descriptors of Venezuelan cocoa but also new aromas and flavours not described until now, which allowed us to expand the range of aromas and flavours by profiles, reaffirming the immense genetic variability of our cocoas. The new scents are: leather, medicines, wild flowers, forest, herbal, tobacco, cloves, wine, guava, coconut, cherries, banana, fermented fruits, perfume and alcohol; while the new flavours are: caramel, banana, ripe banana, plums, panela, dry wood, walnuts, tangerine, apple and cinnamon. With these additional descriptors, the diversity of aromas and flavours of Venezuelan cocoa is expanded, which allows them to be discriminated by type and quality, being the new areas evaluated, Trincheras, Canoabo, Patanemo in Carabobo state, Orinoco Delta and Cocuina - La axis. Horqueta in Delta Amacuro state and finally La Azulita and La Tendida, in Mérida and Táchira states, respectively.

Keywords: Venezuelan cocoa, Aroma wheel, Flavour wheel

Sensory and chemical quality of Venezuelan cocoa (*Theobroma cacao* L.)

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ABSTRACT

The most widely used tools that best describe the quality of cocoa are molecular studies, physicochemical characteristics and sensory profile. Historically, Venezuelan cocoa has stood out for its high quality in the international market. The different techniques of physicochemical analysis and sensory evaluation have made it possible to correlate the different variables in order to express a profile of the quality of cocoa. This research has compiled a series of physical, chemical and sensory results of some of the most relevant cocoas in the areas with the highest production and quality in Venezuela. The cocoa samples have been selected directly from producers' plantations. All the samples have been fermented according to the different protocols established according to the type of cocoa (Criollo and Trinitario). The drying was carried out gradually in wooden drawers under sun exposure. The roasting of cocoa was carried out based on the results of the cutting test, especially considering the percentage of fermented, slate and Creole beans. All maintaining the sensory evaluation protocols with a trained panel. The results indicate that the cocoas studied present characteristics that allow them to be clearly differentiated from the Forasteros cocoas and commercial samples. In this way, it has been achieved that ancestral Creole cocoas maintain particular characteristics that make them more attractive to international chocolatiers. On the other hand, it is confirmed that there is a direct influence between the type of cocoa and the study area, with specific chemical variables and indisputable sensory attributes linked to its genetics, for which it is recommended to continue with the collection, conservation and propagation programs of ancestral cocoas and other Fine Flavour cocoas in Venezuela. On the other hand, it has been achieved that the genetic variability of Venezuelan cocoa is a fundamental resource in national cocoa farming both for the producer and for agricultural research.

Keywords: Venezuelan cocoa, Flavour cocoa liquor, Cocoa liquor

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Tracking Green Commodities, Ghana Beyond Aid and Cocoa-based Agro -Tourism in Ghana: The Nuances of Certification and Chocolate Consumption

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ABSTRACT

The production cocoa as a smallholder commodity crop are grown on land sizes of five hectares or less in tropical forest areas including Ghana. Certification of cocoa have arisen to address environmental, social and economic issues and improves the quality of the crop for consumers. Voluntary sustainable standards increases the capacity of farmers to strengthen conservation and sustainable use of biodiversity and natural resources, by reducing their vulnerability to climate change, enhancing sustainable agriculture and rural development . Certification incorporates development, welfare of smallholder producers while mainstreaming gender, human rights which influences consumer choices for responsible travelling. Certification implementation of commodities and outcomes are subjective roles from third party certification bodies. “Tracking Green Commodities” as an initiative and innovative model, promotes biodiversity conservation and rural development that would transform the lives of smallholder producers to complement for the low prices on the world commodity markets. “Tracking Green Commodities” seeks to increase tourism receipts for economic development in developing countries. This paper has been written mainly from literature review and other secondary sources, focus group discussions, practice and personal observation. Consumers sourcing for eco -labelled chocolate and cocoa products must crave to visit cocoa production sites in Ghana as deforestation-free community-tourism destination to help improve the livelihoods of cocoa production communities. It is also a catalyst for growth by reducing poverty and creating employment to improve development of host communities. This approach of facilitation for an alternative livelihood should be a big boost for small holder sustainable cocoa producers. The innovative business model should excite global consumers of green products. The Ghanaian government is implementing “Ghana Beyond Aid” policy to address issues of balance of payments and other financial shortfalls to resuscitate the economy as well as achieving the Sustainable Development Goals (SDGs) and targets.

Keywords: sustainable cocoa, Ghana, certification

Effect of inclusion of cocoa powder on proximate composition, chemical, mineral and sensory qualities of Unripened cheese-‘Warankashi’

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ABSTRACT

Unripened soft cheese “warankashi” was made by partially replacing soya milk (SoM) with cocoa powder (CoP) at 0.0% : 100% (A), 2.5% : 97.5% (B), 5.0% : 95% (C) and 7.5% : 92.5% (D) for CoP : SoM respectively. Proximate composition, antioxidants analyses: DPPH, radical scavenging abilities, Vitamin C and mineral analysis of the cheese were carried out. The sensory evaluation of the samples was done using taste panelists comprising 15 female and 13 male members of staff of the Cocoa Research Institute of Nigeria who are regular consumers of cheese. The proximate chemical components showed significant difference ($p < 0.05$) in protein, crude fat, and total ash content which increased from 4.34% to 5.47%, 16.76% to 26.90% and from 16.15% to 17.44% respectively as the inclusion level of cocoa powder increases. The radical scavenging activities of the cocoa based cheese, FRAP assay and the Vitamin C contents also increased from 61.50% to 68.14%, 29.78% to 37.14% and from 16.69mg/100g to 21.43mg/100g respectively as the cocoa powder addition increases. The range of increase in values obtained for mineral like Calcium, Iron and Magnesium were 66.25mg/100g – 83.01mg/100g, 20.13mg/100g – 24.07mg/100g and 45.10mg/100g - 60.96mg/100g respectively. The result of consumer acceptability test shows that sample C (5% : 95%) and D (7.5% : 92.5%) were accepted as well without any significant differences with the control sample.

Keywords: Unripened cheese, soymilk, Cocoa powder, Partial substitution, Antioxidants, Minerals

Harnessing publicly available data to improve transparency in cocoa supply chains

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ABSTRACT

Several ongoing initiatives strive to make cocoa supply chains more sustainable. These include the Cocoa Forests Initiative (CFI), pending legislation from importing markets (the US, UK and EU) on forced labor and deforestation, the introduction of the Living Income Differential by the governments of Côte d'Ivoire and Ghana, and ongoing efforts towards an African Regional Standard for sustainable cocoa. Information is scarce, however, about the companies and supply chains which source cocoa and are instrumental in implementing these commitments. In this presentation, we present a novel dataset to improve transparency in the Côte d'Ivoire cocoa supply chain. As part of the Trase initiative (<https://trase.earth/>), we combined multiple publicly available datasets on cocoa trade, production, and land cover to identify the companies handling cocoa exports in 2019 and the origin of their sourcing. Eight trading companies handled 60.6% exports of cocoa products (beans, paste, butter, and powder), with 64.7% of exports flowing to the European Union. Overall, 44% of cocoa was traced back to specific cocoa cooperatives, with the remaining 56% sourced through other intermediaries (traitants, pisteurs). We then crossed our maps of each trading company and importing market's sourcing with data on sustainability risks (deforestation and child labor) in specific sourcing regions. We show considerable heterogeneity in the sustainability risks to which different exporting companies are exposed, and between cocoa sourced via cocoa cooperatives and other supply chain intermediaries. Our analyses identify the key regions in Côte d'Ivoire from which cocoa is sourced mainly from traitants and pisteurs and thus on which trading companies have less direct leverage on sustainability risks. We also identify key landscapes where multiple companies can work together to invest in sustainable cocoa production and improve livelihoods for cocoa farmers. Finally, we discuss the limits of what is possible using public data and how the approach presented can improve accountability and monitor progress on promises of sustainable cocoa.

Keywords: Transparency, sustainability, zero deforestation commitments

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Development and selection of new yeast starters for cocoa beans fermentation – effect of different *Saccharomyces cerevisiae* yeast strains on the volatile profile and sensory attributes of resulting chocolates

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ABSTRACT

Selection of natural yeast for cocoa bean fermentation is of growing interest as it is now considered as a tool for cocoa quality improvement. To better understand mechanisms that lead to upgraded cocoa, a lab-tool bioreactor was designed to reproduce at best field fermentation conditions by controlling cocoa mass temperature through watered double-jacket, using innovative pales to wave mix or harvesting resulting juices in a draining chambre. This tool then allowed cocoa fermentation study by using low quantity of fresh cocoa beans rarely available in non-producing countries, as well as an in-depth analysis of the performance of three diverse yeast starter cultures and their effect on chocolate quality. These yeast strains were either isolated from a non-cocoa environment (strain VIB3), an autochthonous cocoa yeast (strain VIB2) or a hybrid between the two (strain VIB1). The former two were selected for their high thermotolerance, shown to be a pivotal feature of cocoa starter cultures (Meersman et al. 2015). Selected microorganisms were evaluated on different beans origins e.g. Ivory Coast, Guyana, and Ecuador. Following a standard approach of beans fermentation, phenotyping highlighted new potential yeasts starters that implanted well in cocoa matrix environment, exhibited as well interesting characteristics such as temperature resistance or good interactions with endogenous lactic or acetic acid Bacteria. Resulting chocolates were compared each other through analytical and sensorial approaches. Chocolates turned out to contain mainly alcohols and acids, 2-Phenylethanol (Lilac, Rose) and Acetic acid (Vinegar, Pungent) Even though most concentrated volatiles compounds may directly impact sensorial properties, esters are also well known for their fruity, floral contribution They could come from either beans compositions or yeasts' metabolisms, as well as a new a marker most likely produced by one of the screened strains Indeed this is the first reported ester in the final chocolate that may come from yeasts sugar consumption. Resulting chocolates eventually presented different aroma profiles

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such as fruity or floral, showing that yeasts starters played a considerable role to unlock cocoa flavor potential.

Keywords: Yeasts, Fermentation Control, Organoleptic improvement

Quality and Yield Management during Winnwoing

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ABSTRACT

Quality and Yield Management during Winnowing One of the most important steps within the cocoa processing is certainly the separation of cocoa shell (testa) and the nibs (fruit meat). In order to separate the nibs from the shells an equipment so called winnower is used. This equipment is first breaking the beans in fragments and separate the shells from nibs via density. However, this section in the cocoa processing is poorly monitored and managed, since the quality monitoring and adjustment process at the winnower is time consuming. Even though this process is most relevant for yield and quality management and therefore key for sustainability the regular monitoring sequence of the winnower is around one time per shift. However, fluctuation of bean quality within a LOT (fermentation index, bean count, ect.) causes changes in the beaker and winnower performance. Ideally a contentious monitoring and adjustment of the winnower would be needed in order to increase sustainability in regard of quality and yield. To be able to observe the separation efficiency more frequent, an online Shell/Nib detection system the so-called “Quality Yield Cockpit” (QYC) was developed. Using the QYC-System the operator is now able to adjust the winnower performance over the whole shift accordingly to obtain the maximal yield by keeping the expected quality. By means of camera and corresponding evaluation algorithms to identify the shells on the main mass-flow sieves, the shell content in the nib flow will be monitored evaluated. If quality parameters or yield setting fails a signal will be send to operator. Autonomous adjustment can be done with the aspiration system. In future, we also plan to integrate the automatic crusher control, i.e. to vary the crusher speed and crushing intensity automatically. By means of camera and corresponding evaluation algorithms to identify the shells on the main mass-flow sieves. The so detected shell content is classified in regard of pre-set minimal and maximal thresholds. This allows the operator to react accordingly when the cocoa bean properties are changing to guarantee quality and yield. The winnower system can now be adjusted linked to the bean properties online and the “un-know” performance area is removed in order to increase quality and yield.

Keywords: Winnover, Yield, Quality

Steering cocoa fermentation, a fine-scale follow-up of mixed-strain starter cultures

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ABSTRACT

The application of starter culture mixtures for cocoa fermentation has been proposed as an effective way to achieve a homogeneous quality of cured cocoa beans. Moreover, the development of a diverse range of flavour compounds during fermentation can be enhanced by applying different yeast strains. However, fine-scale monitoring of inoculated starter culture strains was still lacking up to now, as microbiological analyses relied on culture-dependent techniques and those applied culture-independently do not always reach enough discriminatory power below genus level. In the present study, functional starter culture mixtures, composed of the lactic acid bacterial (LAB) strain *Limosilactobacillus fermentum* IMDO 0611222, the acetic acid bacterial (AAB) strain *Acetobacter pasteurianus* IMDO 0506386 and different combinations of candidate yeast starter culture strains, *Saccharomyces cerevisiae* IMDO 050523, *Pichia kudriavzevii* IMDO 020508, and *Hanseniaspora opuntiae* IMDO 040108, were applied in Costa Rican Trinitario cocoa fermentation processes. These starter culture-initiated cocoa fermentation processes were compared with spontaneous ones. In addition to classical microbiological and metabolomic analyses, high-throughput sequencing of the V4 region of the 16S rRNA gene (bacteria) and the internal transcribed spacer (ITS1) region (yeasts) were used to examine the microbial community dynamics in the fermenting cocoa pulp-bean mass. A temporal prevalence of enterobacteria, yeasts (*Hanseniaspora* and *Saccharomyces*), LAB (*Leuconostoc*, *Weissella*, and/or *Limosilactobacillus*), and AAB (*Acetobacter* and/or *Gluconobacter*) was found. The relative abundance of the inoculated LAB, AAB, and yeast genera was higher in the starter culture-initiated cocoa fermentation processes. In addition, the amplicon sequence variants (ASVs) generated by the DADA2 R-package were used to monitor the inoculated bacterial and yeast strains throughout the fermentation processes in detail. A high correlation was found between the occurrence of specific ASVs at high relative abundances and the starter culture strains inoculated, as these were almost exclusively present in the

starter culture-initiated fermentation processes. Indeed, sequence alignment demonstrated that these ASVs were identical to the corresponding genomic region of the inoculated strains, for which the whole-genome sequences were available. Thus, ASVs emerged as a suitable approach to follow-up the starter cultures applied and, therefore, evaluate their impact on the outcome of the fermentation processes and, ulteriorly, the quality of the cured cocoa beans.

Keywords: Starter culture fermentation, high-throughput sequencing, amplicon sequence variant

Mathematical prediction of sensory properties in cocoa liquor using volatile compounds composition

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ABSTRACT

The tasting process is used worldwide for the sensory characterization of beans and cocoa's liquor. However, in many countries, there are not enough tasting panels to qualify the quality of cocoa's liquors. On the other hand, it is well known that composition of volatile compounds are associated with sensory properties and this knowledge has been used to obtain mathematical models in order to predict sensory profiles of wine and cheese matrices. However, to the best of our knowledge, there are not mathematical models proposed to predict the sensorial profile of cocoa liquors using its profile of volatile compounds. Therefore, this work was focused on the proposal of six mathematical models to predict the sensory attributes as follows: cocoa, nut, floral, fruity, acid, and sweet. To accomplish this aim was proposed the following; first, the volatile compounds were extracted from cocoa's liquor by solid phase micro-extraction/headspace (SPME-HS). Second, volatile compounds were identified and quantified using GC-MS-FID. In parallel, the same samples of cocoa's liquor were subjected to sensory analysis using a tasting panel. These steps were developed to 20 samples of cocoa's liquors. Then the results were statistically correlated using the odor active value (OAV) as the parameter key in a principal component analysis (PCA), which drove to prioritize the compounds used in the fit of predictive models by partial least square (PLS). From chemical characterization and sensory analysis, 77 volatile compounds were identified and quantified in the 20 cocoa liquors and 6 sensory attributes were perceived in them. These results allowed it to determine the chemical profile and the sensory profile of each of the liquors. The PLS regression method was able to mathematically model the 6 sensory attributes from the chemical profile of volatile compounds obtained. The predictive variables (volatile compounds) that contributed to the modeling of sensory attributes were reduced from 77 compounds to 16 volatile compounds using OAV as the key parameter in PCA analysis. The models obtained had coefficients of determination (R^2) of 0.85, 0.70, 0.89, 0.87, 0.79 for the cocoa, nut, floral, fruity, acid, and sweet attributes showing that the proposed models describe and adjust in large proportion

to the analyzed data and besides, these models predict with a high confidence level the sensory perceptions studied.

Keywords: mathematical models, sensory attributes, volatile compounds

Kinetics of Cadmium Bioaccumulation in Seeds of Five Cacao Varieties

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ABSTRACT

In order to evaluate the accumulation of cadmium (Cd) in cocoa beans seeking to identify those with hypoaccumulative potential, the trial was carried out at the Tulumayo Station. As genetic material, five cocoa genotypes S-08 (ICS-95 x UF-296), S-12 (ICS-1 x SCA-6), S-23 (IMC-67 x U-68), S- 28 (ICS-39 x U-45) and C-60 (farmer's selection) of different genetic origin and organoleptic quality, were tested. Chemical analyzes of Cd in seeds were carried out by atomic absorption spectroscopy. The data were analyzed using curvilinear polynomial regression, Pearson's correlation and biplot analysis. The kinetics of the accumulation of Cd in the seeds showed a reductional trend from June to September (summer) characterized by the scarcity of rains, and a slight increase from October to November (beginning of winter) with more frequent rains, accumulating on average 0.894 ppm of Cd. There was a differential response between genotypes, being S-8 and C-60 the ones with the lowest accumulation with 0.650 and 0.815 ppm of Cd, respectively, resulting less than and equal to the maximum permissible limit established by the EU for chocolates with dry cocoa solids $\geq 50\%$, respectively. Positive and highly significant correlations were also found between Cu / Zn ($r = 0.869$), Mn / Fe ($r = 0.755$), Fe / Zn ($r = 0.655$), while highly significant negative correlations for Cd / Zn ($r = -0.666$) and Cd / Cu ($r = -0.531$) were found. The values of pH, O.M, C.E.C, N, P and K of the initial and final chemical analysis of the soil, did not show statistical differences. Future studies of bioaccumulation of Cd in cocoa beans should include a greater number of genotypes of different genetic origin and hypoaccumulative potential. Key words: Cacao, varieties, seed, Cd hypoaccumulation, microelements interaction

Keywords: Cacao, Variety, Cadmio hypoaccumulation



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