UNIVERSITY OF CAMBRIDGE

The CUPGRA Potato Research Fellow annual report 2023

A report for the Cambridge University Potato Growers Research Association

DECEMBER 2023

The University of Cambridge extends its sincere gratitude to the Cambridge University Potato Growers Research Association for the gift to support a Research Fellow in Crop Sciences focusing on potato improvement in the UK.

In this report, Professor Giles Oldroyd gives an overview of the the exciting work to develop the Crop Science Centre and establish it as one of the leading places in the world for plant research with a focus on improving the sustainability and equity of global food production.

CUPGRA fellow Dr Sebastian Eves-van den Akker also provides an update on his work.

An introduction from **Professor Giles Oldroyd**

My vision for the Crop Science Centre is to create an environment where impact can be recognised from excellence in plant research, with a specific focus on improving the sustainability and equity of global food production. In order to achieve this vision, I believe it is essential to create an environment where impact is valued, where facilities are available to support crop science and where staff members are able to arrive at work authentically themselves. I believe the impact of the centre can be in delivering products for sustainable and equitable food production; training the future leaders of food security and empowering diversity in plant and agricultural sciences.

Since starting as the Professor of Crop Sciences and the Director of the Crop Science Centre in October 2019, I have established a functioning and well-funded research centre, with extensive collaborations between the University of Cambridge and NIAB. We have strong and growing relations with philanthropic individuals and organisations that are committed to our vision and partnering with us to achieve our goals. Our income is projected to grow significantly over the following years, based on existing commitments. We currently receive 75% of our funding from charity and philanthropy, and this share of our income is projected to grow to 82% by 2024. Our principle donors are the Bill and Melinda Gates Foundation (BMGF); Bill and Melinda Gates Agricultural Innovations; the Foreign, Commonwealth and Development Office; Rob Cawthorn; NIAB and CUPGRA. All of these organisations and individuals are committed to ongoing support for the research at the centre. In addition to these organisations we have secured a commitment for $12m from the Allan & Gill Gray Foundation, supporting research across the breadth of science at the Crop Science Centre.

Director of the Crop Science Centre
Russell R Geiger Professor of Crop Science

Development

I have established the Crop Science Centre recognising different phases of our establishment through each academic year:

- **Phase 1, Establishment (Academic year 2019-2020)**: Set the vision for the centre; recruit the core team; get the CSC building operational; launch CSC.

- **Phase 2, Consolidation (Academic year 2020-2021)**: Move Oldroyd and Paszkowski groups to the centre; recruitment of CSC fellows; initiate new facilities development; establish culture for staff; expand existing relationships with funding partners.

- **Phase 3, Growth (Academic year 2021-2022)**: Support fellows to grow their programmes; further expand research facilities; encourage collaborations between University of Cambridge and NIAB; embed a culture of impact; develop new funding partnerships; facilitate engagement with industry.

- **Phase 4, Towards Impact (Academic year 2022-2023)**: Launch AGGF programmes; establish MPhil of Crop Science; establish partnerships in Africa; ENSA renewal (BMGF funding); consolidate engagement with industrial partners; further diversify our funding.

We now have six research groups physically located at the Crop Science Centre: Professor Giles Oldroyd (sustainable crop nutrition); Prof Uta Paszkowski (cereal symbioses); Dr Jeongmin Choi (nutrient perception and capture); Dr Sebastian Eves-van den Akker (plant-parasitic interactions); Dr Lida Derevina (crop pathogen immunity) and Dr Natasha Yelina (crop breeding technologies). The four CSC research fellows are funded from donations from Rob Cawthorn; CUPGRA; NIAB Trust, as well as BBSRC David Philips and Royal Society University Research Fellowships.

We are already recognising our vision of moving science from the lab to the field, with the first GM field trials ever run from the University of Cambridge, now in the field, testing varieties of barley engineered to over-proliferate with arbuscular mycorrhizal fungi. This is a joint initiative between the University and NIAB, funded by Bill and Melinda Gates Agricultural Innovations. With our new funding opportunities and focus on impact in crops, I hope that such field work will expand significantly over the following years.

In the academic year 2022-2023, we have completed:

1. Launch of the new research programmes resulting from the AGGF donation (see annex 1): this donation supports research across the pillars of the Crop Science Centre, improving photosynthesis; replacing inorganic fertilisers; reducing losses from pests and pathogens, as well as supporting a new pillar of activity in improving crop resilience to climate change. The research projects cut across the University and NIAB.

2. Launched the new MPhil in Crop Science (see annex 2), first intake of students was October 2023, with 15 students registered. As part of the AGGF donation we have bursaries for two places per year (for four years) for students from sub-Saharan Africa and the Mastercard donation provided a further four bursaries for students from sub-Saharan Africa. AGGF also provide a bursary for one PhD student per year (for three years) for students from sub-Saharan Africa, providing an opportunity for the best master's student to follow on with a PhD.

3. **Develop alliances in Africa**: a critical aspect of our mission is to impact small-holder farmers in Africa. This aligns with all of our charitable and philanthropic donations. Critical to recognising this impact will be alliances with partners in sub-Saharan Africa. We are exploring an alliance with the University of Ghana, with two reciprocal visits already undertaken.

4. **ENSA renewal**: funding from the Bill and Melinda Gates Foundation, Bill and Melinda Gates Agricultural Innovations and the Foreign, Commonwealth and Development Office has been critical to the establishment of CSC. The ENSA programme that underpins funding from all of these organisations was renewed in April 2023, with a $35m commitment from Bill and Melinda Gates Agricultural Innovations.

5. **Engagement with industry**: to recognise our impact, we have to have effective engagement with industry. We have secured considerable engagement with the potato breeding company Solynta and now have three joint studentships with them: one supervised by Dr Sebastian Eves-van den Akker on potato pests; one supervised by Prof Giles Oldroyd on gene editing in potato; and one supervised by Prof Ian Henderson on potato breeding. We have also had extensive discussions and visits with G's growers, with joint projects currently under discussion.

6. **Diversify our funding**: We have been successful in securing additional BBSRC funding, including in the area of potato pest research. In addition we are in the process of securing funding from the Novo Nordisk Foundation, with two projects focused on utilising the wheat genetic resources at NIAB to dissect microbiome interactions, heat tolerance and emerging pests and pathogens. These projects are at variable stages of approval, but very likely to be funded.

Establishing the Crop Science Centre labs and services

The following positions have been established and recruited:

- Research Laboratory Manager
- Media Technician
- Horticultural Technician
- Operations assistant
- HR manager
- Administrator
- Facilities manager
- Impact Manager
- Platform Manager
- Phenotype and Genetics Manager
- Facilities manager
- Research technicians

We acquired an empty building in February 2020, with no equipment and only limited resources (£250K) remaining from the RPIF funds to procure essential basic equipment. We have had to rely heavily on other funds to equip the laboratories. Much of the most essential equipment is in place, however, we have yet to establish the radioactive room and continue to receive requests from research staff for additional items of equipment. We are addressing these needs as we are able to do, with available resources.

Core functions have been established at CSC including a media/ glassware service; horticultural service; genotyping platform; automated construct production and a phenotyping platform for symbiosis and disease.

Appropriate health and safety procedures, including forms, inductions and inspections have been established, reporting to the Department of Plant Sciences Biological health and safety committee and coordinating with NIAB through monthly meetings.

The number of staff in the CSC building has increased in several phases and we are currently around 80 members of staff at the facility. This number of staff is currently reaching capacity for office space. We are exploring with NIAB opportunities to rent additional space.

Additional Facilities Development

The Speed Breeding Facility

In this period we have created a new speed breeding glasshouse facility on the NIAB Park Farm site, using funds from the RPIF, augmented by funds from Bill and Melinda Gates Agricultural Innovations. The facility comprises two large compartments sufficient to grow 6,000 plants, in temperate or tropical conditions. The glasshouse is equipped with active heating, cooling and fogging to allow temperature and humidity control. Automatic irrigation and Heliospectra LED lights can be individually controlled via the building management system. The speed breeding conditions for which the glasshouse is designed reduce the generation time of most temperate crops. For instance, these conditions can drive barley to anthesis in around 37-38 days, approximately half the time under conventional growth conditions. We are currently installing reverse osmosis water (RO) into the glasshouse to support experiments requiring close control of macro- and micronutrients.

The Microscope Suite

We have developed a suite to house several microscopes (Figure 1): a new confocal microscope funded by Bill and Melinda Gates Agricultural Innovations; two existing confocal microscopes at NIAB and two existing epiflorescent microscopes. The new build was supported by funds from Bill and Melinda Gates Agricultural

Figure 1: Designs for the development of a microscope facility for the Crop Science Centre.

Innovations. The microscope rooms have dedicated temperature control in addition to the general building environmental control systems to ensure consistent operation of the microscopes.

Seed store

We have much need for long-term seed storage and the original build provided no seed storage capacity. To meet the immediate need for long-term seed storage we have designed and built a walk-in seed storage facility in the undercroft of the Crop Science Centre. This is in operation and holds seeds securely at below 4oC with capacity to hold relative humidity at below 15%. The amalgamation of seeds for the Oldroyd and Paszkowski groups is likely to fill this capacity and additional facilities for further seed storage are being explored.

The Plant Growth Facility

The initial build provided 6 walk-in CERs. Already this capacity is limiting and as the new groups expand, we need to address the need for additional plant growth facilities, recognizing the increasing diversity of crop species studied. To this end we have initiated a project to design and cost a new CER facility in the undercroft (Figure 2). We need complete containment of these CERS within a corridor directly connected to the main building to allow appropriate handling and movement of genetically modified materials to and from these rooms. This has been designed to provide infrastructure for six new CERs, a corridor for security and GM containment, facilities and services for an autoclave, additional storage space, and a facilities workshop. We are currently costing these facilities and will explore later how we might fund this project. As a short term remedy for our controlled growth space need, we are also exploring adding additional lighted shelves to the existing CERs and this is something we can undertake using donations already committed.

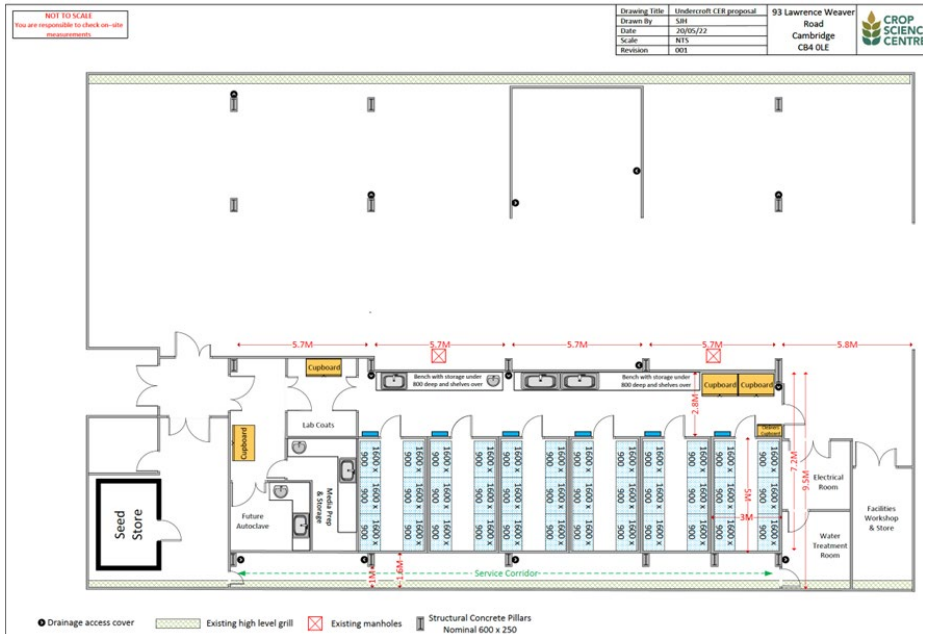

Figure 2: Proposed development project for a contained plant growth facility with six new CERs and associated services in the CSS undercroft.

Staff Wellbeing

The CSC aims to support the wellbeing of its staff and foster good practices to create a positive working environment where everyone feels comfortable, healthy, and happy. To this end, the CSC launched: the wellbeing advocate team, the CSC society and peer coaching.

The Wellbeing Advocate Team

The wellbeing advocate team has been established from the CSC, but functions across the whole Department of Plant Sciences. It is led by the CSC fellow, Jeongmin Choi, and consists of 8 members: the CSC research lab manager (Susana Sauret Gueto), the HR team (Frederique Anand, Katrina Wilson, Joanna Carruthers), a communication officer (Katherine Maltby), a student rep (Medhavi Kakkar) and a postdoc rep (Eftychios Frangedakis). The wellbeing team meets monthly, with a remit to proactively ensure staff wellbeing is addressed. Events so far organised by the team include:

- A wellbeing photography walk in collaboration with the Office of External Affairs and Communications at the University.
- Mental Health Awareness Week events held both at the CSC and the Department
- CSC Craft Club
- CSC BBQ to celebrate one year of the CSC

Peer Coaching

A CSC Peer Coaching/Support group was launched in October 2021. The group members meet bi-weekly for an hour in a supportive and safe environment to discuss any issues or concerns. The group strives for active listening and peer coaching following the "GROW" model.

CSC society

The CSC Society was launched in February 2022 to foster supportive community activities across the CSC, providing events to support community spirit and inclusivity. Currently, the Society is comprised of 12 members including a president, a treasurer, a Happy Hour Officer, a NIAB-CSC Liaison, and 8 team representatives.

The Society has established: a Monthly Happy Hour on every 3rd Thursday of the month, with different themes each month, with pizza and drinks provided. Attendance has been high from both University and NIAB staff; a weekly Tea Time Tuesday on every Tuesday of the week with tea and treats.

We host an annual CSC retreat.

Establishing collaborations between NIAB & University staff

We have established a number of events to facilitate scientific engagement between University and NIAB staff:

- A weekly CSC Seminar series. The format of this seminar is once a month we host an invited external speaker, otherwise, we have two internal speakers, one from NIAB and one from the University. We are running this seminar as a hybrid event, allowing both in person and online attendance.

- A monthly PI meeting of University and NIAB staff, where one PI presents their research vision, with detailed input and discussions.

- Occasional joint engagements with potential funders or industrial partners. So far these have been with The Morley Agricultural Foundation; Novo Nordisk Foundation; Bill and Melinda Agricultural Innovations and a consortia of Wheat breeders and G' growers.

- Explorative meetings for aligned research areas. The principle focus so far has been creating a UK Legume Initiative. We have so far held three meetings between NIAB, University of Cambridge and the John Innes Centre. In addition we organised a joint meeting between CSC and Kew, with ongoing follow-up discussions.

Many collaborative research activities have emerged between NIAB and the University of Cambridge since the launch of CSC. Funded collaborations are:

1. BBSRC CTP-SAI

- Abhi, Natasha: "Manipulating Meiotic Recombination for Crop Breeding".

2. Other PhD studentships

- Uta, Emma, Matt: "Mycorrhizal symbiosis in wheat" (BBSRC DTP)

- Jeongmin, Matt: "Improving nitrogen use efficiency in cereals" (TMAF).

3. BBSRC

- Uta, Emma: "Evolution of D14L signalling specificity for symbiosis and development" 2021-24

- Natasha, Emma: grant submitted.

4. BMGF/FCDO

- Giles, Uta, Richard – ENSA

5. Bill and Melinda Gates Agricultural Innovations

- Giles, Richard, Ji, NIAB field trails team

6. Currently unfunded collaborations:

- Sebastian, Tally, Ji “AI-based nematode detection to enable GWAS analysis”

- Lida & Ji “Gene regulatory network using Trans-Learn”

- Sigrid & Jeongmin “Rice genetic diversity for mycorrhizal interactions”

The donation of $12m from the Allan & Gill Gray Foundation is creating a very significant new opportunity for aligned research. Annex 1 provides the proposed research projects that will be funded by this donation.

CSC Grant income – only University of Cambridge staff located at CSC

Grant funding secured since starting at CSC, awarded up to October 2023:

Giles Oldroyd

- Foreign Commonwealth and Development Office UK Government (through Bill and Melinda Gates Foundation): Supplement to Engineering the Nitrogen Symbiosis for Africa (£8,452,141 of which £4,619,288 at University of Cambridge)
- Bill and Melinda Gates Agricultural Innovations: Accelerating translational Research (£3,781,952, shared between the University and NIAB)
- Bill and Melinda Gates Agricultural Innovations; Engineering the Nitrogen Symbiosis for Africa Phase 3 (£30,049,984 of which £15,769,365 at UCAM/NIAB).
- BBSRC; Molecular dissection of symbiosis regulation of plant immunity £619,284.
- BBSRC CTP Studentship; Using virus-induced gene editing in potato to genetically dissect plant-microbe interactions; £114,365.

Uta Paszkowski

- BBSRC: Discovery of symbiotic signalling mechanisms from maize (£204,199)
- BBSRC: Evolution of receptor signalling specificity for symbiosis and development (£557158)
- NSF USA: Adapting to a Harsh Environments: Arbuscular Mycorrhizal Fungi, Drought Stress and Plasticity of Plant Architecture for a Beneficial Outcome. (£162,144)
- NSF USA: Adapting to a Harsh Environments: Arbuscular Mycorrhizal Fungi, Drought Stress and Plasticity of Plant Architecture for a Beneficial Outcome Phase 2 £281,548.

Sebastian Eves-van den Akker

- ERC starting grant (£1,100,000)
- BBSRC Impact accelerator award (Collab with Solynta + NIAB; £23,000)
- CTP/Cambridge Trust & Rosalie Crawford Girton Scholarship (£150,000) x2

- Rob Cawthorn Trinity Studentship (£100,000)
- BBSRC CTP Studentship: Disrupting the master regulators of cyst nematode parasitism £114,365
- BBSRC: The genetics of environmental sex determination £163,956
- 2023-2026: Co-I - BBSRC Responsive Mode Standard Grant ~£1,000,000 (£250,000 to us) – Potato PCN Resistance: Cloning effective resistances against potato cyst nematodes"
- 2023-2026: PI – Leverhulme research grant ~£200,000 – An mRNA vaccine-like approach to overcome genetic intractability
- 2023-2026: Co-I BBSRC Responsive Mode Standard Grant ~£600,000 (£20,000 to us) – Damage signalling by endo-parasites: A key role for extracellular ATP and calcium channels

Jeongmin Choi

- Frank Smart – School of Biological Sciences PhD Studentship (~£120,000)
- The Morley PhD Studentship, co-supervisor (~£112,786)
- Research Fellows Enhanced Research Expenses 2021, The Royal Society (~£170,000)
- The Rank Prize New Lecturer Grant (~£12,500)
- Royal Society University Research Fellowship (£598,429)
- The Royal Society; Enhanced Research Expenses 2022 £280,482.

Lida Derevina

- Gatsby grants to exceptional researchers – £16,432,38 (matching funds – £16,432,38 - from the Department of Plant Sciences)
- British Society for Plant Pathology (BSPP) undergraduate Vacation bursary – to support a summer student over 10 week - £4,000 (co-supervised by Sebastian Eves-can den Akker).
- Prevalence and distribution of the single greatest threat to crop production in the tropics: the root knot nematode Meloidogyne incognita. - £23,666

Natasha Yelina

- Royal Society Research Grant (£20,000, 12 months)
- ISSF – Cambridge Joint Research Grants Scheme, (£85,000, 24 months)
- 4-year PhD Studentship funded by AFCP Charities and Department of Plant Sciences, (£120,000).

2022-2023 update from CUPGRA fellow Dr Sebastian Eves-van den Akker

Head of Plant-Parasite Interactions Group

Plant-parasitic interactions

The investment in the CUPGRA fellowship allowed the establishment of a group at the Crop Science Centre working on plant-nematode interactions, since July 2021. The group, led by me the CUPGRA fellow, now consists of ~10 researchers – amplifying the investment by a factor of 10. The group is internationally recognised as a leader in the field of pathology in general, and plant-parasitic nematology in particular, as evidenced by the following achievements since 2022:

- Twelve invited talks (of which eight were plenary addresses);
- Nine publications;
- Six research grants;
- And a personal promotion to Principal Research Associate, Professor Grade 11 (promotion to this level is regarded as exceptional, awarded to those who clearly demonstrate that they are recognised at an international level for the advancement of their area of research).

Over the last year, we have been extremely successful in fundraising to further support research, from a variety of national and international sources. These include several industry collaborations, UK research councils, EU research organisations, and philanthropic entities. Current active grants total £4.2 million (approximately £2.7 million since 2022) – already nearly 10 times the total five-year investment of CUPGRA. This exemplifies the distinct advantage in investing in an individual rather than a project: 10-fold amplification in personnel, and research spending power.

Given that the group of the CUPGRA fellow resides in an academic institution, our research must meet the highest standards for academic research on a global stage. At the same time, being supported by CUPGRA and being based at the Crop Science Centre, the research must focus on a pressing need (i.e. the nematode problem). Often viewed as competing goals, we see them rather as the small but nevertheless most exciting set of questions that are both academically interesting and agronomically important. As such, research in the group as a whole, but individual projects also, span from fundamental to applied research.

The focus on the group is on plant-parasitic nematodes. There are essentially two fundamental questions that encapsulate most of the work in the lab: 1) What at the plant genes that underly nematode infection, and 2) What are the nematode genes that underly nematode infection? In both cases, answering these questions has intuitive routes to impact that we push at every credible opportunity.

In summary, our group operates a large, ambitious, and internationally-leading research programme that is aimed at answering fundamental questions about the nature of plant-parasitism by nematodes in order to identify/facilitate routes to control. While the kind of research we do is, by its nature, long-term – the interactions I have had with CUPGRA members validate the overarching aim, feed into the thinking, and instil an even greater sense of urgency.

Annex 1: Projects funded by the Allan & Gill Gray Foundation donation

MAXIMISING MYCORRHIZAL BENEFIT IN MAJOR AFRICAN CEREAL CROPS

Prof Uta Paszkowski, Prof Giles Oldroyd, Dr Jeongmin Choi, Dr Leonie Luginbuehl, Dr Emma Wallington.

Vision:

Of the ~250 mio ha arable land in Africa, an area of ~100 mio ha is used for the cultivation of cereals (source: African Development Bank Group, 2015). Maize is a major staple food for Sub-Saharan Africa (SSA), its production having overtaken traditional millets and Sorghum. Rice on the other hand is a strategic and priority commodity for food security in SSA. Our vision is to improve the benefits maize and rice derive from engaging with arbuscular mycorrhizal (AM) fungi. In the resulting mutualistic interaction, the fungus significantly enhances crop mineral nutrition, particularly pronounced for phosphate, thereby operating like a sustainable biofertiliser. However, mycorrhizal benefit has largely been overlooked in crop breeding programmes that rather focused on boosting yield by synthetic/mined fertilizer application, at the same time preventing establishment of the symbiosis. From previous efforts using genetically diverse maize (Sawers et al., 2017) and rice (Emily Servante, PhD thesis, ongoing) germplasm panels, we have identified lines that show significantly enhanced benefit. In parallel, signalling components have been discovered whose manipulation enables AM interactions under suppressive high fertilizer conditions (Li et al., under revision). In this project, we will generate maize and rice germplasm with boosted symbiotic benefit through combining the previously gained insights on genetic diversity and enabling continuous symbiotic signalling with integrated phosphate fertilization management and abiotic stresses, enabling us to optimize the benefits from mycorrhizal fungi.

Impact:

The impact will be threefold. 1) For maize and rice QTL and gene leads for beneficial traits and tractable parental contributions will be introgressed into local accessions for use by farmers. 2) Resource development for genomic selection. 3) Development of a pre-breeding population that can be used to for crop improvement and mapping of key traits to accelerate future improvement.

Milestones:

- Year 1: Identified QTLs and gene leads underpinning agronomically relevant symbiotic traits.
- Year 2: Validated QTLs and gene leads (proof of concept, greenhouse UK).

- Year 3: Introgressed/transformed promising QTLs/ gene leads into preferred African backgrounds.
- Year 4: Generated promising African germplasm.
- Year 5: First field-characterization of preferred backgrounds carrying promising QTL/gene leads.

Partnerships:

IRRI for African rice germplasm; CIMMYT for African maize germplasm. Moroccan phosphate industry for integrated sustainable phosphate fertilization.

IMPROVING PHOTOSYNTHESIS IN AN ORPHAN LEAFY VEGETABLE

Prof Julian Hibberd, Dr Johannes Kromdijk, Dr Tally Wright, Dr Leonie Luginbuehl

Vision:

Orphan leafy vegetables provide an important source of vitamins, minerals and protein, as well as a substantial income component of small-holder farmers. Our vision is to improve photosynthesis and therefore leaf yield in the highly nutritious leafy vegetable orphan crop Cleome gynandra (sometimes known as spider-plant or African cabbage). This species is valued for high vitamin and iron content, but also for treatment of a variety of medical conditions. Leafy vegetables represent the bulk of African orphan crops and particularly make substantial contributions during food shortage. However, genomic information is limited, and compared with orphan crops such as legumes, grains, millets and root or tuber crops they have received less attention. In this project we will characterize variation in important agronomical, nutritional, photosynthetic and yield traits across an existing pre-breeding population (developed in-house) which leverages strong differences in nutrient content and morphology associated with the geographic origin (African and Asian) of the parent lines. We will also develop a new pre-breeding population of this species for which parental lines will be selected based on the most relevant germplasm to support the rate of crop improvement for Sub-Saharan Africa.

Impact:

The impact will be threefold. 1) QTL for beneficial traits and tractable parental contributions will be introgressed into local accessions for use by farmers. 2) Resource development for genomic selection. 3) An immortalized pre-breeding population that can be used to for crop improvement and mapping of key traits to accelerate future improvement.

Milestones:

- Year 1: Established an C. gynandra ideotype for sub-saharan farmers/consumers to generate a trait list.
- Year 2: Used an existing Multi Advanced Generation Intercrossing (MAGIC) population for QTL mapping of agronomic and photosynthetic traits.
- Year 3: Have initiated backcrossing of promising QTL into preferred backgrounds
- Year 4: Delivered a dedicated African MAGIC panel for C. gynandra
- Year 5: First field-characterization of preferred backgrounds carrying promising QTL.

Partnerships:

This work requires partnership with Enoch Achigan-Dako (University of Abomey-Calavi, Cotonou, Benin) to generate the trait list and ideotype as well as the field-based analysis of the populations.

ENHANCING HEAT TOLERANCE IN THE MAJOR LEGUME CROPS OF AFRICA

Dr Natasha Yelina, Dr Sigrid Heuer, Dr Emma Wallington

Vision:

The average global temperature has increased by 1°C already causing increasingly erratic and severe weather events, such as extreme heat waves, drought and floods. Plants are sensitive to heat stress, which is aggravated by drought, and temperatures above a critical threshold cause failure of seed set and reduced grain size and quality, as well as a decline in photosynthesis. Fortunately, natural genetic variation exists that can be exploited for the development of tolerant crops and it is the vision of this project to develop heat tolerant legumes for Africa. We will initially focus on two grain legumes (or pulses) that are important in Sub-Saharan Africa, namely common bean and cowpea. Both are produced by small holder farmers and are important sources of protein, calories, vitamins, and minerals.

Building on our current know-how and available germplasm collections, which includes a validated heat-tolerant bean adapted to South America (developed by CIAT, Colombia), we aim to identify relevant traits and understand the mechanisms underlying heat tolerance in common bean and cowpea. Our vision is that this knowledge, combined with improved breeding technologies, development of which we propose to initiate, will enable the generation of heat-tolerant legumes for Sub-Saharan Africa. Studying common bean and cowpea in parallel will allow us to understand whether plants use similar or divergent strategies for heat stress adaptation. This will be complemented with data derived from our ongoing projects on heat tolerance in rice and wheat. This project will thus inform targeted development of heat tolerant common bean and cowpea, as well as other legumes and cereal crops.

Impact:

Our anticipated impact is: Common bean and cowpea cultivars with reproductive heat tolerance as a resource for pre-breeding; Traits and associated genomic regions underlying resilience to reproductive heat stress for marker-assisted breeding; new common bean and cowpea cultivars with improved reproductive heat resilience.

Milestones:

- Year 1: Heat stress screening capacity established in Cambridge and available heat-tolerant common bean characterized in detail and made available to African breeding programmes
- Year 2: Novel sources of heat tolerance identified in common bean and in cowpea, und associated traits characterized
- Year 3: Tolerant cultivars used in breeding programmes by African partners and IITA (cowpea) and for crossing into locally adapted African varieties
- Year 4: Heat-tolerance candidate genes available for functional validation and conversion into selection tools (molecular markers) for breeding
- Year 5: Breeding lines validated in farmers' fields in African target countries

Partnerships:

CIAT (Uganda & Colombia) for heat tolerant phaseolus, IITA (Nigeria) for cowpea diversity, Kirkhouse Trust (African Bean Consortium).

INCREASING RESILIANCE TO PESTS AND DISEASES IN AFRICAN LEGUME AND TUBER CROPS

Dr Sebastian Eves-van den Akker, Dr Ji Zhou, Dr Lida Derevnina, Dr Kostya Kanyuka, Dr Tom Wood, Dr Emma Wallington

Vision:

Pests and diseases are major, and in some cases the dominant, threats to food security for small holder famers. This theme aims to use our fundamental understanding of the plant genes underlying pest and disease establishment to improve - or better realise the potential of – tuber and pulse genetic material available to breeders in Sub Saharan Africa (SSA) to mitigate endemic pests and diseases.

Our recent discoveries involving pathogen biology, genetics, and robotics and AI collectively indicate that genetic material in existing breeding programmes is not fully utilised: there is untapped potential either because the capacity to screen for agronomically relevant traits is absent, or because the true gamut of natural resistance of the plants is rendered ineffective by highly adapted pests and diseases. We therefore propose to transfer our knowledge of these constraints from various model systems (*Arabidopsis spp., Nicotiana benthamiana*) to the tuber (Solanum spp. and Ipomée spp.) and pulse (Phaseolus spp.) crops of relevance to SSA. We will focus on two sets of endemic pathogens for which there is both a substantial unmet need and considerable expertise at the Crop Science Centre: the “plant-parasitic nematodes” and the “rusts”. Each pathogen is widespread, devastating, and extremely challenging to control in low input systems. Genetic solutions are key, and we are well placed to deliver them.

Impact:

We anticipate the principal impact of this programme will be the long-term capacity to breed for effective resistance to endemic pathogens in SSA in legume and tuber crops.

Milestones:

- Year 1: Establish cultures and genetic resources for crops, pests, and diseases endemic to SSA
- Year 2: Build low-cost and high-throughput pathogen screening capability.
- Year 3: Screen plant material for resistance to pests and diseases.
- Year 4: Define resistance gene complements in tuber and pulse crops and determine how they are overcome by endemic pests and diseases.
- Year 5: Design novel genes and/or genomes with improved resistance to pests and diseases.

Partners:

Danny Coyne (IITA, Kenya station) – Nematologist; Pamela Paparu (National Crops Resources Research Institute, NaCRRI, Uganda) – Legume pathologist; Clare Mukankusi (CIAT, Uganda) – Legume breeder.

Annex 2: MPhil in Biological Sciences, Crop Science

Overview

Global food security sits at a nexus. Do we continue with unsustainable practices benefiting farmers in high and middle income countries, while small-holders barely produce enough to support themselves? Or can we find a new way for agriculture that delivers food in an equitable and sustainable manner? Envisioning agriculture in 2050 needs to take into account the global population, the planets' biodiversity, global climate change and the current inequities in the system. The Masters of Philosophy in Crop Science will explore new ways of thinking about what agriculture should be in 2050 and how we might get to that point. We will take a broad view of potential solutions, with an emphasis on practical, scientific approaches, from genetic engineering to regenerative agriculture. Our aim is to train future leaders to take creative approaches to global food security.

A major theme of the course will be connecting knowledge across varying scales and we will draw upon the breadth of relevant expertise within the University, across the School of the Biological Sciences, the Judge Business School and the Centre for Development Studies. Notably, we can deliver a programme that includes field-based study through our partnership with NIAB. We will extend our reach with speakers from outside the University to add to the discussion.

Together, this will provide the students with an integrated perspective on food security that spans plant biology, global ecology, conservation and economics. The course will explore a range of topics, from plant form and function, to scrutinising diverse solutions to improving crop production, by using our international strength in these fields within the Department of Plant Sciences, Crop Science Centre, NIAB and the Sainsbury Laboratory. The unique concentration and combination of excellence in plant sciences research at Cambridge will ensure that our Masters course is highly attractive to students, both nationally and internationally.

Rationale and educational aims

a) Purpose of the course and what the institution is trying to achieve in providing it:

- An integrative training in cutting-edge crop science that will prepare the students to make major contributions to global agriculture.
- Interdisciplinary taught modules encompassing crop science research at the genetic, cellular, organismal and ecological scales.
- Training in critical thinking, writing grants and papers and presenting complex ideas in a clear and compelling way.

- Supervised training in literature synthesis and data analysis via an 'Insights' essay. The students will also prepare a grant proposal based on their research area.

- An 8-month primary research project where the students will work embedded in a research team investigating questions at the cutting-edge of crop science. This will prepare students for highly competitive PhD programs and Agritech positions, in addition to diverse other career paths.

- **Research skills to be developed**: Controlled experimental design and statistical analysis. Bioinformatics and programmatic approaches. Depending on the project, skills in molecular biology, genetics, genomics, tissue culture, transformation, gene-editing, plant-microorganism interactions, biochemistry, metabolomics and computer modelling will be acquired. Projects in a wide range of plant species and approaches will be available for students to select from.

- **Transferable skills**: Project management, data presentation and seminar design and delivery, time management, conceptual thinking, analytical thinking, skills in scientific writing that enable complex concepts to be communicated in an engaging and illuminating way. Specific training on grant and research proposal writing will be delivered. A deep, integrated understanding of global agriculture will be acquired that can be applied in a range of career paths.

The taught component of the Masters in Crop Science will feature 4 interconnected and interdisciplinary thematic modules. Each module will run for two weeks, with four interactive sessions per week.

(i) **The future of sustainable agriculture**. The global system of agriculture will be examined, drawing on University expertise in ecology, economics and social science. A high-level perspective of current and future modes of agriculture will be delivered. The grand challenge of sustainably adapting global agriculture to climate change will be highlighted.

(ii) **Crop development, metabolism and physiology**. An integrated understanding of plant function at the molecular, cellular, tissue and whole organism levels will be taught. We will examine how this knowledge is relevant for crop yield and performance, and how this can be used to address challenges to food security.

(iii) **Plant-biotic interactions**. The spectrum of plant-microbe, plant-animal and plant-plant interactions will be explored, and the key features that distinguish parasitic and symbiotic relationships. The vital importance of these interactions for plant health and nutrition within agriculture will be examined.

(iv) **Crop Improvement**. The organization and function of plant genomes will be explored and how this is relevant for crop breeding and engineering. We will examine how quantitative genetics, genomics and gene editing can be combined to rapidly adapt crops to novel environmental conditions and safeguard food security. We will explore how genetics can be combined with agronomy to enhance sustainable productivity.

We will model delivery of our teaching on the successful 'Frontiers and Techniques in Plant Science' course run at Cold Spring Harbor Laboratory. Each lecturer will teach for 2 hours per interactive session, which will be group-guided discussions centered around key questions. The first hour will provide an introduction to the area/field, followed by questions and discussion. In the second hour, the lecturer will present on their latest research discoveries, followed by a final discussion session. Each session will be associated with a short reading list of recent important work that

the students will read prior to attending. Through this teaching method we will stimulate a high level of dialogue and discussion between the lecturers and students.

We will additionally provide Methods based workshops, on topics including statistics and bioinformatics, quantitative genetics, crop transformation, gene editing and grant writing. Students will participate in journal clubs and attend research seminars within the Department of Plant Sciences, CSC and NIAB to develop critical thinking skills and learn about current research.

b) Audience for whom the course is intended:

The course is aimed at those who aspire to make major contributions to global agriculture in future years. As agriculture is of critical importance to both developed and developing economies, we anticipate that our course will be widely attractive nationally and internationally. Crop Sciences teaching on our Masters course will be significantly advanced over delivery at Part II and III, and will be taught using discussion based interactive sessions. Therefore, our course will also be attractive to Cambridge graduates wishing to train in this field.

The integrated training the students will acquire will prepare students for multiple career paths. The research experience gained will prepare students for highly competitive Ph.D positions and research-based positions in Agritech, both internationally and within the UK. The training in wide-ranging transferable skills, will be valuable for students pursuing careers in science policy and governance, social science, science communication, and non-research based positions in Agritech and international charitable bodies. We intend that our student cohorts will continue into diverse spheres of research, policy, and science communication with a significant downstream influence on the development of global agriculture and crop science.

Market Demand

We identify below a set of Masters level courses that overlap to some extent with our new M.Phil stream in Crop Science. However, our course is distinct and unique in that it takes a broader perspective – covering crop science from the molecular scale, to the larger ecological and socio-economic scales. Only by taking a more cross-disciplinary, holistic approach can we hope to address the question 'what will agriculture look like in 50 years?' The University is uniquely placed to do this, because unlike many other HEIs, we can draw on the exceptionally wide range of expertise available to us (as outlined above), notably the Crop Science Centre and NIAB, which provide a unique educational experience that we believe will be widely attractive to students and complements the other national provision in this area.

In terms of nationally competing programs, there is some overlap with the following courses:

- (i) MSc in Plant Genetics and Crop Improvement, John Innes Centre/University of East Anglia. https://www.jic.ac.uk/training-careers/postgraduate-opportunities/plant-genetics-crop-improvement/
- (ii) MSc in Global Plant Health, The Sainsbury Laboratory, Norwich. http://www.tsl.ac.uk/opportunities-overview/post-graduate-research/msc-global-plant-health/
- (iii) MSc in Sustainable Crop Production, University of Warwick. https://warwick.ac.uk/study/postgraduate/taught/courses-2021/sustainablecropproduction
- (iv) MSc in Plant Science and Biotechnology, University of Leeds. https://courses.leeds.ac.uk/g065/plant-science-and-biotechnology-msc

In terms of internationally competing programs, there is some overlap with the following courses:

- (i) MSc in Plant Breeding and Plant Genetics, University of Wisconsin, USA. https://guide.wisc.edu/graduate/agricultural-life-sciences-college-wide/plant-breeding-genetics-ms/
- (ii) MSc in Plant Breeding. Texas A&M, USA. https://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/agriculture-life-sciences/soil-crop-sciences/plant-breeding-ms/
- (iii) Masters in Agricultural Sciences, University of Hohenheim, Germany. https://www.uni-hohenheim.de/en/agricultural-sciences-masters
- (iv) Masters in Plant Biotechnology, University of Wageningen, Netherlands. https://www.wur.nl/en/Education-Programmes/master/MSc-programmes/MSc-Plant-Biotechnology.htm

Relationship with existing provision

Currently, the University does not offer a Masters level course in Plant Science, or more specifically in Crop Science. As the pace of climate change increases, adapting our crops and agriculture has become vitally important. Therefore, high level training in the latest approaches in Crop Science, embedded in a more holistic societal context, will be attractive both nationally and internationally. Development of our course is also timely due to the recent establishment of the Crop Science Centre and the strengthening alliance between the University and NIAB.

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