Climate smart cowpea for Africa

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Summary of the topic area

Cowpea (*Vigna unguiculata* (L.) Waulp) is a critical grain legume grown in sub-tropical and tropical regions such as West Africa, Brazil and the southern United States. Nigeria is the world's largest producer of cowpea. It is an important food source for humans and animals. Cowpea can be grown as a sole crop, but is often intercropped with pearl millet, sorghum, maize or cassava. As a legume, it enters nitrogen-fixing symbioses with *Rhizobia* bacteria, provides an important source of dietary protein, and also improves soil fertility as part of crop rotations.

Cowpea is utilised as a food source in different ways. The seeds contain 22-32% protein by weight, contain essential amino acids such as lysine and tryptophan, and are rich in vitamins such as folic acid. The leaves and immature green beans are also consumed. It complements the calorie-rich grains of cereals, helping contribute to nutritious and balanced diets. Cowpea is tolerant of abiotic stresses such as heat and drought, thus playing an important role in sustaining food supplies under challenging environmental conditions.

The importance of this crop has led to the development of improved cultivars which can improve agricultural output whilst minimising the need for additional inputs. However, yields under sub-optimal growth conditions (e.g. those limited by water or nutrient availability) are typically between 500-2000 kg ha^{-1} compared to 4000-7000 kg ha^{-1} under optimal conditions. Therefore, there is considerable room for improvement in cowpea productivity.

In this project we focussed on phosphorus (P) availability as a key limitation to cowpea productivity in West Africa. Adequate P is essential for plant growth and yield and is also essential for effective Biological (Rhizobial) Nitrogen Fixation (BNF). Previous studies conducted as part of the N2Africa project[1] have shown that productivity gains resulting from improving BNF by inoculation with highly effective Rhizobia are improved further if P fertilisers are added[2].

In our focus group meetings held with colleagues in Ghana and Nigeria, many of the same issues arose hence the problems, and potential solutions, apply to both countries.

Challenges and barriers

In 2018, an exchange visit between The University of Sheffield, UK and Ahmadu Bello University, Nigeria highlighted the importance of phosphorus availability for cowpea production but also placed this specific need within a wider context of cowpea improvement and smallholder cropping systems. The ‘Climate-Smart Cowpea for Africa’ project (2025) undertook focus group meetings with colleagues in Nigeria and Ghana to update priority areas and explore potential shared solutions.

After the 2018 exchange visit, Cosmas Alamanjo started a PhD at The University of Sheffield (supervised by Prof Stephen Rolfe and Dr Ian Lidbury, with academic guidance from Dr Saba Mohammed at Amahdu Bello University) to explore soil P nutrition and cowpea.

Soil phosphorus availability

A transect of soil samples from cowpea growing areas along a latitudinal transect of Nigeria showed that soil P levels were extremely low (in all forms) therefore amendment of soil with P sources is required.

Plants can only take up P when present as bioavailable inorganic phosphate (Pi). Unlike N, P is a non-renewable resource. It is typically mined from rock phosphate deposits (e.g. Sokoto Rock Phosphate in Nigeria) and then converted into P fertilisers by treatment with sulfuric acid to produce Single Super Phosphate (SSP) or phosphoric acid to produce Triple Super Phosphate (TSP). These are highly effective fertilisers containing soluble Pi, but there are significant problems associated with their use:

- Sokoto Rock phosphate contains P as apatite minerals which are insoluble and unavailable to plants directly.
- SSP and TSP are difficult for small holder farmers to afford at the levels needed.
- Applications are required every year, which limits sustainability.
- Pi is lost by run-off or leaching which reduces availability to crops and also pollutes water courses.
- Pi can react with the soil and is converted back into insoluble mineral forms that are unavailable to plants – Calcium-P in alkaline soils or Iron/Aluminium-P in acidic soils.
- Pi that is taken up by plants is converted to organic P. Although the return of plant residues to the soil is vital for improving and maintaining soil health, the organic P is not readily available to plants.

The challenge we have focussed on in this project is to enable cowpea to access diverse P forms either directly, or by interacting with beneficial soil microbes.

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[1] https://www.n2africa.org/home

[2] https://cgspace.cgiar.org/server/api/core/bitstreams/7e46135f-1385-4f09-9661-df5fd9fb8338/content

By solving this challenge, we can address the issues associated with P fertilisers described above, providing affordable and sustainable solutions to farmers directly in their fields.

Wider challenges

Improvements in P nutrition must be integrated into wider activities to improve cowpea productivity, and agricultural productivity overall, if they are to be effective. The scientific literature and focus groups with colleagues in Nigeria and Ghana identified a range of challenges that must be addressed to improve cowpea productivity. These include biotic, abiotic and socioeconomic challenges. These issues are common to Nigeria and Ghana. Progress has been made in some areas (e.g. Striga-resistant cowpea) whereas others have become more pressing.

Table 1 Factors that limit cowpea productivity as indentified in focus groups

Biotic factors	
Insect pests	Aphids Maruca (bean pod borer) Pod sucking bugs
Parasitic plants	*Striga gesneroides* *Cuscuta campestris*
Weeds	
Pathogens	Bacterial Fungal Viruses
Shading	Non-optimal growth in intercropped systems
Abiotic factors	
Overall soil fertility/health/degradation	Low pH Low soil organic carbon and matter (SOC/SOM) Acidic soils – potential to use biochar to increase SOC and raise pH
Nutrients	Particularly N and P (in acidic soils)
Drought/Water availability/Heat	Exacerbated by climate change
Socioeconomic	
Farmer and consumer acceptance of new varieties	Palatability Size Colour
Seed quality	
Post harvest losses	
Farmer take-up	Risk aversion Farmer education Failure to address issues erodes trust
Adulteration of agrochemicals	
Labour limitations	
Sustainability of solutions	Long term solutions required
Landscape degradation	Bush burning Urbanisation Pollution

It is imperative that adoption of new cultivars, and approaches to address existing stress limitations, must take place in a context that is acceptable to farmers. This is particularly challenging for smallholder farms in low-income areas as labour limitations, lack of additional resources and risk aversion can mean that implementation is limited or results sub-optimal. This can lead to a loss of trust. Also, new varieties must produce crops that are palatable and acceptable to farmers and consumers. Failure to address these socioeconomic factors leads to reduced take up of new cultivars and agricultural practices.

The sustainability of interventions is essential, particularly in response to worsening environmental conditions due to climate change. For example, subsidies allow farmers to purchase fertilisers to address nutrient limitations, but when these are withdrawn, farmers often cannot bear the full economic costs. Therefore, strategies need to address the immediate needs of farmers but also improve soil fertility and crop resilience in the longer term.

Climate-smart cowpea for Africa

An overview of different stages of a potential project are shown below.

Every stage of the project must involve local researchers as they have extensive experience in developing improved cowpea varieties and testing under realistic field conditions. They also have the links to 'extension' projects that enable these approaches to be deployed in the field (see Barriers to Transformational Change) and are already participating in international projects to improve cowpea, and agricultural practice overall.

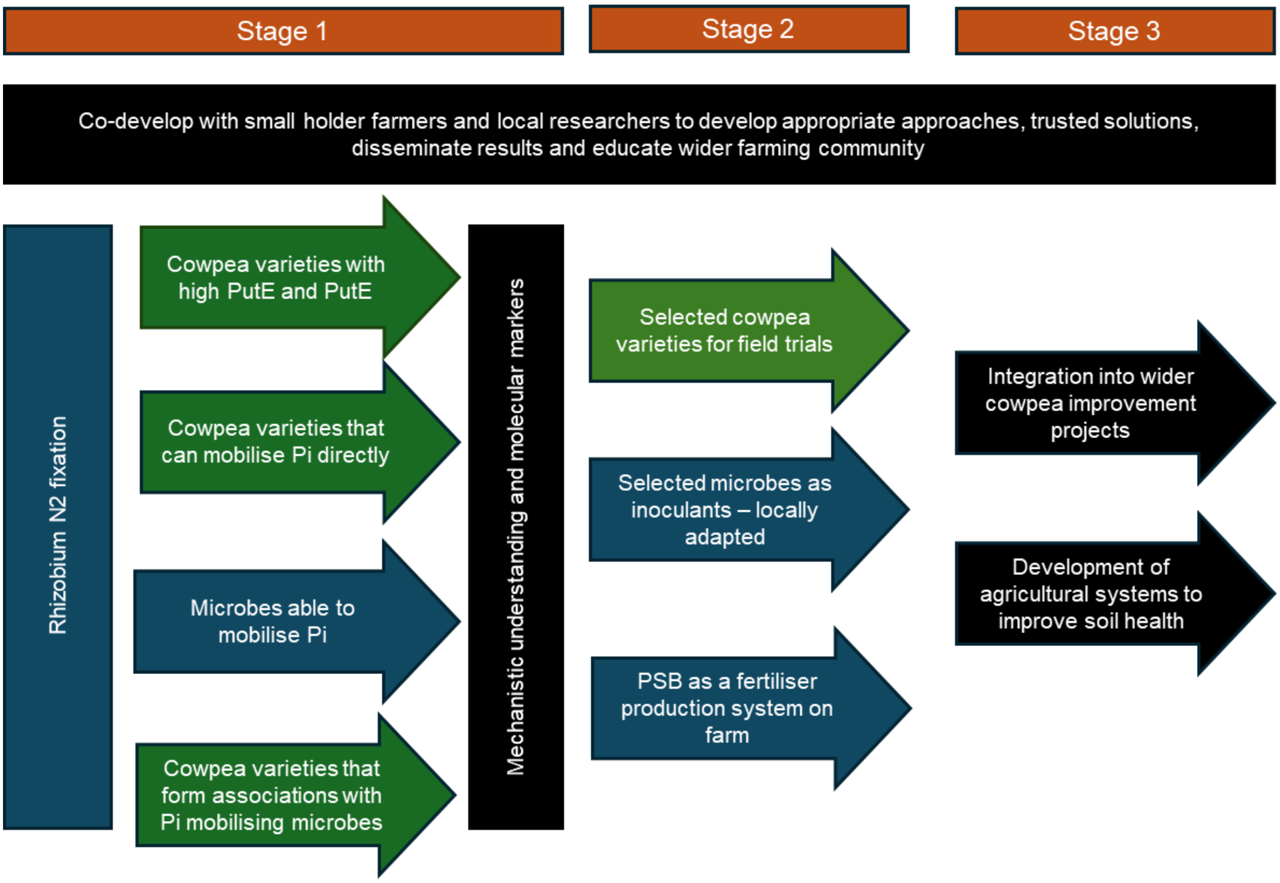

Figure 1 A strategy for Climate-Smart phosphorus cowpea improvement

Stage 1: Improved cowpea varieties and associated microbes

There is a long history of producing improved cowpea varieties by the Bean/Cowpea Collaborative Research Support Program (CRSP) and the Dry Grain Pulses CRSP supported by the United States Agency for International Development (USAID). Improved cultivars provide an efficient way in which to deliver benefits to smallholder farmers.

A significant number of genetic resources have been developed for cowpea improvement, including the recent sequencing of the cowpea genome. Cowpea varieties have been collected from around the world and held in seed banks at IIATA[3] and CGIAR[4]– these are being used to identify cultivars and associated genetic markers that improve yield under field conditions and also improve stress resistance. The coupling of genome information and molecular markers will greatly facilitate understanding the mechanisms underlying yield improvements and stress resistance.

Cowpea with Improved Phosphorus Uptake and Utilization Efficiency

Sustainable approaches require agricultural inputs to be minimised and used effectively by the crop. Research at Sheffield has shown that cowpea varieties differ markedly in their phosphorus uptake efficiency (PupE: how much of the available P in the soil can a plant take up) and phosphorus utilization efficiency (PutE: how much plant biomass is produced per g of P taken up). A survey of 53 African cowpea identified a clear trade-off between PuPE and PutE – the best performing varieties at low Pi supply rates maximised either PupE or PutE, but not both. The reason for this trade-off is not currently understood.

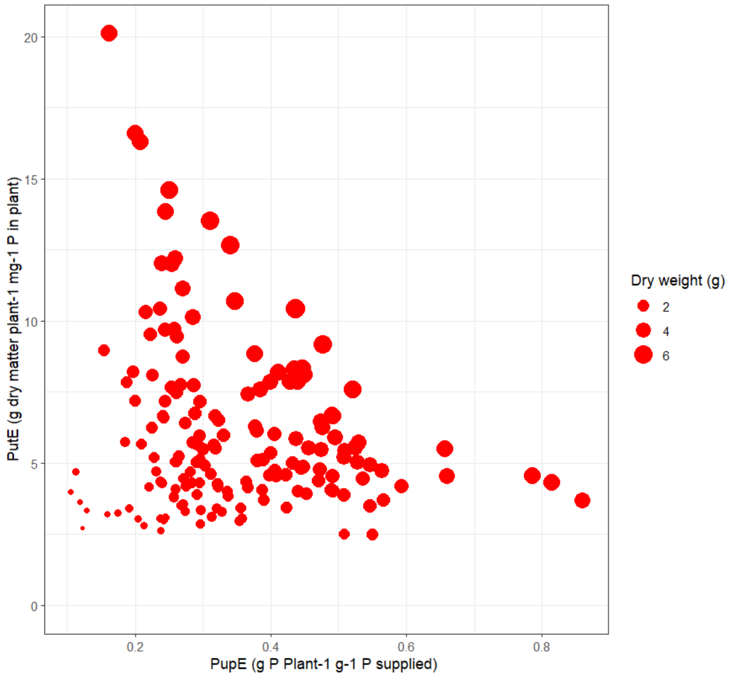

Figure 2 Trade-offs between P uptake Efficiency (PupE) and P utilisation Efficiency (PutE) in cowpea grown at low Pi supply rates. The size of the point is the total biomass of the cultivar.

- Surveying a wider range of cowpea varieties from more diverse geographical regions or soil types may identify varieties with better combined PupE and PutE. It would also allow identification of genetic markers associated with these traits that could be used in cowpea improvement programmes.
- Developing a mechanistic understanding of the processes controlling PupE and PutE at the molecular level will enable improvement of these processes and understand whether trade-offs are inherent or can be mitigated.

Cowpea varieties that can mobilise P directly

P supplied as rock phosphate, or Pi that has reacted with soil minerals, contains insoluble P which is unavailable to plants. Our preliminary studies have shown that incubation of Sokoto Rock Phosphate in soil from Nigerian cowpea growing regions results in conversion from Ca-P apatite minerals to Al-P and

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[3] https://www.iita.org/cropsnew/cowpea/

[4] https://genebanks.cgiar.org/resources/crops/cowpea/

Fe-P minerals. However, P can be solubilised from these minerals by organic acids released in root exudates (in a manner analogous to the creation of synthetic P fertilisers by acid treatment).

There is evidence in the scientific literature that additions of Sokoto Rock Phosphate to field trials can improve cowpea productivity, particularly in acidic soils and when supplemented with synthetic NPK fertilisers. However, a systematic survey of cowpea varieties in their ability to mobilise insoluble P directly, coupled with an analysis of root exudates to identify organic acids, or enzymes, associated with this process will provide a foundation determining whether direct mobilisation of insoluble P by cowpea can be improved, the molecular mechanisms that underpin this process and genes associated with improved cowpea function.

Microbes able to mobilise P

As well as forming associations with N_2-fixing Rhizobium bacteria, cowpea can form symbiotic associations with arbuscular mycorrhizal fungi (AMF) and rhizosphere associations with Phosphate Solubilising Bacteria (PSB). Both groups of micro-organisms have the potential to improve the rate and extent of P mobilisation, both from insoluble P forms and also organic P present in organic matter.

Studies have shown that cowpea forms extensive mycorrhizal networks, although inocula have not been selected to improve this function. AMF inocula can be challenging to deploy as these are obligate symbionts and cannot be grown independently in culture. However, with improvements in overall soil health, establishing and maintaining beneficial AMF interactions will benefit cowpea production and resilience to abiotic and biotic stresses.

PSB provide an attractive route to facilitate P solubilisation from diverse P sources. Researchers (including Ahmadu Bello University and The University of Sheffield) have isolated PSB from the cowpea rhizosphere and these can be tested to determine their effectiveness at mobilising the different forms of P which may be present in improved African soils. PSBs can also be readily cultured which would allow their deployment alongside Rhizobial inoculants, using the same supply chains.

An alternative route to deployment of PSBs emerged during the course of the scoping project. Whilst soil amendments have the best long-term potential to improve soil health and field productivity, short term gains could be possible by incubating PSBs (or other microbes) directly with Sokoto Rock Phosphate and organic matter in containers (oil drums) on farm. A similar approach has been deployed with small holder farmers in Madagascar to release nutrients and then apply them directly to plants. This could also be an avenue to create microbial inoculants on farm.

Cowpea varieties that form associations with P mobilising microbes

The use of PSBs in agriculture is in its infancy, but translation from other countries and cropping systems provides exciting possibilities. Brazilian soils share many similarities with African soils. Researchers at EMPRAPA[5] have identified PSB that enable re-mobilisation of P from acidic soils in soybean. Two Bacillus strains have been commercialised as BIOMAPHOS have shown effectiveness in improving soybean production. A trial is currently underway in Ghana to see if these can be used to improve cowpea productivity.

A common feature of using microbial soil amendments is that they struggle to persist in the rhizosphere and soils, particularly if isolated from different locales. Recent developments in microbial genomics means that whole genome sequencing and identification of Biological Gene Clusters (BCGs) associated with specific traits can be used to understand the mechanisms underlying a phenotype. This facilitates the identification of locally-adapted bacterial isolates that have the same function, allowing selection *in*

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[5] RevistaCultivar

vitro before field testing. Bacilli are prevalent in the cowpea rhizosphere, so even if the Brazilian strains do not persist, identification of related strains which form effective associations with cowpea and optimised for the different soil types found in West African cowpea growing areas is a highly promising strategy.

The interactions of cowpea with mycorrhizae and/or PSBs may also provide a way in which to break the trade-off between PupE and PutE that we have identified in cowpea.

Stage 2 Field trials

During stage 1 the individual components of routes to improve P nutrition in cowpea will have been developed. The next stage will be to undertake field trials of selected cowpea genotypes, microbial inoculants (or off-field P mobilisation systems) to determine their effectiveness in local agricultural environments.

Questions to be addressed will include:

- Which cultivar-microbe combinations perform best in the field?
- How much P is mobilised from added Sokoto Rock Phosphate under field conditions?
- What is the impact of soil geochemistry, climate and agricultural practice on the effectiveness of this approach?
- What are the impacts on yield and stress resistance?
- What improvements can be made by co-designing and running experiments with local farmers? Feedback on practicality, affordability, desirability.
- To what extent are results transferable between different regions? Are locally-adapted solutions needed – and what are these adaptations?

Stage 3 Integration

There are extensive efforts to improve cowpea production and the general productivity of agroecosystems in West Africa. Our initial discussions with diverse stakeholders showed an enthusiasm for these approaches, but integration into the overall improvement projects will be needed for deployment. In the short term, genes associated with improved P nutrition and beneficial microbial interactions can be incorporated into wider breeding programmes for cowpea improvement. However, there is also a need to improve overall soil health, particularly with the challenge of climate change.

As the productivity of the system increases, smallholder farmers will be more able, and amenable, to returning organic matter to the soil (at the moment nearly all organic matter is removed for human and animal consumption or to be used as fuel). A key determinant of soil health is Soil Organic Carbon (SOC) which is associated with increased stress resilience of crops grown in those soils. For example, increased Soil Organic Matter (SOM) results in greater water retention and resilience to drought. Soils with high SOC/SOM typically show increased resilience to pests and diseases. Improving soil health is a slow process, but removing P limitation as a key block to productivity should unlock multiple benefits.

Key stakeholders and their roles

Small-holder farmers

The ultimate target of the project is small holder farmers in West Africa. Although the initial focus is on cowpea, this crop is grown in rotation and/or as intercrop systems, therefore a holistic approach to agricultural production is needed. This will enable effective deployment and also address the longer-term aim of improving soil health and climate resilience.

Farmer’s associations

Farmer's Associations are active in Nigeria and Ghana and provide the essential link between research development and farmers. These associations are able to identify the issues affecting their members on the ground and also act as effective routes for communication and dissemination. There was strong engagement during the project with these associations including: Peasant Farmers Association of Ghana, Kumo Altalaja Multiple Purpose Cooperative Society, Tetfund Centre of Excellence Farmers Co-operative Society, Kumo Alfijir Farmers Association, Wheat Farmers Association of Nigeria Kaduna State, Kashda Farmers Association, Ganji Dakare Farmers Multipurpose Cooperative Society Limited.

This project has identified phosphate limitation as an important issue affecting crop productivity in these regions, but in previous on-site visits (2018) and during this scoping trial, the multifaceted nature of issues facing farmers was raised repeatedly as outlined in 'Wider challenges'. Therefore, improvements in one area must be integrated into wider efforts to improve agricultural productivity.

Local research institutions, extension programmes and NGOs

As discussed under 'Barriers to transformation change', ensuring that research developments make '*the last mile*' to farmers is essential. Local researchers and extension programmes associated with local Universities and NGO Research Organisations play an essential role in this process. The project involved input from Taraba State University, Ahmadhu Bello University (and the Institute for Arable Research), Joseph Sarwuan Tarka University and The Federal Polytechnic, Bauchi. At Ahmadhu Bello University, researchers have focused on producing cowpea with improved resistance to abiotic and biotic stresses and are working on the next generation of cowpea that includes GM approaches (expression of *Bacillus thuringiensis* toxins for insect resistance). Several partners participated in the N2Africa project and had identified genes and Quantitative Trait Loci (QTL) for improved nitrogen fixation which have been introgressed into local varieties with good disease resistance. There has also been extensive work to improve Rhizobial inoculants (both nationally and internationally). Phosphorus limitations are recognised and there are small scale projects exploring the use of rock phosphate, cowpea with improved P utilisation efficiency and microbial associations. Cowpea improvement programmes are making significant advances (e.g. the development of cowpea varieties with resistance to *Striga*).

NGOs are very active in this area. Key stakeholders include IITA (International Institute for Tropical Agriculture), CSIR-PGRRI (Council for Scientific and Industrial Research – Plant Genetic Resources Research Institute) , CSIR-SARI (CSIR – Savanna Agriculture Research Institute), CGIAR (Consultative Group on International Research). These organisations and associated staff hold extensive cowpea stock centres, are producing resources for cowpea improvement (including genotyping studies), improving agricultural practice, have divisions with a focus on many of the wider issues associated with cowpea production and extensive field sites and experience in running field trials.

Government

Local and national governments play an important role in setting and enacting policy areas. In Nigeria, we spoke with The Permanent Secretary for Solid Mineral Development, The Director of Artisanal and Small-Scale Mining and The Deputy Director, Cowpea Value Chain, The Federal Ministry of Agriculture & Rural Development. A multifaceted approach to improving cowpea production of small holder farmers was a priority area.

International partnerships

Discussion with researchers at The Brazilian Agricultural Research Corporation (Embrapa) highlighted the possibility of transferring approaches developed in Brazil (which grows cowpeas and other legumes, and which shares many climate and soil characteristics). The *Bacillus* strains they have developed for P recovery in soybean growing regions are currently being trialled in Ghana. The strains, or the overall approach of identifying PSB adapted to local crops and soil conditions, is an attractive strategy for integration into a project to address P limitations on cowpea production. We also discussed this approach will colleagues at Rothamsted Research, who host the UK Crop Microbiome Bank[6]. Their expertise in high-throughput collection of crop-associated root microbiomes and elucidation of their function be highly beneficial to this approach. The Centre for Process Innovation (CPI) (Redcar, UK) is focussing on improving cassava yields through the use of microbial products (pesticides and/or biofertilizers). Cassava is often grown in rotation with cowpea. There is an international interest in developing improved Rhizobial inoculants for enhancing BNF in legumes, so integrating alternative beneficial microbes into these activities is of particular interest. Microbial inoculants can improve yields and also protect against biotic and abiotic stresses.

The international community has significant involvement in cowpea improvement. USAID has funded cowpea improvement programmes for decades and the N2Africa project (funded by the Bill and Melinda Gates Foundation) was led by researchers at IITA (Kenya), TSBF-CIAT Mbsa/MARI – Tanzania and Wageningen University and Research centre (WUR) (Netherlands).

We spoke with researchers at CSIRO, Australia who have been developing GM cowpea with insect resistance and deploying these in Nigeria and Ghana (USAID). Within the focus crop meetings there was a diversity of opinion on the use of GM approaches, but CSIRO team's development of transformation systems for cowpea allows rapid scientific progress in many areas even if deployment in the field uses different technologies. They are currently participating in the Bill and Melinda Gates project 'RIPE: Realising Increased Photosynthetic Efficiency', which includes cowpea as a target crop.

We had conversations with colleagues at Kew Gardens, UK who are integrating climate modelling with crop breeding to generate the next generation of climate smart crop varieties. The approach involves predicting likely future climate scenarios in target regions, then identifying areas where these conditions already exist. By studying crop varieties that are already adapted to the specific climate conditions (and soil types), new varieties can be bred which will be better adapted to future climates. This work currently involves beans and other legumes, but not cowpea. However, extension to include cowpea would be straightforward. This approach could also be extended to explore the impact of associated microbes in the cowpea root rhizobiome.

Gender and social inequality

Social inequality is prevalent in both Nigeria[7] and Ghana[8]. Small holder farmers produce, and consume, much of the country's food but yields are low and decreasing for most crops. The resources available to these farmers are very limited, therefore solutions must be deliverable in a cost-effective manner. Co-design, and co-implementation of research projects provide a route to capture farmer's knowledge and experience and ensure trust and buy-in to project. Small-holder farmers are the poorest part of the agricultural sector and efficiency is low due to an almost complete lack of mechanisation and a lack of resources to invest in land and crop improvement. Although only 10% of landowners in Nigeria are female[9] (data not available for Ghana), close to 100% of women in these areas are involved in unpaid agricultural activities. These inequalities can be addressed through farmers and women farmers

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[6] https://www.rothamsted.ac.uk/news/crop-microbiome-bank-opens-business

[7] https://www.oxfam.org/en/nigeria-extreme-inequality-numbers

[8] https://www.oxfam.org/en/ghana-extreme-inequality-numbers

[9] https://ourworldindata.org/country/nigeria

associations (e.g. see [10]) and NGOs (e.g. Women in Mining[11]) but overall investment is still far below what is needed.

Barriers to transformational change

A multifaceted approach is needed

No single area of research on its own will generate a transformational change in small holder farmers productivity in Nigeria and Ghana. There are multiple biological and socioeconomic factors at play, hence a multifaceted approach is required to ensure progress. However, a focussed effort on specific problems can be integrated into wider activities to improve yields, productivity, sustainability and ultimately, lives. There have been long-standing programmes in cowpea improvement therefore the expertise and infrastructure to integrate new developments exists.

Phosphate availability limits cowpea (and crop) productivity

Phosphate deficiency was identified as a major limitation to crop productivity. When soil bioavailable soil P is low, yields are reduced and the benefits of biological nitrogen fixation in legumes not fully realised. The removal of plant matter from agricultural land and the lack of agrochemical inputs has led to the soils becoming extremely P depleted. Therefore, amendments are essential. In the longer term, shifts to agricultural practice that become viable as yields increase will allow prioritisation of soil health and retention or recycling of nutrients.

Inorganic phosphate fertilisers are not a sustainable solution

Nigeria has extensive deposits of rock phosphate (2-5 million tonnes in the Sokoto region – other deposits are less well surveyed) but imports rock phosphate to produce artificial phosphate fertilisers. Artificial P fertilisers are expensive and therefore unaffordable for small holders. Sokoto rock phosphate (SRP) has not been developed at a large scale due to the lack of investment in infrastructure and the long ‘pay-back’ time associated with these developments. An artisanal mining community exists which could be developed to allow rock phosphate supplies for small holders.

Direct use of rock phosphate has the potential to improve sustainable crop production

Phosphate in rock phosphate is not bioavailable. Application of soluble inorganic phosphate fertilisers to acidic soils also leads to immobilisation in non-bioavailable forms. However, small scale trials have shown that application of SRP can improve crop production, particularly if co-applied with other nutrient sources. The mechanisms underlying this have not been established, or optimised, but demonstrates the feasibility of the approach. Plants could access P in SRP either directly, or via interactions with microbial partners.

Recent developments in cowpea genetics (including the sequencing of its genome) have led to rapid identification of genes or genetic markers associated with yield or stress resistance. The development of these well-established (in the crops of developed countries) approaches to cowpea is generating transformational change in cowpea improvement. Incorporating GM approaches also increases the ‘toolbox’ available to breeders and researchers to address otherwise intractable problems.

A systematic study of cowpea P nutrition, its efficiency to take up and utilise bioavailable P, mobilise P directly from non-bioavailable forms and interact with P mobilising microbial partners will provide a sustainable route to addressing the key issue of P limitations. There is already activity in some of these

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[10] https://internationalbudget.org/women-smallholder-farmers-in-nigeria-secure-investments-in-agriculture/

[11] https://wimng.org/

areas, so integrating them and coordinating with wider activities in cowpea improvement and sustainable agriculture will generate transformational change – speeding up research in this specific area, improving cowpea production overall and helping the shift to sustainable agricultural production in a 'climate-smart' manner.

Microbes to the rescue?

Cowpea is grown in association with Rhizobia to form highly effective nitrogen fixing associations, reducing the need for artificial nitrogenous fertilisers. Optimised inocula improve yields further. A related approach is proposed to address phosphate limitations. Phosphate solubilising bacteria have been identified which can mobilise P from insoluble P minerals. In Brazil, two of these have been commercialised and have led to widespread and significant increases in soybean productivity. A trial is underway to test their effectiveness in Ghana, but it is unlikely that a single solution will work in all crops, soil types and climates. However, this shows the method can work and be developed commercially. Therefore, following the same strategy with African microbial isolates adapted to local soil types, climate and crops is extremely attractive.

Farmer involvement is essential

Many innovations in crop productivity in Africa fail to make it 'the final mile' to the farmer. Project partners recognise this and have implemented 'tripod' systems where researchers, extension officers and farmers work together from the earliest stages of a project throughout its development. This ensures that the project aims are acceptable to farmers at every level (e.g. palatability, variety choice, integration into wider farming practice, identification, and amelioration of limiting factors) and engender trust in the products. Cowpea 'cultivation hubs' allow farmers to access a site with similar agricultural practices to their own. Farmers can explore different strategies and compare their results with alternative approaches. This strategy also upskills the extension officers who play a vital role in disseminating information more widely.

Acknowledgements

We would like to acknowledge the many participants who have informed project. We are indebted in particular to Dr Saba Mohammed at Ahmadhu Bello University, Nigeria who sadly passed away in December 2024. His insight, vision and comradeship will be missed.