Public facing Report

Developing Partnership/Collaboration for Climate Smart and Sustainable Cocoa Production Systems in Brazil, Ghana, Nigeria, and UK.

1.0 Background / Summary

Need for climate smart cocoa systems in Brazil, Ghana and Nigeria

Cocoa is grown throughout the humid tropics, supporting an estimated 5-6 million smallholder farmers and providing an essential ingredient to the chocolate and confectionery industry worldwide, and specifically in the UK (Fairtrade, 2025). Over 70% of the world supply of cocoa is supplied from West Africa (ICCO, 2025a) but yields from this region have recently declined sharply, whilst in Brazil countrywide yields are approximately half of that achieved in the 1980's due to the impacts of Witches' Broom Disease. In West Africa, four factors are considered to account for recent yield declines: the impact of climate change, increasing age of tree stocks due to a lack of investment in new plantings, poor farming practices, including poor soil management, and increased incidence of pests and diseases, possibly due to the negative impacts of climate change. Future cocoa production can be improved in the short term by changing farming practices and in the medium /long term by the replacement of tree stocks with high yielding genotypes with more resilience both to abiotic stresses resulting from climate change and to pests and diseases.

The University of Reading (UoR) is recognised as a centre of excellence for cocoa research with a programme that has spanned over 40 years (https://research.reading.ac.uk/cocoa/). Ongoing research lead by UoR in collaboration with the Cocoa Research Institute of Ghana (CRIG), Kwame Nkrumah University of Science and Technology (KNUST) and other key stakeholders in Ghana has shown that organic amendments and surface mulches improve cocoa establishment and yield. These research findings are being translated into practical field solutions to deliver more sustainable farming systems through an NERC Knowledge Exchange Fellowship at UoR . Physiological studies, also at UoR, funded by Cocoa Research UK, has led to the development of methodology to identify climate resilient cocoa genotypes with increased water use efficiency and sensitivity to high temperature stress amongst accessions held at the International Cocoa Quarantine Centre, also at UoR. Material previously identified at UoR has been incorporated into breeding trials and selections from these trials have the prospect of providing a major step towards a new generation of climate adapted genotypes. Development of planting material that is more resilient to high temperatures and drought would be a step-change in the adaptation of cocoa farming to climate change.

The aim of this project is to develop existing networks, currently maintained through knowledge exchange between UoR and key institutions and stakeholders in Ghana, and expand networks to two other key cocoa producing countries, namely Nigeria and Brazil.

2.0 Challenges, Barriers and Technology gaps

What are the challenges, barriers and technology gaps impacting the potential for climate-smart and sustainable cocoa production systems in Brazil, Ghana and Nigeria.

Cocoa is grown throughout the humid tropics, supporting an estimated 5-6 million smallholder farmers (Fairtrade, 2025) and providing an essential ingredient to the chocolate and confectionery industry worldwide, and specifically in the UK. Over 70% of the world supply of cocoa is supplied from West Africa with Côte d'Ivoire, Ghana, Nigeria and Cameroon supplying 38%, 12%,7% and 7% respectively (ICCO, 2025a) but yields from this region have recently declined sharply (ICCO, 2025a), whilst in Brazil, which supplies 4% of the world supply of cocoa, yields are approximately half of those achieved in the 1980's due to the impacts of Witches' Broom Disease (Pereira et al., 1996).

Cocoa beans are required by the chocolate industry which is a profitable, innovative sector of the global food industry. It has grown consistently by 2% per year for the last 50 years, and is predicted to continue growing, perhaps at an even higher rate in the future. Global chocolate market size was valued at approximately USD 47 billion in 2022 and is expected to grow to approximately USD 68 billion by 2030, growing at a Compound Annual Growth Rate (CAGR) of 4.98% in the forecast period (2023-2030). Global cocoa production is about 5m tonnes per year, with substantially more tonnage required to meet anticipated growth. Cocoa productivity in West Africa is generally low with average yields in Ghana of 300–600 kg ha^{-1} (Wessel & Quist-Wessel, 2015), compared with experimental yields up to about 3000 kg ha^{-1} (Appiah et al., 2000) and average profitability of ~ $150 USD per ha (Kongor et al., 2018). However, the yields across cocoa farms are highly variable and while some of this is due to different management practices (e.g. cocoa and shade tree density, fertiliser use, and the age of cocoa trees), there is additional variability due to differences in climate and soil types (Daymond et al., 2018 ; Asante et al., 2021). Regional yields in West Africa have also declined significantly in recent years due to a number of factors: the impact of climate change, increasing age of tree stocks due to a lack of investment in new plantings, increased incidence of pests and diseases (possibly due to the negative impacts of climate change) poor farming practices and poor soil management. Future cocoa production can be improved in the short term by changing farming practices and in the medium /long term by the replacement of tree stocks with high yielding genotypes with more resilience to climate change.

The impact of climate change: lack of awareness of climate-smart practices among farmers

There is increasing evidence that climate change is having negative effects on cocoa production in West Africa. Black et al. (2020) have predicted that both temperature and rainfall will increase in the long term in this region. However, climate extremes, particularly in rainfall, causing severe drought in dryer dry seasons and more intense wet seasons and less predictability around the start of wet seasons is impacting yields in this region.

Cocoa trees are particularly susceptible to the impacts of climate change which can include reduced yields, poor establishment and more severe pest/disease outbreaks. Farmers who perceive these changes are more likely to adopt climate smart agricultural practices such as the planting of new varieties (Buxton, 2020). However, a relatively low proportion of cocoa farmers in Ghana take action to build resilience against climate shocks and the few that do tend to diversify their income sources rather than apply biophysical interventions to improve the productivity of their own cocoa trees (Wongnaa & Babu, 2020).

Cocoa yields are particularly sensitive to rainfall (Adet et al., (2024). However, the greatest impact from climate extremes is occurring at planting as seedlings are more susceptible to drought and flooding leading to significant losses at this stage (Acheampong et al., 2019). This combined with soil degradation has been making establishment of new cocoa plantings more difficult. Mature cocoa is generally more resilient to drought with leaf fall and reduced flowering being observed under typical dry season conditions, but total losses of trees have been more frequent under recent severe drought conditions. Subsistence farmers usually have insufficient capital to invest in irrigation although better farm management using increased shade and adopting agroforestry practices may offer ways to mitigate the impacts of climate extremes. In Brazil, larger farms have invested in irrigation and fertigation with cocoa intercropped with rubber and coconut as shade species.

There are a range of other means by which cocoa farmers in Ghana can diversify their income to cope with a reduction in cocoa yields due to climate change and declining soil fertility, including the provision of services such as weeding, fertilisation, and harvesting to other farmers (Amfo & Ali, 2020). A range of socio-economic factors, including the gender and education level of the farmer have been shown to be associated with level of adoption of recommended practices (Aneani et al., 2012).

Whilst climate change is having a range of negative impacts on cocoa production including establishment, survivorship and pests and diseases, a recent study by Asante et al. (2025) actually predicts long-term average yield benefits of climate change in much of West Africa. This is due to the positive impacts of greater rainfall and higher carbon dioxide concentrations on productivity and yield compared to the negative effects of warmer temperatures. Moreover, Asante et al. (2025) also predict that the benefits of climate change by 2060 from west to east in West Africa so that there are likely to be potential opportunities for cocoa farmers in Nigeria to significantly increase production with greater areas available for cocoa production than presently available The ameliorating impact of elevated [CO_2] on higher temperatures and drought has been demonstrated in physiological studies by (Lahive et al., 2018; Lahive et al., 2021) and Mateus-Rodríguez et al. (2023).

Increasing age of tree stocks due to a lack of investment in new plantings

Much cocoa in the west African region was planted 25-35 years ago and so many cocoa farms are reaching the end of their productive life with gradually declining yields because of the combined effect of aging trees and declining soil fertility as a result of low inputs cocoa farming systems that are used in this region. These farms should be replanted but aging farmers often are either physically unable or do not have adequate funds to replant. In addition, farmers frequently have inadequate resources to hire labour to help on the farm in the absence of help from younger family members who are often attracted to leave the farm for better paid work elsewhere; this often leads to a progressive deterioration in the condition of farm. After one cocoa cycle of circa 35 years, soils are depleted of most essential nutrients and soil organic matter; therefore replanting in once used cocoa lands is much harder. New cocoa plantings usually require establishment of shade in advance of planting cocoa; this adds significantly to the replanting process; replanting on depleted cocoa lands is much more complex than was the case when farmers planted under thinned forest shade after timber extraction. Planting material (typically hybrid seed), for example, produced by COCOBOD Seed Production Division are not produced in adequate numbers and so are not easily available to farmers and many of the Seed Gardens are reportedly heavily infested with Cocoa Swollen Shoot Virus (see below). As a result, farmers often plant using seed from their own, or neighbours farms leading to highly variable segregating plant populations.

When cocoa production declines due to aging tree stock there are a variety of context-specific factors that lead to a decision about whether to rehabilitate (i.e. improve the fertility of existing trees) or renovate (i.e. replant trees) (Somarriba et al., 2021). A system whereby annual replacement of 5-7% of the cocoa trees on a cocoa farm helps to increase cocoa yields and stabilise income volatility for Ghanaian cocoa farmers (Nalley et al., 2014). However, there are multiple factors which may lead to the land becoming abandoned or changed to another land use rather than rehabilitation or renovation. The cocoa land tenure landscape is shifting in Ghana away from long-term right-based mechanisms to more short-term contracts such as sharecropping and rental agreements and this might reduce the incentives for farmers to rehabilitate aging cocoa farms (Asumang-Yeboah et al., 2025). There is a need to change the current land tenure systems to introduce formal documentation of benefit sharing agreements in Ghana to encourage farmers to adopt sustainable agricultural practices (Quaye et al., 2015).

Increases in pests and diseases

It is estimated that30-40% of potential global cocoa yield is lost through the effects of pests and diseases (ICCO, 2025b). Cocoa Swollen Shoot Disease (CSSV) is reported to be increasing in both Ghana and Côte d'Ivoire and continues to devastate cocoa areas with the level of infection seemingly increasing unabated and out of control. It is suggested that infection is increased under stress conditions linked to climate change and, once infected, trees can die in a few seasons. No resistance to CSSV appears to exist and the only method of controlling the disease is to cut out infected trees and replant. Infected trees can be asymptomatic while more CSSV strains (of varying virulence) have been identified (Ameyaw et al., 2024).

Cocoa trees in West Africa are rarely pruned and often of excessive height; such trees cannot be easily pruned to remove mistletoe that debilitates cocoa trees; mistletoe continues to spread across the region (Osei & Ansong, 2023).

Cocoa is attacked by a number of pests. Cocoa mirids (capsids) are important pests of cocoa that have been reported to causes up to 30% yield loss in Ghana where they feed on pods and shoots (Asare et al., 2018). The most important species of the cocoa mirids in Ghana are *Distantiella theobroma*, *Sahlbergella singularis* and *Holopelti* ssp. If untreated mirids can wipe out cocoa trees and cocoa farms. Control requires farmer vigilance, adequate funding for, and the local availability of chemicals. Many farmers cannot afford to buy pesticides (Asare et al., 2018)

In Brazil, witches' broom disease (*Moniliophthora perniciosa*) spread to the state of Bahia from the Amazon in 1989 causing widespread devastation of cocoa trees (Scarpari et al., 2005) . Since this occurred when the cocoa price was low, many farmers abandoned their farms resulting in further spread of the disease. More proactive farmers continued to produce cocoa but 30 years later output from Bahia is still only half what it was prior to disease introduction. New varieties have been introduced in Brazil that are more resilient to witches' broom disease (Lisboa et al., 2020).

Frosty pod rot disease (*Moniliophthora roreri*) has spread across many parts of central and south America but is not currently in Bahia (Cubillos, 2017). However, it is in some parts of the Amazon region and has recently spread to the Caribbean.

Phytophthora (black pod) disease (*Phytophthora palmivora*) is present wherever cocoa is grown and is responsible for significant losses of cocoa particularly in humid, high rainfall areas whilst the more virulent *Phytophthora megakarya*, also infects cocoa across many areas of West Africa (Akrofi et al., 2015). Fungicides are available but disease spread can also be reduced by avoiding rain splashing by using mulches and removing diseased pods from the trees.

More detailed information on pests and diseases of cocoa is given in the public facing report provided by Sarah Arnold and Adreanna Welch.

F**arming practices**

Varying levels of farm husbandry are carried out by subsistence farmers in Ghana and Nigeria from farmers just visiting the farm to harvest the pods and others that undertake considerable farm management. The majority of farmers in the region maintain a low input farming practice. Farmers have generally not routinely applied fertilizers and so nutrient levels in the soils of cocoa farms are not maintained. There have been schemes in Ghana where farmers have been provided with fertilisers because fertiliser prices fluctuate (see later) but this has not been consistent and recent high fertiliser prices have meant that farmers often cannot afford to apply fertilisers (Wokibula et al., 2024). Similarly, cocoa pesticide spraying programmes for Black pod and mirids have occurred in Ghana in the past and a tree cutting programme against CSSV has been maintained over many years (Amon-Armah et al., 2024). Cocoa farmers rarely prune trees and trees are often not planted in clearly defined rows (Daymond et al., 2018). In the past, shifting cultivation has meant that cocoa farmers have abandoned farms when they become unproductive and have cleared rainforest to replant cocoa farms. However, now cocoa buyers require farmers to provide evidence that they are not growing cocoa on recently cleared rainforest (TraseEarth, 2024).

In contrast, cocoa farmers in Brazil generally grow on larger farms and maintain more sustainable farming practices, some framers are adopting high input systems using irrigation and fertigation on farms planted with more productive clones with increased use of mechanisation to prune trees and collect and process cocoa pods. However, the number of farmers that have access to those resources only represent approximately 5% of cocoa farmers according to our expert elicitation during online bilateral meeting.

Soil management

Soils in West Africa are often of low quality. An assessment of soils across all the cocoa growing regions of Ghana reveals sandy soils with low soil organic carbon (0.78-2.68%) and low pH (with a mean pH of 4.91) whilst phosphorous is the nutrient that most limits cocoa production (Afrifa & Dogbatse, 2018; Quaye, Doe, Attua, et al., 2021).

A key driver of productivity gains in Ghanaian cocoa farms has been fertiliser application promoted by the Hi-Tech programme of fertiliser subsidisation (Jebuni-Dotsey & Senadza, 2023). However, the high variability of cocoa yields and soils highlights the need for spatially explicit fertility strategies to account for local soil organic carbon and pH levels rather than blanket fertiliser recommendations (Quaye et al., 2021). The exact nutrient requirements for cocoa are still largely unknown since there is no widely accepted methodology to make recommended fertiliser applications based on soil or leaf sample analysis and there is a wide diversity of responses to fertiliser applications observed across different field trials conducted on different farms (Van Vliet & Giller, 2017).

Amongst cocoa farmers surveyed by Quaye et al. (2021), only 13% use purely organic integrated soil fertility management but 87% use a combination of organic and inorganic fertilisers and the adoption of organic integrated soil fertility management increases with the age of the cocoa trees. The adoption of 'Asaasenufosuo' organic fertilisers for cocoa production has been influenced by a range of socio-economic factors, but constraints to use has included slow nutrient release, the odour, the cost of transportation, and the high cost and limited availability of the product (Avane et al., 2022). The demand for organic fertilisers in Ghana is estimated to be approximately 0.7 million tonnes per year, but has the potential to rise to 2.7 million tonnes per year and to make Ghana a net exporter of organic amendments (Bidzakin et al., 2023). There is an emerging market for poultry droppings in Ghana and currently 76% of the droppings produced in Ghana (particularly the western districts of the Brong-Ahafo region) are sold in Côte d'Ivoire via an informal cross-border trade with an average price of $8.39 USD per tonne (Ruf et al., 2015; Gbordzoe et al., 2024). These external markets represent a potential net export of organic nutrients from Ghana and both a barrier to achieving climate smart cocoa systems and opportunities to close nutrient cycles on cocoa farms.

For each 1000kg of cocoa beans harvested there is approximately 1400kg of pod husk which contains 14.0kg of N, 4.2kg of P, 68.0kg of K, 6.6kg of Ca, and 6.5kg of Mg (Snoeck et al., 2016). Cocoa pod husks are therefore particularly rich in K, but some decomposition is necessary to release the K and expose it to leaching, which is mainly driven by rainfall intensity (Hougni et al., 2021). Recycling the nutrients from cocoa pod husks (particularly P and K) back into soils may help to restore degraded cocoa soils and close yield gaps (Amponsah-Doku et al., 2022).

In Ghana, cocoa pod husks can be composted with poultry manure, and *Panicum maximum* at an optimum ratio of 6:1:2, resulting in a compost that has a pH between 6.5 and 8.5, a high nitrogen content, permissible copper concentrations, and no presence of *Phytophthora palmivora* and *Phytophthora megakarya* (Dogbatse et al., 2020). Significant research has been carried out on the production of biochar in Ghana and a variety of feedstocks have been evaluated, primarily as a soil amendment to improve maize grain yield (Yeboah et al., 2022). The application of biochar made from pruned cocoa branches and compost from The Accra Compost and Recycling Plant significantly improved the growth parameters of cocoa seedlings in an experiment conducted at the Kumasi Institute of Tropical Agriculture in Ghana (Salifu et al., 2020). Research undertaken in the UK, in collaboration with Ghanaian partners indicates that addition of raw cocoa pod husks to an acidic Ferralsol and an alkaline Nitisol can result in high greenhouse gas emissions and microbial immobilisation of nitrogen, but applying a mixture of cocoa pod husk compost and cocoa pod husk biochar can increase overall soil fertility, in acidic soils (Mwafulirwa et al., 2024). Compost production is included in a "Climate-Smart Agriculture in Cocoa" training manual for field officers in Ghana developed by the World Cocoa Foundation and Rainforest Alliance in collaboration with Ghana Cocoa Board (Dohmen et al., 2018). A collaboration between The University of Reading, Kwame Nkrumah University of Science and Technology, and the Cocoa Research Institute of Ghana has resulted in the establishment of 15 field trials across cocoa growing regions of Ghana to test the crop and soil response to different ranges and concentrations of cocoa pod husk composts, inorganic fertilisers, and biochars. Whilst results from these trials are currently being analysed and have not yet been disseminated, farmer testimonials have been positive (see: https://research.reading.ac.uk/cocoa/soil-amendments-project/).

In Nigeria, four field trials established in Ondo State showed that a combination of compost and inorganic fertilisers resulted in 72.4% higher cocoa bean yields than the unfertilised control and reduced black pod disease (Ogunlade & Orisajo, 2020). Research has shown that a farmer in Cross-River State, Nigeria using a cocoa pod husk fertilizer has a higher economic efficiency index than a farmer that is a non-user (Agbeniyi et al., 2011). The use of dried and milled cocoa pod husk as an organic soil amendment increased pod production by 64% and 68% on two old moribund cocoa plantations in Nigeria (Okeniyi et al., 2020). The fortification of cocoa pod husks with Neem and application as a soil amendment reduced the root-knot disease caused by *Meloidogyne ingonita* on cacao seedlings (Orisajo & Fademi, 2005). Experiments applying cocoa pod husk composts (co-composted with poultry manure or Neem leaf) have demonstrated that these are a good fertiliser, increasing N, P, and K availability and uptake by okra (Kayode et al., 2018).

Research on the use of cocoa pod husk composts for cocoa cultivation has been undertaken in other cocoa growing countries. For example, the rehabilitation of a 22 year old cocoa plantation in Malaysia was achieved through the use of shade trees and a compost made from cocoa pods, cocoa leaf litter, organic waste, chicken dung, and soil (Vanhove et al., 2016). Research undertaken in Papua New Guinea has indicated that composting cocoa pod husks with either triple super phosphate and poultry manure resulted in a compost with good quality parameters and improved the growth of cocoa seedlings (Fidelis & Rajashekhar Rao, 2017). Experiments on cocoa pod husk-based soil amendments in Cameroon indicated that 20% (v/v) applications of these composts supressed black pod disease in cocoa plantlets, compared to plantlets grown in unamended control soils, both by reducing the pathogen loading due to increased soil microbial activity, and by inducing resistance in the plant by increasing soil pH, and reducing aluminium toxicity (Doungous et al., 2018).

Taken together, it is clear that appropriately made cocoa pod husk composts can help to recycle nutrients back into cocoa soils and the use of biochar can improve the soil fertility. However, the introduction of carbon markets and the value of feedstock for biochar may result in a new wave of 'land grabs' where carbon is 'chopped out' of the ecosystem and social context to offset emissions elsewhere in the global economy (Leach et al., 2014). There may also be unintended consequences of using cocoa pod husks for making compost if they divert raw materials away from other value-added products. Alongside soil amendments, cocoa pod husks have been used for soap making, animal feed, activated carbon, paper making, biofuels, and as a source of dietary fibre and antioxidants (Lu et al., 2018). Research in Brazil has highlighted the potential for using cocoa residues (including cocoa pod husks, cocoa bean shells and cocoa sweatings) to produce high-value-adding molecules for the food, pharmaceutical, or cosmetic industries (Vásquez et al., 2019).

Other factors affecting cocoa production in West Africa: Gold mining

There has been recent concern about the impact of gold mining in Ghana on cocoa production. Significant areas of suitable cocoa land and of established cocoa farms are being 'sold' to artisanal gold mining actors (both legal and illegal); it is estimated that the area covered by Galamsey increased from 10,907 to 36,696 ha between 2011 and 2015 (Snapir et al., 2017) . High earnings by the so-called galamsey operators, extracting gold far exceed those earned by the cocoa farmer and so miners offer an attractive price for cocoa farms, that are then completely destroyed (Snapir et al., 2017). Mercury is widely used in the process of gold extraction and this leaves behind contaminated/poisoned ex-cocoa farms as well as pollution where farms are downstream. Such lands are unlikely to be usable for planting cocoa again unless technologies for remediation of mine contaminated land are developed (Osman et al., 2022).

Conclusions

Future cocoa production can be improved in the short term by improving farming practices and in the medium /long term by the replacement of tree stocks with high yielding genotypes with more resilience to climate change.

Specific programmes are required that have a shared goal of increasing the economic and environmental sustainability of cocoa production on less land (Wessel & Quist-Wessel, 2015). Participation in a certification scheme (Fairtrade, Rainforest Alliance, or Organic) can promote sustainable agricultural practices in Ghana (Krumbiegel & Tillie, 2024). Furthermore, a positive association between participation in The Cocoa Life Project (which included subsidised fertilisers, pesticides, and equipment) and farm productivity and household income has been observed amongst cocoa farmers in the Eastern Region of Ghana (Attipoe et al., 2021).

3.0 Opportunities for collaboration

What are the opportunities to collaboratively transfer, develop, commercialise, adopt and scale-out technologies and practices to address the challenges above?

- Compost production in West Africa could be expanded and transferred to Brazil
- Breeding of climate resilient varieties could be transferred to West Africa

The following activities were conducted in order to identify opportunities for collaboration:-

<u>Bilateral meetings with stakeholders</u>

We undertook online bilateral meetings with stakeholders in UK, Brazil, Nigeria, and Ghana identified in our own network and based on the authors of key publications and reports. During meetings we sought to learn from stakeholders (i) contextual information about their organisation and its remit, (ii) the perceived challenges facing the cocoa sector in their country, and the barriers to climate resilient cocoa production, (iii) their knowledge about the use of soil amendments by farmers in their country, (iv) the availability of breeding programmes or climate resilient germplasm in their country, (v) the barriers and enablers of climate smart cocoa technology adoption in their country, and (vi) their interest in future collaborative research.

Webinar on climate smart cocoa

On 21st February we hosted an interactive webinar on climate smart cocoa where presentations were the following presentations were given by speakers in UK, Ghana, Nigeria, and Brazil:

Introduction to the Cocoa Programme at Reading – Andrew Daymond University of Reading, UK
Introduction to the UKRI / Innovate Scoping Project – Paul Hadley University of Reading, UK
Utilising compost and biochar from cocoa pod husks – Laura Atuah KNUST, Ghana
Integrated Crop Pest Management for Climate-Smart Cocoa Production – Samuel Orisajo CRIN Nigeria
Breeding for climate resilient cocoa – Uilson Lopes CCEPEC/CEPLAC, Brazil

The webinar attracted 106 attendees. During the webinar we requested that participants complete a short survey to capture information about the demographics of the attendees. This survey also included the option for delegates to leave their name, organisation, contact details and area of expertise/interest if they wanted to be contacted after the webinar about joining a climate smart cocoa network. 59 attendees completed the survey and 49 provided contact details.

At the end of the webinar we hosted an interactive session where attendees were asked to post on an online discussion board to provide their opinion on (i) the greatest challenges facing the cocoa sector, (ii) the greatest barriers to climate resilient cocoa production, (iii) the barriers to using soil organic amendments, (iv) what types of organic amendments they have observed to shop a positive response on cocoa farms, (v) their awareness of cocoa genotypes that are resilient to climate extremes, and (vi) their awareness of breeding programmes that are focused on developing germplasm resilient to climate extremes

4.0 Key stakeholders and their roles

Who are the key stakeholders in each country who would be relevant partners for collaborative projects on climate smart cocoa production systems?

Brazil

Comissão Executiva do Plano da Lavoura Cacaueira (Ceplac): CEPLAC have responsibility for research and policy in the whole Country and have various centres across the Country. CEPLAC is part of the Ministry of Agriculture and their main mission is to develop Science and Extension. Dr Uilson Lopes presented at the webinar that we organised on breeding approaches to climate resilience building on approaches used for disease resilience.

Universidade Estadual de Santa Cruz (UESC) have been working on the breeding of drought-resistant genotypes

Nigeria

Cocoa Research Institute of Nigeria (CRIN): CRIN has mandate for research and development on the productivity, quality and value addition Cocoa. The organization does these by improving the genetic potential, agronomic and husbandry practices of cocoa.

International Institute of tropical Agriculture (IITA): ITA is a Non-Profit institution that generates Agricultural Innovations to meet Africa's most pressing challenges of hunger, malnutrition, poverty and natural resourtce degradation. Their works cut across Sub-Saharan Africa. Work on cocoa started 16 years ago with Dr Bhattacharjee and covered Nigeria, Ghana, Côte d'Ivoire, Togo, Cameroon and Sierra Leone.

University of Ibadan, Nigeria: University have three lines of services which includes teaching, research and community Services. Through Professor Adeoluwa, the University has been working with Farmers Development Union (FADU) technically to fulfil the mandate on research and community services. FADU is in 22 out of 36 states of Nigeria.

Ghana

Cocoa Research Institute of Ghana (CRIG): CRIG is a division of the Ghana Cocoa Board and has carried out research on many aspects of the cocoa value chain for more than 80 years. They have conducted research around Innovation in compatible agroforestry systems, pest and diseases management options, agroecology-specific nutritional requirements and fermentation chemistry.

Bunso Cocoa College: The college is the premier cocoa training college of the Ghana cocoa Board and currently develop and implement appropriate training for farmers, extension agents, technical staff of agencies under cocoa Board and other stakeholders in the cocoa sector.

Kwame Nkrumah University of Science and Technology (KNUST): The University have been working on cocoa research in collaboration with CRIG, University of Reading, and others. Their interest is specifically on using cocoa pod husk for compost and biochar.

EMFED Farms: Have produced compost for experiments as part of a collaboration between KNUST, CRIG and University of Reading

Mondelez: Producer of chocolate and due to need for Cocoa as raw materials, they instituted a programme called "Cocoa Life" for sustainable cocoa production. The programme helps cocoa farmers to enhance productivities and farmer's livelihood. They connect with research institutes like IITA, CRIG and others to achieve their goals.

UK

University of Reading: The University of Reading has gained an international reputation for cocoa research since the early 1980s. Custom-built greenhouse facilities allow plants to be grown under conditions simulating cocoa-producing regions, facilitating innovative research on how the crop responds to its environment. The genetic resources database and quarantine facility hosted by the University support international cocoa research and breeding by enabling scientists to find out about and exchange planting materials, while minimising the risk of spreading devastating pests and diseases. Excellent links with institutes in the tropics have resulted in joint projects to study and conserve the genetic diversity of the crop, to improve crop establishment, and to detect and control pests and diseases. Such projects have established the University of Reading as a globally important centre for cocoa research.

University of Nottingham: Research on cocoa at the University of Nottingham is focused on understanding cadmium absorption and sequestration in cacao. This research aims to provide plant breeders with genetic and physiological markers that can predict cadmium accumulation in cacao. Further work is identifying cadmium-sequestering or cadmium-excluding rootstocks that can be used in high cadmium soils. Research is also being conducted using microbial/rhizosphere engineering to improve water use efficiency, drought tolerance, and nutrient uptake in tropical farming systems and to encourage nitrogen fixation and nutrient recycling by integrating biofertilizers into farming practices.

National Institute of Agricultural Botany (NIAB) and Durham University: Sarah Arnold (NIAB) & Andreanna Welch (Department of Biosciences, Durham University) are developing a Sustainability Network for Cocoa through a Scoping Project for Climate-Smart Agriculture Partnership: UK- Brazil-Africa. This project aims to identify best practices and opportunities for sustainable cocoa production and processing in Brazil, Ghana, and Nigeria, with the aim to introduce new technologies for research, monitoring and plantation management that best suit each environment. This includes both research tools (e.g. eDNA monitoring) and agri-tech to support farmers and production.

Cranfield University: Are developing carbon and soil health indicators for West African cocoa plantations. Project aims to develop low-cost, scalable metrics for monitoring soil health and soil carbon storage in cocoa farms and apply the metrics to assess changes in soil health and carbon over time under management and quantify corresponding changes in carbon losses to the atmosphere and water.

5.0 Gender and social inequality

How could technologies or practices be applied or developed for climate smart cocoa production systems to reduce i) gender and ii) social inequality in climate vulnerable populations?

Women cocoa farmers often face more barriers to achieving sustainable cocoa production due to issues of land tenure and less access to inputs, training, and finance. Because there are large differences in the access to extension services and new agricultural technologies between male and female cocoa farmers in Ghana, there is a clear need for programmes to deliver innovation through a gender sensitive extension service (embedding women in leadership positions) which acknowledge the diversity in the capacities and practices of individuals, account for different literacy levels, and promote indigenous knowledge (Dalaa et al., 2020). Consequently, we have been pro-active in our current collaborations in Ghana to ensure that on-farm field trials have included a significant representation of women farmers. Furthermore, we have ensured significant representation of women farmers in training events in Ghana. Our experience has been that we have been able to achieve a greater gender parity in workshops geared towards farmers compared with those geared towards extension officers (reflecting that there are a low proportion of female extension officers). We will continue to be conscious of gender barriers when drafting collaborative proposals as a part of this project. Specifically, by supporting the research programme of Dr Laura Atuah, a leading female academic and former Head of Department at Kwame Nkrumah the project is directly helping to overcome the struggle of women for power and leadership in African Higher Education. We aim to use a similar approach in developing new collaborations in Nigeria and Brazil.

Smallholder farmers are specifically vulnerable to climate change being resource poor and therefore less able to adapt new technologies to adapt to climate change. Our current work on soil amendments in Ghana has focussed on low cost solutions utilising cocoa farm wastes. As part of this work, we have conducted training workshops where we have strived to be inclusive by inviting farmers directly to engage in such events.

6.0 Barriers to transformational change

What are the barriers preventing 'transformational change' within the topic area? Comment on while discussing the barriers here:

Various barriers identified through discussions with stakeholders including:-

- Lack of farmer awareness/ education
- Dirth of research findings or evidence on resilient production systems to show the farmers
- Lack of access to irrigation systems
- Availability of planting materials that are drought resistant are lacking
- Capital investment for irrigation
- Need for speed breeding

7.0 Next Steps

We will continue with achievements made in our Scoping Project for Climate-Smart Agriculture Partnership: UK- Brazil-Africa through an additional BBSRC International Partnerships Project which has recently been awarded to us.

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Title: Development of a partnerships for collaborative research on resilient cocoa systems

Start Date: 1st March 2025

This project will include:-

- a workshop to be held at KNUST, Ghana which explore opportunities for collaborations centred around use of soil amendments and breeding for climate resilience. The event will also include field visits.
- Further population of a Knowledge Exchange website, based in part on the outcomes of the workshop
- Development and submission of project proposals

8.0 Concluding Remarks

The following research outcomes have been achieved from the project:

- A number of commonalities of research interests between Ghana, Nigeria and Brazil have been identified.
- Research needs have been identified which are common to the different partners
- Potential collaborative projects have arisen from partnership discussions

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