


RESEARCH ARTICLE

Building capacity in vector-borne plant virus research: The CONNECTED Network

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Societal Impact Statement

Plant viruses spread by insects decimate crop yields globally, causing food security challenges in vulnerable areas including regions of Africa. Interdisciplinary research is needed to protect future crop supplies. CONNECTED, the Community Network for African Vector-Borne Plant Viruses, increased research capacity in Central, East, West and Southern Africa through networking, funding research and training. Here, we describe how CONNECTED developed a community of 1675 members across 97 countries, delivered new research and trained early career researchers in interdisciplinary techniques. The approach used by CONNECTED can be replicated by other initiatives to increase international plant research capacity and collaboration, particularly between the Global South and North.

Summary

- Plant viruses, often spread by insects, decimate staple and nutritious crop yields globally. This contributes to economic and food security challenges in vulnerable areas, including regions of Africa. Interdisciplinary research is required to better understand plant virus epidemiology to protect future crop supplies, but this is often hindered by limited collaboration and knowledge exchange between plant pathology and entomology research communities. Collaborative networks are a useful model for promoting collaborative and interdisciplinary research. CONNECTED, the Community Network for African Vector-Borne Plant Viruses, was a collaborative research network supported by the UK Global Challenges Research Fund. CONNECTED sought to convene international plant pathology and entomology communities through networking, pump-priming new collaborative research, and training, to increase vector-borne plant virus (VBPV) research capacity in Africa.
- Combining analysis of CONNECTED's activities programme with qualitative methods, we identify the outcomes achieved by CONNECTED for the global VBPV community, and the value it provided to its members.

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- CONNECTED developed a multidisciplinary community of 1675 members across 97 countries. CONNECTED delivered 20 new strategically-relevant research projects involving 55 researchers from 33 institutions across 14 countries working on 11 different crops. CONNECTED trained over 140 early career researchers from 23 countries in interdisciplinary VBPV techniques, providing new training materials co-created in partnership with Africa-based research organisations.
- These outcomes demonstrate the impact of CONNECTED's phased programme of activities in building the capacity of international VBPV research communities, towards plant science and food security outcomes, which can be expanded and replicated in different contexts.

KEYWORDS

capacity building, collaborative network, food security, insect vectors, interdisciplinarity, plant viruses

1 | INTRODUCTION

Global food supplies are severely jeopardised by pests and diseases. Plant viruses that are vectored by insects cause major annual crop losses: their diversity, severity and distribution are being driven by climate change, globalisation and agricultural practices (Bebber et al., 2013; Jones, 2009; Radouane et al., 2021; Tatini & Hein, 2023). Vector-borne plant viruses (VBPVs) involve complex virus–plant–vector–environment interactions, which complicate their epidemiology (Lefeuvre et al., 2019; Trebicki, 2020). Significant gaps remain in our understanding of VBPVs, particularly how new diseases emerge, virus–vector interactions, vector biology and ecology and methods for diagnostics, surveillance, forecasting and control (BBSRC, 2016; Lefeuvre et al., 2019; Trebicki, 2020). The impacts of VBPVs in economies vulnerable to the effects of natural crises extend beyond food provision to encompass social and economic factors, including rural development, poverty and standards of living (Jones & Naidu, 2019; Vurro et al., 2010). As such, VBPV research requires multidisciplinary collaboration across scientific fields and agricultural sectors, and particularly between researchers in the Global South and North (Jones & Naidu, 2019).

Collaborative networks are an approach to increasing research capacity in specific disciplinary and cross-disciplinary domains. Where they bridge previously separate fields, collaborative networks can lead to novel and disruptive research (Wang et al., 2023). Recent publications provide useful case studies describing the successful establishment and evaluation of collaborative networks in particular subject areas (Parry et al., 2020; Bailie et al., 2021). This work describes the formation, development and outcomes of an international interdisciplinary scientific collaborative network, which aimed to increase capacity in VBPV research, particularly in Central, East, West and Southern Africa: the Community Network for African Vector-Borne Plant Viruses (CONNECTED). This UK-funded research network designed, implemented and evaluated a multi-year programme of activities, running from 2017 to 2023. Here, we identify and assess

the outcomes and impacts of CONNECTED's activities to (1) demonstrate the community capacity development achieved in the field of VBPV research and (2) describe the value CONNECTED represented to its members. Together, these results provide actionable insight for designing and implementing collaborative network approaches to build plant health and agricultural research communities, particularly across disciplinary and Global South/North boundaries.

2 | MATERIALS AND METHODS

Network membership was analysed using data from member submission forms: New members submitted an online form providing individual professional characteristics including country of work, institution, gender, career stage and expertise areas. The outcomes achieved by CONNECTED for the VBPV research community were extracted and compiled from monitoring, learning and evaluation (MLE) data collected and compiled over the duration of the CONNECTED Network activities programme. For events and training courses, participant information (institution, country, career stage, position/job title and gender) was recorded in Microsoft Excel spreadsheets. Workshop sessions which co-created and captured network member priorities and needs, including priority research topics and research community knowledge and skills requirements, were captured on flipcharts. Surveys were used to evaluate the efficacy of training offerings in delivering new knowledge and skills, which added value to research and teaching and could be shared with others, and in enhancing the professional networks of participants. The surveys were completed by participants prior to, immediately after and at 6 months following training completion. See Table S1 for an example 6-month follow-up training survey. This permitted assessment of learning objective usage in network member research, value added to the quality of research and teaching within the network and quantification of the numbers of individuals that the new skills were shared with and how, plus quantification of changes to participant professional networks. The

performance of pump prime funding (PPF) projects was monitored and evaluated via (1) data collected from funding bid submissions (team member institutions, country, career stage and gender; relevant strategic priorities) and (2) end-of-project reports. The latter were completed using a standardised report template issued to all PPF teams (Table S2). These reports provided detailed information on project research topics, crops, diseases and insect vectors, the nature of the collaborations involved, the number and types of outputs/innovations, project dissemination metrics, contracting and due diligence information, the number and nature of new working relationships developed, capacity built within and outside the team, outcomes for the DAC-list participants (relevant to the ODA objectives of the funding), anticipated future impact of the work and feedback for the CONNECTED Network Team.

A qualitative study was conducted to understand CONNECTED member opinions of the network and how they formed connections and collaborations. This comprised a short survey and semi-structured interviews (Table S3). Thirty-seven members completed the survey representing various disciplinary backgrounds, including plant virologists and entomologists from Burundi, Kenya, Rwanda, South Africa, Tanzania, the Democratic Republic of the Congo, Uganda, Zambia and Zimbabwe. All interviews took place virtually and were assisted via standardised interview questions. Nine interviews were undertaken with network members, including academics and industry experts from Kenya, Nigeria, South Africa, the Republic of Benin and the UK. Two of these interviews were with senior academics (Lecturer, Associate Professor or Professor) and seven with ECRs.

The interview data was analysed using analytic coding, a qualitative method that identifies themes and patterns by systematically categorising data (Kawulich, 2017; Pratt, 2023). During the first round of data analysis, open-ended codes were assigned to interview transcripts (Braun et al., 2021). This inductive approach focused on identifying themes directly from the participants' words and phrases, rather than relying on concepts derived from prior research (Friedman, 2011). The initial coding identified broad themes, which were then refined into more specific subthemes through subsequent iterations of data re-analysis. This iterative process produced a detailed coding schema that not only identified key themes and subthemes but also uncovered deeper layers of subthemes within the data (Table S4).

3 | RESULTS

3.1 | The establishment and operation of the CONNECTED Network

CONNECTED was co-led and hosted by the University of Bristol and Newcastle University, UK, from 2017 until late 2023. Funded initially by a £2M UK government Global Challenges Research Fund (GCRF) grant (2017 to 2021), CONNECTED was the only plant-focused network in a portfolio of four other vector-borne disease community networks. The funding scheme supporting this portfolio aimed to

tackle vector-borne disease challenges relevant to low-and-middle-income countries. CONNECTED subsequently (2022 to 2023) received onward funding from UKRI and the University of Bristol's Bristol Centre for Agricultural Innovation. From this point at which UK funding for CONNECTED ceased, hosting of the network was handed over to an Africa-based partnership between the International Institute of Tropical Agriculture (IITA), Nigeria, and the Biosciences for Africa (B4A)–International Livestock Research Institute (ILRI) Hub, Kenya.

CONNECTED worked to deliver the following objectives:

- Build a sustainable and long-lasting network of multi-disciplinary international scientists to address the problems created by vector-borne plant viral diseases.
- Run a series of activities to promote and embed interdisciplinary working and to strengthen research capacity, capabilities and methodologies particularly focused on the vectors of plant disease.
- Support collaboration between researchers in the UK and low- and middle-income countries (LMICs) and engagement with end-users, stakeholders and policy makers.
- Capacity build, via improved communication and collaboration networks, seminars and workshops and training courses both in the UK and Africa.
- Use PPF for a range of innovative projects identified by the CONNECTED Management Board ultimately leading to more competitive, collaborative, cross-disciplinary and integrative research proposals, as well as real impact.
- Develop early career researchers (ECRs), by focusing part of the pump-primed funding on proposals submitted by them, providing support to enable proposal development and delivery of projects.
- Provide legacy benefits from the network by facilitating the opportunity for further funding for the projects bringing the greatest impact to the region.

As such, the primary goals of the CONNECTED Network were to stimulate interdisciplinary and international collaborations and increase research capacity in VBPV research, specifically between the UK and African countries on the Organization for Economic Co-operation and Development (OECD) Development Assistance Committee (DAC) list (OECD, 2018). Being initially funded through the GCRF set particular terms and conditions for how funds could be spent, shaping the network activities programme. The project included a ringfenced budget for pump priming new international VBPV research projects.

The network was coordinated by a Network Team made up of an Executive group (lead academics and Network Managers), supported by a Communications Officer and Executive Assistant. The Network Team designed, implemented and evaluated the programme of activities. From the outset, network governance was overseen by a Management Board of approximately 20 experts in plant virology, entomology, plant health and agricultural impact from across the UK and Africa (CONNECTED Network, 2017; Table 1). The Management Board was initially chaired by Professor Nicola Spence, UK Chief Plant

TABLE 1 Members of the CONNECTED management board (in alphabetical order of surname).

Name (role)	Organisation	Country	Served 2017–2020	Served 2021–2023
Titus Alicai	National Crops Resources Research Institute (NaCRRI)	Uganda	✓	✓
Toby Bruce	University of Keele	UK	✓	✓
John Carr	University of Cambridge	UK	✓	✓
Richard Hopkins	University of Greenwich	UK	✓	✓
Esther Kimani	Kenya Plant Health Inspectorate Service (KEPHIS)	Kenya	✓	-
Lava Kumar (Co-Chair/Chair)	International Institute of Tropical Agriculture (IITA)	Nigeria	✓	✓
Christophe Lacomme	Science & Advice for Scottish Agriculture (SASA)	UK	-	✓
Simon Leather	Harper Adams University	UK	✓	-
James Legg	International Institute of Tropical Agriculture (IITA)	Tanzania	-	✓
Stuart MacFarlane	James Hutton Institute	UK	✓	-
Isaac Macharia	Kenya Plant Health Inspectorate Service (KEPHIS)	Kenya	-	✓
Jacob Mignouna	Biosciences for Africa (B4A) – International livestock Research Institute (ILRI) Hub	Kenya	-	✓
Emmanuel Okogbenin	African Agricultural Technology Foundation (AATF)	Kenya	✓	✓
Jon Pickup	Science & Advice for Scottish Agriculture (SASA)	UK	✓	-
Yvonne Pinto	ALINE	UK	✓	✓
Sue Seal	University of Greenwich	UK	✓	✓
Michael Siva-Jothy	University of Sheffield	UK	✓	-
Julian Smith	Fera Science, Ltd	UK	✓	✓
Nicola Spence (Chair)	Department for Environment, Food & Rural Affairs (DEFRA)	UK	✓	-
Lesley Torrance	James Hutton Institute	UK	✓	✓
John Walsh	University of Warwick	UK	✓	✓
Anne Wangai	Kenya Agricultural and Livestock Research Organization (KALRO)	Kenya	✓	-
Rehema White	University of St Andrews	UK	✓	-
Cathrine Ziyomo	Biosciences for Africa (B4A) – International livestock Research Institute (ILRI) Hub	Kenya	-	✓

Health Officer, and co-chaired by Professor Lava Kumar (Nigeria), Head of the Germplasm Health Unit and Virology and Molecular Diagnostics Unit at IITA in Nigeria—roles that were agreed during the development of the CONNECTED funding bid (Professor Kumar later became Management Board chair).

The CONNECTED Network began enrolling members via a website (CONNECTED Network, 2017: www.connectedvirus.net) from November 2017 following a publicity campaign. Early members encouraged to join included key academics, researchers and stakeholders from within the existing professional networks of the project leads, many of whom were Africa-based collaborative partners of the UK leads and who were consulted during the development of the CONNECTED funding bid. Subsequent membership growth was organic in response to communications activities and publicity via social media and e-newsletters, particularly in response to network events and competitions. CONNECTED intentionally did not limit the focus of network growth on any particular countries in Africa nor on any particular organisations.

Early in the project, the network established an actor-centred linear Theory of Change approach to guide the programme of activities

towards long-term impact on smallholder farming contexts in Africa via building capacity in VBPV research (Figure 1). This was enabled by expertise within the Management Board, with key elements emerging from the UK and Uganda launch conferences. The Theory of Change focused the activities of the network into three overarching themes: pump-priming new collaborative research projects, training, and networking opportunities.

The Theory of Change was underpinned by a MLE system to track progress: This used surveys, case studies and web-based analytics to monitor event participation, learning and development outcomes, digital resource utilisation and reach. Outreach, engagement and publicity to researcher and stakeholder audiences were managed via a communications strategy: project website, including news blog, social media channels, monthly e-newsletters and bespoke internal/external relations.

By the conclusion of CONNECTED's UK-based hosting, the network community comprised 1675 members across 97 countries—a truly global research community (see Figure 2). At least 79% of the community was composed of ECRs, the vast majority of whom were based in OECD DAC-list countries. Membership represented actors

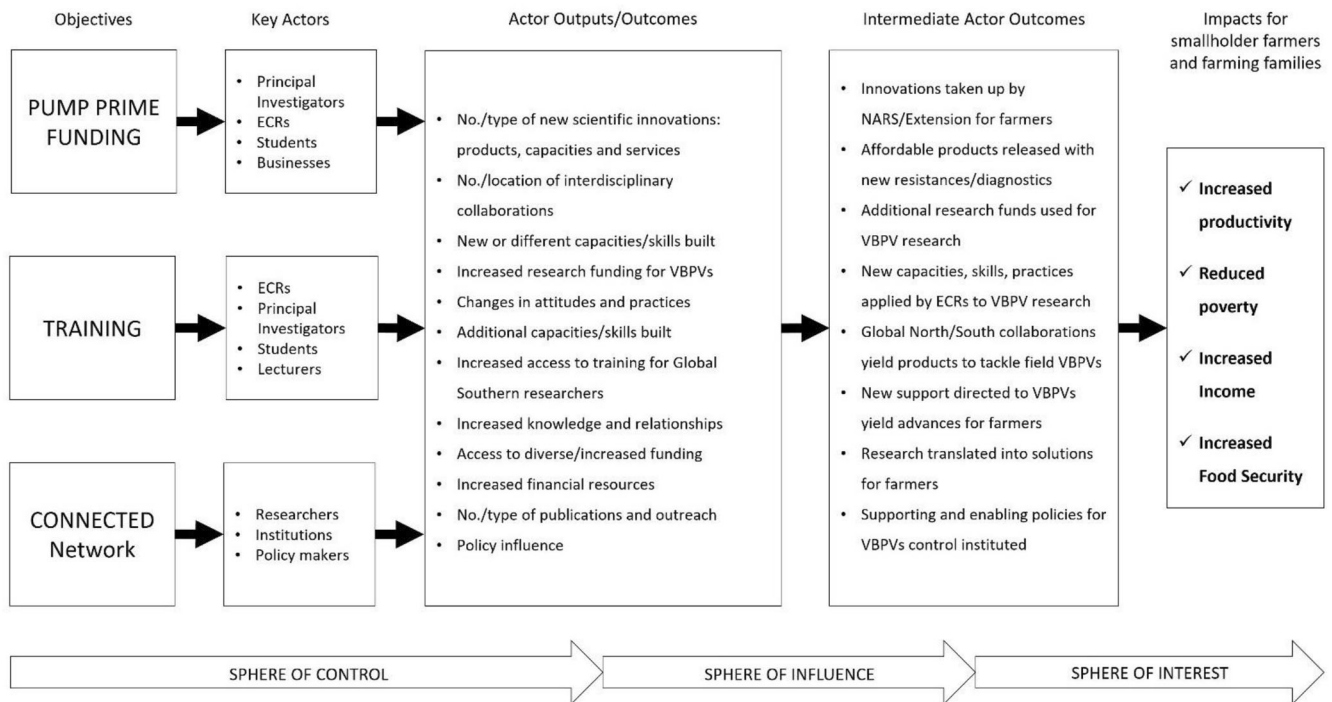


FIGURE 1 Actor-centred linear Theory of Change developed for the CONNECTED Network. From left to right, this shows the three themes of activities designed to achieve network objectives and the key actors to whom these activities are relevant. It then identifies the outputs and outcomes for those actors resulting from engagement with the activities, outcomes for intermediate actors (who are not shown) and the impact ultimately desired. Arrows highlight the spheres of control, influence and interest for implementors of the Theory of Change (‘ECRs’: early career researchers; ‘VBPV’: vector-borne plant virus; ‘NARS’: National Agricultural Research System).

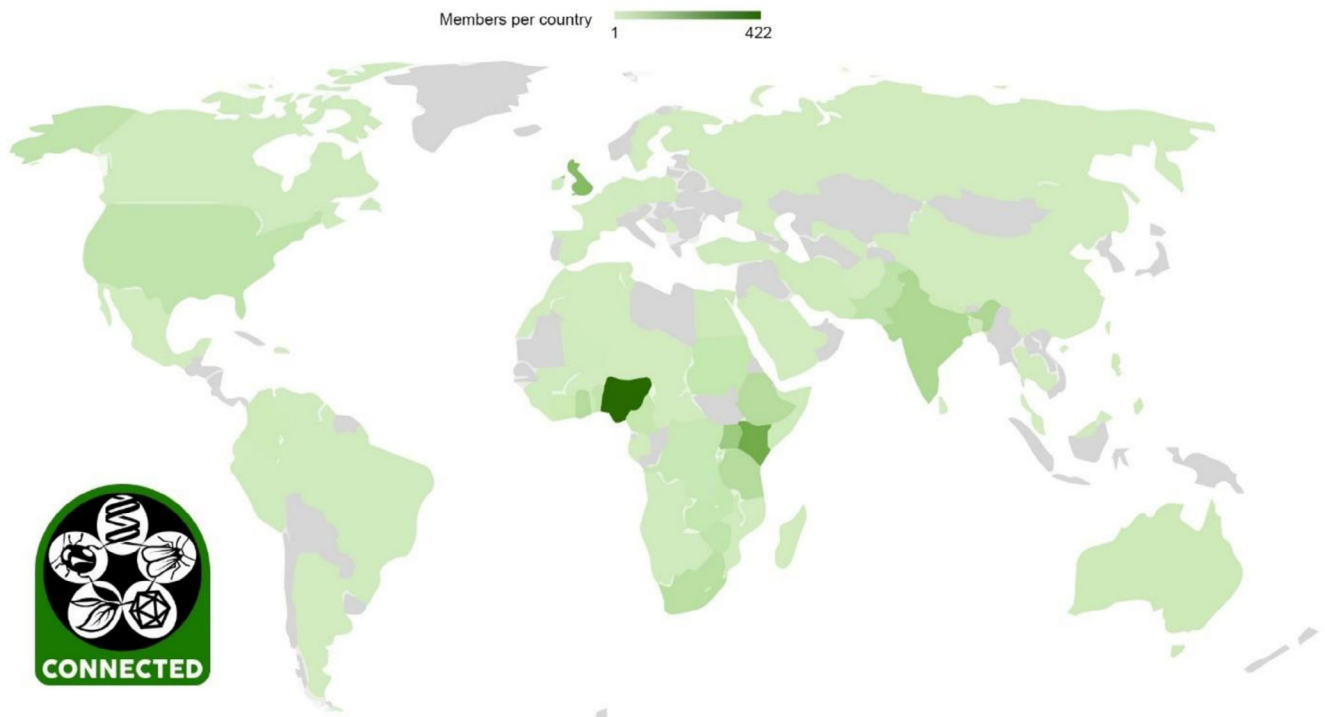


FIGURE 2 Global membership of the CONNECTED Network (derived from a network membership data export in March 2023).

from across the agricultural impact value chain, including research organisations and higher education institutions, industrial/commercial organisations, public and voluntary sector organisations and others (including media organisations, think tanks and consultants).

3.2 | The CONNECTED Network activities programme

The network programme comprised networking opportunities, pump-priming of new international collaborative research and training opportunities. The initial timeline of the grant set the sequence as follows: Initial networking opportunities had to precede PPF opportunities to enable collaborative connections to form and to identify research community needs for targeted capacity building. PPF projects had to have clear end points to enable completion within the original end dates of the CONNECTED grant and impact harvesting; additional value-adding activities (communications, resource provision) could run in parallel.

Initial outreach and engagement activities focused on accruing new membership in target sectors, bringing the early membership together for two in-person launch conferences, the first in the UK, the second in Uganda. These initial in-person meetings captured information concerning the needs of the research community (such as training in grant writing and laboratory techniques) and co-produced research priorities that were communicated to the entire network membership and around which the ensuing programme of activities was designed. These meetings also surfaced important regional differences in how research findings reach end users (farmers and growers) in Africa: In some cases, researchers may communicate directly with farmers and extension services, or only to extension services that then share it with end users. In other cases, research findings are first shared with policymakers, then extension services and then end users. The programme of network activities is outlined in Table 2. These include PPF funding calls and research project delivery; in-person and online conferences, workshops, research/special interest seminars and training courses; and training grant schemes (for attending third-party training courses or conducting educational visits to other research groups), a hybrid training offering co-creation event and a publication mentoring programme. Interdisciplinary training offerings arose as deeper Africa-facing partnerships developed through the Management Board and were supported by the acquisition of Supplementary quality-related GCRF funding from within the University of Bristol. Responsiveness and adaptability to funding opportunities and constraints, plus seeking updated community needs enabled many activities to be pivoted onto widely accessible online platforms, increasing accessibility and reach.

Network activities were supplemented by the provision of digital resources via the project website, which included infographics and seminar recordings. The latter were made possible by the adoption of accessible virtual meeting platforms, primarily Zoom, which generated recordings that were adapted into lasting resources accessible to members via the website. The Network Team also provided member-

only services such as 'matchmaking' members by research interests to support future collaboration. The CONNECTED website provided a virtual space/hub of information, resource and service provision via a news blog, and access-restricted member-only resources, including training materials, a membership directory and other useful support resources for VBPV research. The backbone of communications campaigns was a monthly e-newsletter providing news, information, resources and opportunities for members to connect, alongside a Twitter(X) channel and Facebook page which shared network resources and opportunities, relevant research-related online content and connected members with other relevant accounts of individuals or organisations.

3.3 | Networking opportunities

To promote networking between members, the CONNECTED programme integrated a variety of networking opportunities within conferences, training courses and seminars (Table 2). All events aimed to support the formation of connections between members by reducing barriers to engagement and enabling participants to develop and strengthen connections. Events also aimed to provide lasting awareness-raising and community support resources, including informative videos, interviews and seminar recordings, which were made available via the website.

All in-person and online conferences comprised talks, networking sessions and facilitated workshops, providing opportunities for participants to interact, become familiar with each other's research and form collaborative connections. All events aimed to coax fun, relaxed and respectful professional atmospheres to promote inclusivity and reduce power imbalances, engendering a 'level playing field' for participants of different career stages and backgrounds to facilitate collaborative connections. At conferences, this was enabled by participants giving short 'flash' presentations, and the Network Team pre-determined participant groupings for workshops. This ethos was replicated across all online communications via social media and e-newsletter campaigns. The Network Team also arranged most delegates' travel and hotel accommodations, providing expenses to cover additional costs to enable equitable participation, reducing financial and administrative barriers. Conference programmes were designed to capture insight into the community's needs that subsequently informed capacity-building activities. When in-person, CONNECTED's training courses included group meals to promote the formation of collaborative connections. Seminars and other short events similarly provided additional time for networking, encouraging chatting amongst members to build new or strengthen/reaffirm existing connections. The increasing participation in CONNECTED conferences, consistent seminar attendance and high demand for training awards (Table 2) illustrate the success in engaging and connecting members through CONNECTED's networking activities.

Analysis of interviews with members indicated that the network represented a space that members could forge and deepen connections and that the in-person conferences were generally considered as spaces of meeting. For ECRs, the network enabled building

TABLE 2 Gantt chart of CONNECTED Network activities with attendance information.

Activity	Type	Participation information	2018	2019	2020	2021	2022	2023
UK launch conference	In-person event	60 delegates	█					
Uganda launch conference, including grant writing and project management workshops for ECRs	In-person event	55 delegates (grant writing workshop: 27)	█					
Pump prime funding (PPF) call 1	In-person/online activity	101 applicants (average 3.7 per EoI)	█					
Pump prime funding (PPF) call 2	In-person/online activity	134 applicants (average 3.8 per EoI)		█				
PPF 1 projects	Collaborative projects	9 teams, 32 team members			█			
PPF2 projects	Collaborative projects	11 teams, 47 team members			█			
Training Voucher Scheme round 1	Educational visits	10 participants	█					
Training Voucher Scheme round 2	Educational visits	6 participants		█				
T19 Training Grant Scheme	Educational visits/course attendance	6 participants		█				
Introduction to Virus & Vector Diagnostics (B4A-ILRI Hub, Kenya)	In-person training course	17 delegates		█				
Introduction to Virus & Vector Diagnostics (IITA, Nigeria)	In-person training course	18 delegates		█				
Virus-Vector-Vice-Versa (V4) Training Programme	In-person training course	18 delegates		█				
Bioinformatics Course Sweden	In-person training course	4 delegates			█			
Training Grant Scheme	Educational visits/course attendance	6 participants			█			
Springboard to Impact Conference	Online event	253 delegates				█		
Communications Coaching	Online training course	19 delegates				█		
INEXTVIR Seminar Series	Online event	12 delegates				█		
CONNECTED bimonthly Seminar Series	Online event	Approx. 40 delegates per seminar				█		
Scientific Publication Mentoring Scheme	Online activity	3 mentees					█	
Impact projects	Collaborative projects	7 teams					█	
Virus & Vector Diagnostics and Train the Trainer programme for African NARS Organisations (B4A-ILRI Hub, Kenya)	In-person training course	21 and 18 delegates, respectively					█	
Biorational Specialist Seminar Series	Online event	Approx. 20 delegates						█

Note: The gray colour is used to indicate the years in which the events in each row occurred.

professional and personal networks that supported career progression, researcher collaboration and research impact and dissemination. Being a member enabled ECRs to gain access to relevant research they could not otherwise access and provided a space to receive vital training. As one participant, a PhD student based in Kenya exemplified when asked 'Can you tell me about your interactions with CONNECTED', they explained that by attending the virtual conferences: 'I've benefited by getting information that I could not [have otherwise accessed], [attending the conferences has improved] the way I do my work and my PhD objectives'.

3.4 | New pump-primed research projects

CONNECTED ran two PPF calls, which opened immediately following the launch conferences, enabling international teams to bid for small awards (£30,000–£90,000). The previous experience of Management Board members indicated that sums of approximately £30,000 and of 1–2 years' duration are effective at generating momentum, impact and follow-on funds.

An open competitive two-stage process was used to award PPF funding: expression of interest (EOI) followed by full application. All

funding information, guidance notes and application documents were made available via the CONNECTED website. All proposed projects were required to satisfy one or more of the five vector-borne virus strategic priority areas (control strategies, vector biology, new diseases, vector/virus interactions and diagnostics/surveillance/forecasting), and all team members were required to be network members. To comply with funder requirements, applicant eligibility criteria of the first call specified that all projects had to be led by a Principal Investigator at a UK-based institution eligible to receive BBSRC funding and include at least one co-investigator from a DAC list country. In the second funding call, in response to lobbying by the collective of vector-borne disease networks funded by the same scheme, Principal Investigators based in DAC list country institutions were eligible, while a UK-based co-applicant was required as administrative lead. Both ECRs and Africa-based researchers were specifically encouraged to apply; all ECRs in leadership positions in both calls required a senior established academic as co-applicant.

The Network Team checked all proposals to ensure they complied with the guidelines. Following identification of any conflicts of interest, Network Managers assigned all applications to unconflicted Network Directors and MB members according to areas of expertise: Each application was reviewed by one Director and two MB members who decided whether to invite applicants to submit a full application. EOIs were scored according to a series of assessment criteria: relevance to CONNECTED remit and strategic priorities, ODA compliance, technical excellence, likelihood to succeed, potential for impact, timeliness and promise, value for money and delivery of staff training. Full applications received were assessed by the same Directors and MB members according to the same assessment criteria. Following initial ranking by the Network Team, final scores, ranked order and funding allocation were decided by the Network Leadership Team and MB (quorate, and accounting for conflicts of interest). The funder, BBSRC, approved the final shortlist and awards were made. While individual project cost ratios for UK: DAC-based partners differed, the final investment saw funds allocated in a 50:50 ratio.

The two phases of funding awards led to a funded portfolio of 20 strategically relevant research projects involving 55 researchers from 33 institutions across 14 countries (see Table S5 for details). While the funded projects represent operational international collaborative projects, the EOI stage was an important precursor stage to full scientific collaboration: 56 teams coalesced around priority research questions to submit project outlines as expressions of interest, the drafting of which necessitated online interactions following the in-person conferences.

Of the 20 funded PPF projects: 15 included ECRs, 15 included women, 11 included women ECRs, 15 included ECRs in leadership roles, and 11 included women ECRs in leadership roles. Eighteen of the 20 PPF project teams completed reports on the outputs and outcomes of their project (see Table S2 for an example). Data from these reports demonstrate that the projects undertook research on a wide variety of crops (African eggplant, banana, beans, butternut squash, cabbage, cassava, cocoa, cowpea, cucumber, groundnut, maize, peppers, plantain, pumpkin, quinoa, sweet potato, tobacco, tomato, watermelon and yam)

and insect vectors (aphids, beetles, cassava green mites, leafhoppers, mealybugs, red spider mites, thrips and whiteflies).

The reports also highlight the benefits the PPF schemes generated for UK–Africa collaborative research. Importantly, 16 of the collaborations between UK and Africa research organisations were new: These arose either from the bid development process or through CONNECTED events. Twelve projects developed new collaborative connections in OECD DAC-list countries directly involved in the project. Of these, the majority were with farmers. The remainder were with researchers, extension workers, technicians and policy makers/government departments. Eight projects developed new international connections in non-OECD DAC-list countries, some of which were interdisciplinary in nature: the majority were with policy makers/government departments; others included farmers, researchers, technicians and extension workers.

Supplementary uplift funding, received from UKRI after the end of the initial GCRF grant, enabled CONNECTED to support a number of the original PPF projects that were keen and able to exploit, translate and disseminate their work towards greater impact on agriculture, particularly in OECD DAC list countries ('Impact projects', Table 2). Figure 3 provides an infographic designed to communicate the work and outcomes of these projects.

The projects funded by CONNECTED were pivotal for creating links between disciplines and research topics within the network, enabling members to form productive collaborative relationships that accessed, integrated and implemented new knowledge and skills, often bridging plant pathology and entomology. This was clearly exemplified by one participant, an ECR based in South Africa. In response to being asked about how CONNECTED enabled them to share their work, they explained that *'through the PPF the work that I was doing got more exposure and through those interactions I got ideas on stuff that I could do. So, the guys helped through those interactions via the people that I met so that has helped my research'*. The PPF was pivotal for this participant to access other experts in their field to get feedback and disseminate the work they were doing.

A main aim of the PPF projects was to build skills capacities for individual members and institutions alike. All project teams reported enhancing existing skills by being involved in the PPF projects. These included grant writing, communications/presentations, data analysis, project management, specific lab techniques and field sampling techniques. Teams also acquired new skills, including lab techniques, grant writing, project management and fieldwork. New skills were then commonly shared with others. Five projects used new and enhanced skills to develop new projects. One interviewee highlights a particular new research skill that was valuable: *'I was able to learn CRISPR-Cas gene-editing from his lab which is a cutting edge technique which presents a unique opportunity for developing a virus resistance so it has been quite valuable'*. Skills enhancement, new skills acquisition and skills sharing occurred primarily for/by the project Co-Is. As these were mostly Africa-based researchers, this illustrates an important mechanism of VBPV research capacity enhancement by CONNECTED's PPF schemes. Six respondents received more responsibility and/or were promoted as a result of PPF project participation, illustrating direct benefits to career progression.

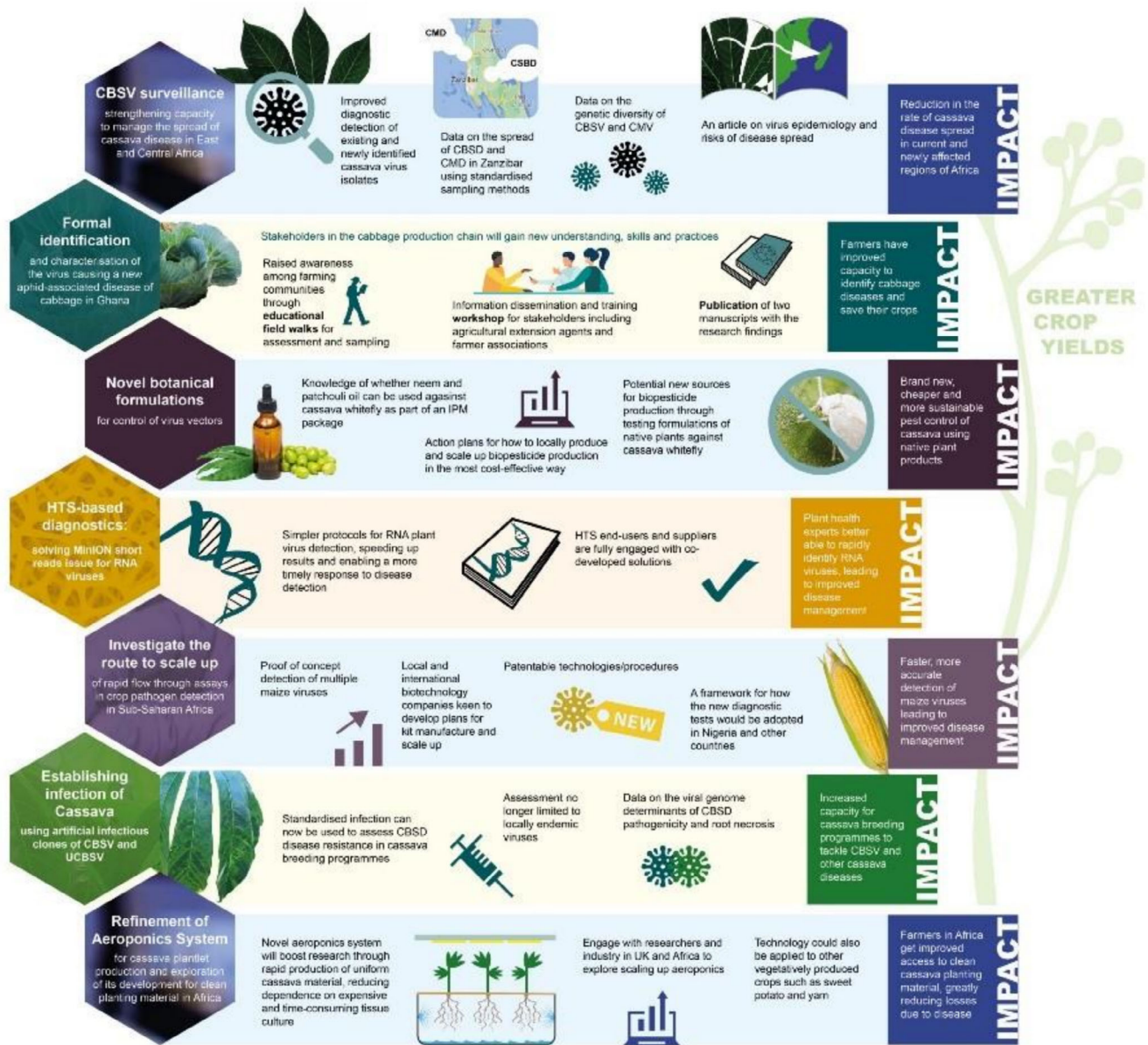


FIGURE 3 Infographic illustrating the seven CONNECTED pump prime funded projects that were taken forward into ‘impact projects’, having the greatest promise for impact delivery. The infographic outlines each project’s purpose, outcomes and projected impact (also see Table S6 for full wording and citations).

The projects led, directly and indirectly, to various academic outputs including pilot data sets, scientific presentations, reports, a policy paper and peer-reviewed publications (Academy of Scientific Research and Technology in Egypt and UK Universities Climate Network, 2022; Adenka et al., 2021; Avedi et al., 2020; Avedi et al., 2021; Carr et al., 2020; Du et al., 2020; Fening et al., 2020; Folarin & Asala, 2022; Forchibe et al., 2023; James et al., 2021; Nanyiti et al., 2023; Poon et al., 2020; Robson et al., 2024; Tembo et al., 2020; Wamonje, Donnelly, et al., 2020; Wamonje, Tungadi, et al., 2020). Four teams successfully applied for further funding, being awarded a collective total of £312,753 from varied sources (Royal Society, British Society for Plant Pathology, National

Institute of Agricultural Botany, Research England GCRF QR funding). Ten projects generated valuable VBPV capacity outcomes: seven projects generated new experimental methods and/or protocols, three generated new DNA constructs, and four projects generated new products. Notable examples include the establishment of a new (to our knowledge the first) licensed entomopathogenic fungi laboratory in Nigeria, at Wesley University. One project developed a new diagnostic protocol to detect the episomal form of badnaviruses infecting yam. Another developed a mobile phone app for improved in-field detection of maize lethal necrosis/atypical maize lethal necrosis for farmers and extension staff.

3.5 | Training

A 'community needs' workshop run during both the UK and Uganda launch conferences identified knowledge and skills areas that were priorities for the community to develop. These helped to co-design the training offerings subsequently provided during the network programme. Top priorities included career development for ECRs, lab-based insect vector and plant virus identification and diagnostic methods and skills-sharing exchanges/visits. It was also noted that offerings should be focused and, where possible, make the most of existing offerings available from third parties. As a result, CONNECTED provided access to a mix of new bespoke training courses, and grants to access existing courses or to conduct educational visits to other research groups (Table 2). ECRs were the focus of all CONNECTED training offerings, making a total of 124 training awards.

The bespoke training courses developed by CONNECTED focused on interdisciplinary skills for plant virologists and entomologists—enabling these two groups to develop sufficient knowledge and awareness of key concepts, technical terminology and methods in each other's fields to be able to productively collaborate on VBPV research projects. To maximise interdisciplinary integration and reciprocity within the research community, the Network Team sought to ensure participants of all training awards comprised a balanced mix of plant pathologists and entomologists where possible. Bespoke courses comprised plant virus and insect vector molecular identification and diagnostics (named 'Introduction to Virus and Vector Diagnostics') and an associated Train the Trainer programme, enabling delegates to deliver the training in their home institutions. Both courses were actively co-created through key partnerships between the UK-based leadership team (University of Bristol, Newcastle University working with the Natural Resources Institute, University of Greenwich) and key agricultural research institutions in Africa (the Biosciences for Africa [B4A]–International Livestock Research Institute [ILRI] Hub, Kenya, and the International Institute for Tropical Agriculture, IITA, Nigeria). Course content and training materials evolved through consecutive in-person training instances at each of these Africa-based institutions and with additional input from senior experts from African National Agricultural Research System (NARS) organisations, integrating the African agricultural context, updating priorities and needs. These partnerships were facilitated by connections to these institutions through members of the CONNECTED Management Board. Online training resources were created from these courses and made available to members via the CONNECTED website.

The Introduction to Virus and Vector Diagnostics course programme was augmented with leadership and personal development training for a two-week in-person course delivered from the University of Bristol's School of Biological Sciences (named Virus-Vector-Vice-Versa, or V4). Training content was delivered by researchers and practitioners from several national and international organisations, including Harper Adams University (UK), Fera Science Ltd (UK), University of Cambridge (UK), Natural Resources Institute (University of Greenwich, UK), Defra (UK), University of West of England (UK),

University of Bristol (UK), West African Virus Epidemiology (WAVE, Cote d'Ivoire), North Carolina State University (USA), National Crops Resources Research Institute (Uganda), Celia Knight Consulting (UK) and CABI (International). All the trainers freely gave their professional time to benefit CONNECTED members, with many contributions arising via the Management Board. This demonstrates the widespread support for the network leveraged by the Network Team and highlights the value of establishing an expert governing board (Parry et al., 2020). Reflecting on the V4 training event, one delegate reported, '*I found the hands-on experience with the latest molecular techniques in plant virology and entomology especially useful. I also gathered good communication and networking techniques, and have been using my new skills to develop new project ideas and prepare for grant applications*'.

Each year, CONNECTED offered a range of small awards for members to access existing relevant courses ('Training grants/awards') or to conduct educational visits to other groups ('Training vouchers scheme'; see Table 2 for the number of members who benefited). Members applied by submitting applications outlining their individual VBPV research career development needs and how the proposed training would satisfy these. The Network Team developed mutually beneficial relationships with key course providers to negotiate benefits (such as discounted attendance rates) for CONNECTED members. These included a residential bioinformatics course run by the Swedish University of Agricultural Sciences, SLU, and the Biology of Vector-Borne Diseases course run by Idaho University.

Further training and mentoring activities were included throughout the programme (Table 2). Grant writing workshops were provided to ECRs (by third-party providers Scriptoria). The Network Team's Communications Officer provided online training in communication skills, and all network members were encouraged to present at the regular online seminars to enhance their scientific communication skills. An online academic publication mentoring scheme was delivered, which paired senior academics with ECRs.

ECR development was also delivered through participation in the PPF projects: ECRs were supported to assume leadership positions, being eligible to apply as PI provided an appropriate senior academic mentor was included in the leadership team. One of the funded researchers was promoted and accredits this to their involvement with the PPF project: '*Yes, my participation in the CONNECTED PPF project offered me some points in terms of research collaborations, access to funding and publications. This has enabled me to have applied for promotion to the Position of Associate Professor of Entomology*'.

The value of the learning and networking experiences provided by CONNECTED training courses or training awards is demonstrated by the results of event follow-up surveys (Figure 4; see Table S1 for example survey questions). One hundred percent of delegates said they have shared the new skills/knowledge they gained with others, resulting in the new skills/knowledge being shared with between approximately 500 and 900 people. Trainees made over 470 new professional connections and strengthened more than 330 existing professional relationships. Since the training, delegates reported being in contact with these connections for varied purposes including

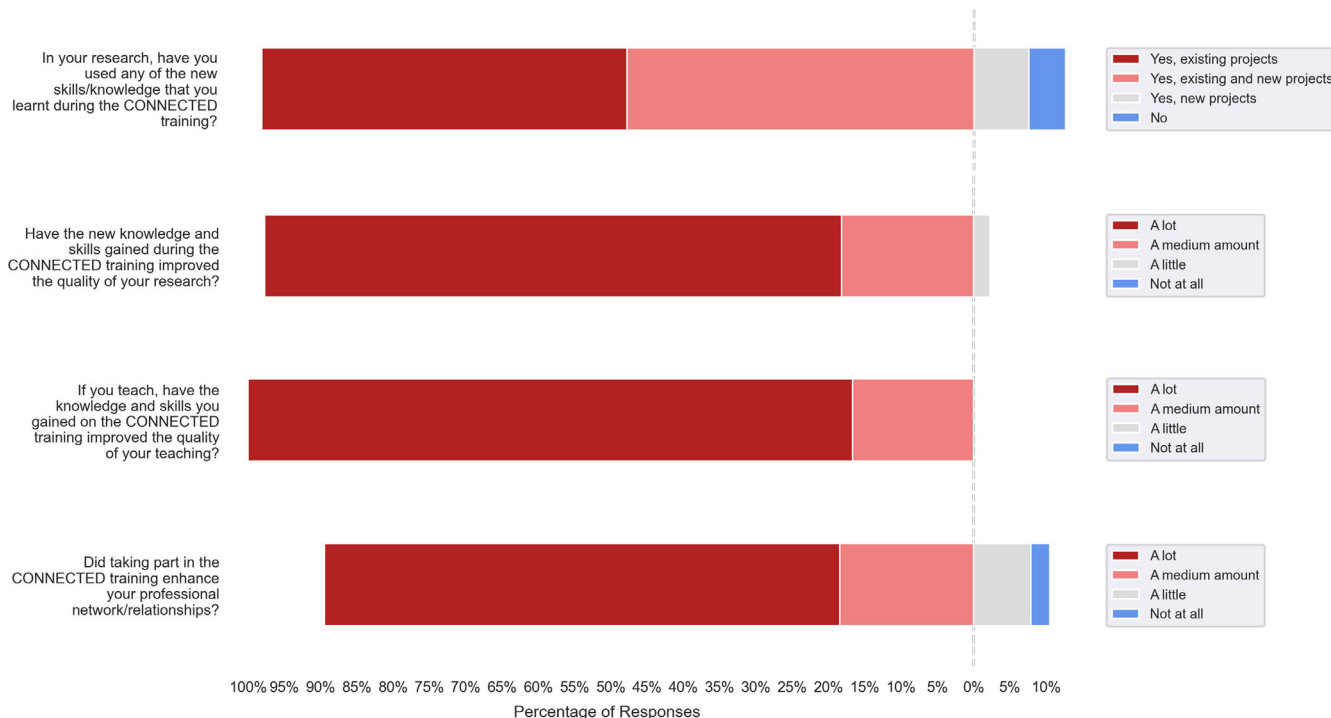


FIGURE 4 Impact of CONNECTED training courses and training awards on network member research, teaching and professional networks. Results are collated from follow-up surveys completed by delegates 6 months after the training (44 responses).

research collaborations (71%), networking events (43%) and funding applications (32%).

Interviews indicated that connections arising through education visits and courses provided pivotal new connections to form for many participants. One participant demonstrated this very explicitly as they explained, ‘It [the training] was brilliant. I made quite a number of connections. Some of the people that I connected with were also working on similar things. We subsequently tried to put a proposal together. Unfortunately, when we submitted it was not funded but at least we have made those contacts. Up until today we are still in touch so that networking was quite important which it indicated as well. It was quite interesting to learn new techniques. (...) I remember I went to dinner with some of the senior scientists and some of these people that we read in papers, they also came to Bristol at the same time and we had an opportunity to interact with them and we got some advice and some guidance. That was quite interesting. Those interactions were of value’. It is evident that the training allowed them to form connections beneficial to knowledge development, including learning about new techniques, which they were then able to adopt in their own lab. Interviews also referenced various in-person and online training events as being impactful for accessing new knowledge and developing members’ research skills.

3.6 | The CONNECTED Network website as a virtual hub for connection

The network website, social media accounts and e-newsletter provided virtual mechanisms by which members could connect and interact. The CONNECTED website (CONNECTED Network, 2017) was

visited by 26,280 people across 185 countries, with over 143,000 pageviews. This included an online resources hub for members offering a combination of signposting and downloadable web resources for members, including a membership directory, links to data-sharing tools, sequencing/genome analysis tools, animated infographics, videos and animations (see Movies S1–S3).

The Network Team issued a monthly e-newsletter to share network activity updates, relevant research and to stimulate online interaction within and between members and the team. For example, the Network Team ran an online ‘matchmaking’ service, inviting members to express interest in connecting and collaborating with other members: These short pieces were included in subsequent issues shared with members. The e-newsletter had an average open rate of 44%, indicating good engagement from its 1423 subscribers.

By the end of the UK-based hosting, the CONNECTED Twitter(X) account (@CONNECTED_Virus) had 2608 followers and the Facebook account had 783 followers. Each year, the links shared on Twitter(X) typically received 1000+ clicks and approximately 700 retweets. However, interviews cited WhatsApp as being used by the majority of event participants to facilitate connection and collaboration. For ECRs and PhD students especially, the connections formed through the PPF projects and education training visits have been developed and nurtured via WhatsApp groups. For some participants, these groups continue to act as essential spaces to share their work, ask subject-related questions, offer peer support and career development opportunities. For one participant, these WhatsApp groups enable the facilitation of connection and collaboration. As they explained when responding to the types of collaboration that have come from being involved with the network, ‘I was able to meet people

of like minds at the training and up to now we still communicate [via WhatsApp] ... some of us have collaborated but I have not collaborated with any of them. But I usually send messages to them, or I usually communicate with them whenever I need any information concerning my area. I am the editor in chief of a journal in my country so invited two of them, as members of the editorial board and they obliged me so currently they are members of the editorial board of that journal'. Although this individual does not observe inviting members onto the editorial board as collaboration, this can be seen as a productive outcome of a connection formed via the CONNECTED training and maintained via WhatsApp.

The ownership and management of CONNECTED's virtual infrastructure (website and associated resources, e-newsletter mailing list and social media accounts) were handed over to an Africa-based partnership between IITA, Nigeria and the B4A-ILRI Hub, Kenya, at the end of the UK-funded phase. This was achieved following a competitive call for applications from suitable organisations/consortia, assessing the relevance of their remit for continuing CONNECTED, proposals for the future of the network, and their commitment to supporting the basic financial requirements of the network's virtual hub. Hand-over was completed through a collaborative process with the successful team.

4 | DISCUSSION

The CONNECTED Network developed an interdisciplinary research community with global reach. The sequenced programme of networking, training and pump priming new research projects delivered substantial benefits for its members and their institutions, building capacity in VBPV research across multiple countries in Africa. Specific benefits included new skills and knowledge, new professional connections, access to mentoring, development of research leadership and career progression. The portfolio of projects pump primed by CONNECTED generated advances in strategically important topics for international VBPV research that led to further funded collaborative research. Evidence of these outcomes was provided by results from the comprehensive MLE conducted throughout the CONNECTED programme, augmented by interviews with network members, and the array of academic outputs, including peer-reviewed publications that arose directly or indirectly from the support provided by CONNECTED.

The approach used by CONNECTED demonstrates how it is possible to intentionally develop an international community with interdisciplinary expertise across the 'research with impact' value chain. This supports the transitioning from knowledge heterogeneity towards knowledge integration, which is necessary to generate interdisciplinarity and innovation (Zhang, 2023). This study adds valuable insight regarding the effectiveness and operation of collaborative research networks, particularly regarding engaging researchers in the Global South. It complements recent work illustrating the increasing diversity and equity in co-authoring that can arise from long-term collaborative networks (Baillie et al. 2021). While CONNECTED aimed to co-create

the approach taken with the Africa-based research community and redress inherent inequalities in international collaborative research, particular aspects of the network activities programme remained constrained by factors including funding terms and conditions. Future similar initiatives should actively integrate principles for transformative partnership working with LMICs (Aboderin et al., 2023).

Particularly in the field of plant science, this study corroborates observations made by, to our knowledge, the only other published study of a long-term plant-focused collaborative research network: the GARNet Network, a UK national collaborative network supporting the Arabidopsis research community (Parry et al. 2020). The evaluation of establishing and operating the CONNECTED Network is in line with Parry et al.'s experiences: factors contributing to success include establishing an advisory board for good governance, provision of designated project management, initial incentivization of community participation, engaging ECRs and securing additional funds to enable community-facing activities. The approach used by CONNECTED contributes additional insight that phasing, flexibility and responsiveness in collaborative network activities can maximise the impact on the capacity and capabilities of the field. CONNECTED's approach illustrates the effectiveness and value of combining a Theory of Change, articulating clear goals for influence and impact, with a comprehensive MLE framework established early in the project to capture and understand research community and collaborative research outcomes (Apgar et al., 2017; Millstone et al., 2010; Perrin, 2012). Together, the learning from CONNECTED is helpful for guiding the establishment, design, operation and evaluation of new collaborative research networks in other contexts.

Challenges encountered during the programme's implementation centred on the PPF projects. Presumably due to being one of the earliest GCRF funding calls, there was initial confusion from the funders regarding the amounts which should be allocated to overseas partners, resulting in a reduction in the available ringfenced budget for these projects. New due diligence requirements on HEIs caused delays in PPF awards being made and hence project commencement. The COVID-19 pandemic severely impacted the progress that could be made by the PPF projects and additionally affected the movements of some network members: the Network Team supported members-in-transit where possible with travel arrangements and information to help them reach their home countries before borders closed. Additional issues related to travel for events and training courses: lengthy delays in visa applications prevented some delegates from participating. The Network Team ensured guidance encouraged applicants to apply early, where needed. Funder criteria prevented funds being used to support students, however, it was often the case that salaried Africa-based research scientists were also studying for masters degrees and doctorates. The Network Team applied common sense approaches, ensuring employment information was clear, to prevent relevant network members from being disadvantaged by inequitable restrictions arising from differences in international research systems.

From the outset, it was the aim of the CONNECTED Network leadership to secure onward funding support for the continuation of the network. This was encouraged by the funders, and significant effort

was allocated to this, including multiple internal and external funding bids, approaching philanthropic donors, and exploring commercialisation opportunities amongst others. However, this was not possible for a range of factors, particularly including the impact of the COVID-19 pandemic on UK government funding and the subsequent ODA cuts (see UKRI ODA updates and letters, 2025). While CONNECTED's networking and training activities incorporated approaches aiming to maximise the effectiveness and sustainability of the new capacities built (Williams et al., 2023; Wisshak et al., 2025), this lack of continuity is likely to impact the research community in the longer term. Nonetheless, network development aimed to strategically embed new interdisciplinary knowledge and skills within Africa-based organisations which deliver training across the sector and internationally to increase the reach of CONNECTED's capacity building for long-term impact.

While onward funding could not be sourced to continue CONNECTED from 2023, transferring the management responsibility for it over to long-term Africa-based partners represents an important legacy benefit of the investment that had supported the network. At this point, the CONNECTED leadership team and Management Board remained keen to support the governance of the network where possible and where sought by the new hosts. It ensured that the future of CONNECTED became embedded within the continent the network intended to serve. The partnership that took this forward was led by key members of the CONNECTED Management Board who had played pivotal roles in the co-development and co-delivery of CONNECTED's novel interdisciplinary 'Introduction to Virus and Vector Diagnostics' training courses and the associated 'Train the Trainer' programme. The organisations involved (IITA, Nigeria; B4A-ILRI Hub, Kenya) exert significant influence in both supporting capacity across African NARS organisations and in international plant health research.

AUTHOR CONTRIBUTIONS

N. O. P.: co-led the design, delivery and evaluation of the CONNECTED Network activities programme as Network Co-Manager (2017–2023); conducted data collection, analysis and interpretation; wrote the majority of the manuscript; edited and prepared all materials for submission; and completed the manuscript submission process.

D. H.: co-led the design, delivery and evaluation of the CONNECTED Network activities programme as Network Co-Manager (2017–2023); conducted data collection, analysis and interpretation; wrote sections of the manuscript; and edited throughout.

A. B.: designed, conducted, analysed and interpreted the qualitative study reported in this manuscript and wrote sections of the manuscript.

H. C.: designed, delivered and evaluated CONNECTED communications strategy as CONNECTED Senior Communications Officer (2021–2023), compiled data for and created Figures 2 and 3.

H. T. H.: oversaw the completion of the qualitative study reported in this manuscript and interpreted qualitative findings in the context of the network aims, objectives and operation, edited the manuscript.

N. B.: Obtained funding to initiate the CONNECTED Network and oversaw all operational delivery of the Network and the Network Team as Co-Director from 2017 to 2022 and edited the manuscript.

G. D. F.: obtained funding to initiate the CONNECTED Network and oversaw all operational delivery of the Network and the Network Team as Director from 2017 to 2022 and edited the manuscript.

B. C.: provided interpretation of the impact of the design and delivery of CONNECTED's phased programme on network development and impact, wrote and edited sections of the manuscript.

A. M. B.: oversaw all operational delivery of the CONNECTED Network and the Network Team as Director from 2022 to 2023, oversaw completion of and edited the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflicts of interest with respect to the work conducted, authorship and/or publication of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

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