

# 1 Building capacity in vector-borne plant virus research: 2 the CONNECTED Network

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## 16 SOCIETAL IMPACT STATEMENT

17 [Andy]

18

## 19 SUMMARY

20 1. Plant viruses, often spread by insects, decimate staple and nutritious crop yields globally. This  
21 contributes to economic and food security challenges in vulnerable regions, including Sub-  
22 Saharan Africa. Interdisciplinary research is required to better understand plant virus  
23 epidemiology to protect future crop supplies, but this is often hindered by limited collaboration  
24 and knowledge exchange between plant pathology and entomology research communities.

25 Collaborative networks are a useful model for promoting collaborative and interdisciplinary  
26 research. CONNECTED, the Community Network for African Vector-Borne Plant Viruses, was a  
27 collaborative research network supported by the UK Global Challenges Research Fund.  
28 CONNECTED sought to convene international plant pathology and entomology communities  
29 through networking, pump-priming new collaborative research, and training, to increase vector-  
30 borne plant virus (VBPV) research capacity in Sub-Saharan Africa.

- 31 2. Combining analysis of CONNECTED's activities programme with qualitative methods, we identify  
32 the outcomes achieved by CONNECTED for the global VBPV community, and the value it  
33 provided to its members.
- 34 3. CONNECTED developed a multidisciplinary community of 1675 members across 97 countries.  
35 CONNECTED delivered 20 new strategically-relevant research projects involving 55 researchers  
36 from 33 institutions across 14 countries working on 11 different crops. CONNECTED trained over  
37 140 early career researchers from 23 countries in interdisciplinary VBPV techniques, providing  
38 new training materials co-created in partnership with Africa-based research organisations.
- 39 4. These outcomes demonstrate the impact of CONNECTED's phased programme of activities in  
40 building the capacity of international VBPV research communities, towards plant science and  
41 food security outcomes, which can be expanded and replicated in different contexts.

42

## 43 KEYWORDS

44 Capacity building; collaborative network; food security; insect vectors; interdisciplinarity; plant  
45 viruses.

46

## 47 INTRODUCTION

48 Global food supplies are severely jeopardised by pests and diseases. Plant viruses that are vectored  
49 by insects cause major annual crop losses: their diversity, severity and distribution are being driven  
50 by climate change, globalisation, and agricultural practices (Tatineni and Hein 2023; Bebber et al.  
51 2013; Radouane et al. 2021; Jones 2009). Vector-borne plant viruses (VBPVs) involve complex virus-  
52 plant-vector-environment interactions which complicates their epidemiology (Trebicki 2020;  
53 Lefeuvre et al. 2019). Significant gaps remain in our understanding of VBPVs, particularly how new  
54 diseases emerge, virus-vector interactions, vector biology and ecology, and methods for diagnostics,  
55 surveillance, forecasting and control (Trebicki 2020; Lefeuvre et al. 2019; BBSRC 2016). The impacts  
56 of VBPVs in economies vulnerable to the effects of natural crises, extend beyond food provision to  
57 encompass social and economic factors including rural development, poverty, and standards of  
58 living (Vurro et al. 2010; Jones and Naidu 2019) . As such, VBPV research requires multidisciplinary  
59 collaboration across scientific fields and agricultural sectors, and particularly between researchers  
60 in the Global South and North (Jones and Naidu 2019).

61 Collaborative networks are an approach to increasing research capacity in specific disciplinary and  
62 cross-disciplinary domains. Where they bridge previously separate fields, collaborative networks  
63 can lead to novel and disruptive research (Wang et al. 2023). Recent publications provide useful case  
64 studies describing successful establishment and evaluation of collaborative networks in particular  
65 subject areas (Parry et al. 2020a; Bailie et al. 2021a). This work describes the formation,  
66 development, and outcomes of an international interdisciplinary scientific collaborative network  
67 which aimed to increase capacity in VBPV research, particularly in Sub-Saharan Africa (SSA): the  
68 Community Network for African Vector-Borne Plant Viruses (CONNECTED). This UK-funded research  
69 network designed, implemented and evaluated a multi-year programme of activities, running from  
70 2017 to 2023. Here, we identify and assess the outcomes and impacts of CONNECTED's activities to  
71 (1) demonstrate the community capacity development achieved in the field of VBPV research, and  
72 (2) describe the value CONNECTED represented to its members. Together, these results provide  
73 actionable insight for designing and implementing collaborative network approaches to build plant  
74 health and agricultural research communities, particularly across disciplinary and Global  
75 South/North boundaries.

## 76 MATERIALS AND METHODS

77 The outcomes achieved by CONNECTED for the VBPV research community were extracted and  
78 compiled from impact monitoring data from the network activities programme and monitoring,  
79 learning and evaluation (MLE) records. These included spreadsheet records of participant  
80 demographic information from all events, PPF project bid information and end-of-project reports, the  
81 latter completed using a standardized report template issued to all PPF teams.

82 A qualitative study was conducted to understand CONNECTED member opinions of the network and  
83 how they formed connections and collaborations. This comprised a short survey and semi-  
84 structured interviews (Supplementary Information, Table S1). Thirty-seven members completed the  
85 survey representing various disciplinary backgrounds including plant virologists and entomologists  
86 from Burundi, Kenya, Rwanda, South Africa, Tanzania, The Democratic Republic of the Congo,  
87 Uganda, Zambia and Zimbabwe. All interviews took place virtually and were assisted via  
88 standardised interview questions. Nine interviews were undertaken with network members including  
89 academics and industry experts from Kenya, Nigeria, South Africa, The Republic of Benin, and the  
90 UK. Two of these interviews were with senior academics (Lecturer, Associate Professor or Professor)  
91 and seven with ECRs.

92 The interview data was analysed using analytic coding, a qualitative method that identifies themes  
93 and patterns by systematically categorising data (Kawulich 2017; Pratt 2023). During the first round  
94 of data analysis, open-ended codes were assigned to interview transcripts (Braun et al. 2021). This  
95 inductive approach focused on identifying themes directly from the participants' words and phrases,  
96 rather than relying on concepts derived from prior research (Friedman 2011). The initial coding  
97 identified broad themes, which were then refined into more specific subthemes through subsequent  
98 iterations of data re-analysis. This iterative process produced a detailed coding schema that not only  
99 identified key themes and subthemes but also uncovered deeper layers of subthemes within the data  
100 (Supplementary Information, Table S2).

## 101 RESULTS

### 102 The establishment and operation of the CONNECTED Network

103 CONNECTED was co-led and hosted by the University of Bristol and Newcastle University, UK, from  
104 2017 until late 2023. Funded initially by a £2M UK government Global Challenges Research Fund  
105 (GCRF) grant (2017 to 2021), CONNECTED was the only plant-focused network in a portfolio of four  
106 other vector-borne disease community networks. The funding scheme supporting this portfolio  
107 aimed to tackle vector-borne disease challenges relevant to low-and-middle-income countries.  
108 CONNECTED subsequently (2022 to 2023) receiving onward funding from UKRI and the University of  
109 Bristol's Bristol Centre for Agricultural Innovation. From this point, hosting of the network was  
110 handed over to an Africa-based partnership between the International Institute of Tropical  
111 Agriculture (IITA), Nigeria and the Biosciences for Africa (B4A) – International Livestock Research  
112 Institute (ILRI) Hub, Kenya.

113 CONNECTED worked to deliver the following objectives:

- 114 1. To build a sustainable and long-lasting network of multi-disciplinary international scientists, to  
115 address the problems created by vector-borne plant viral diseases.
- 116 2. To run a series of activities to promote and embed interdisciplinary working and to strengthen  
117 research capacity, capabilities and methodologies particularly focused on the vectors of plant  
118 disease.
- 119 3. To support collaboration between researchers in the UK and low- and middle-income countries  
120 (LMICs) and engagement with end-users, stakeholders and policy makers.
- 121 4. To capacity build, via improved communication and collaboration networks, seminars and  
122 workshops, and training courses both in the UK and Sub-Saharan Africa (SSA).
- 123 5. To use pump prime funding for a range of innovative projects identified by the Management  
124 Board of CONNECTED ultimately leading to more competitive, collaborative, cross-disciplinary  
125 and integrative research proposals, as well as real impact.
- 126 6. To develop early career researchers (ECRs), by focusing part of the pump-primed funding on  
127 proposals submitted by them, providing support to enable proposal development and delivery  
128 of projects.
- 129 7. To provide legacy benefits from the network by facilitating the opportunity for further funding for  
130 the projects bringing the greatest impact to the region.

131

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

139 The network was coordinated by a Network Team made up of an Executive group (lead academics  
140 and Network Managers), supported by a Communications Officer and Executive Assistant. The  
141 Network Team designed, implemented and evaluated the programme of activities. From the outset,  
142 network governance was overseen by a group of approximately 20 experts in plant virology,  
143 entomology, plant health and agricultural impact from across the UK and SSA (“CONNECTED  
144 Network” 2017).

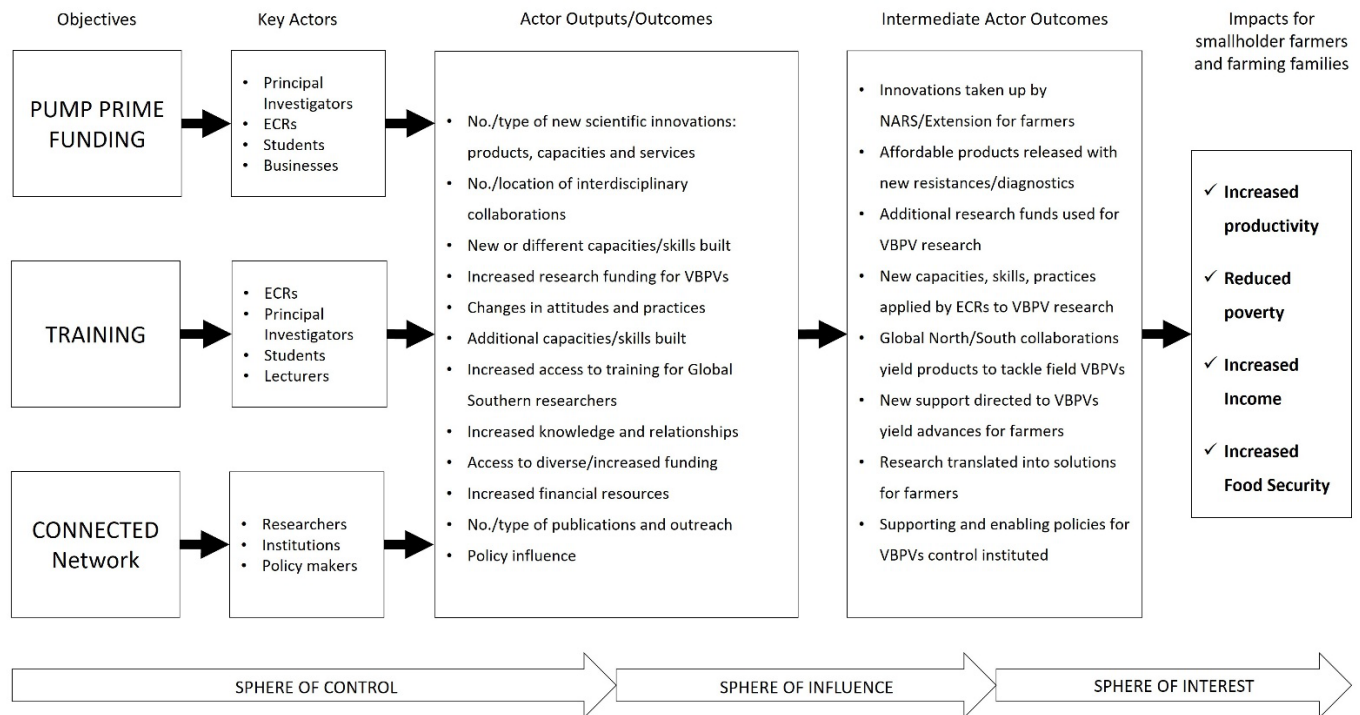
145 The CONNECTED Network began enrolling members via a website (“CONNECTED Network” 2017)  
146 from November 2017 following both a publicity campaign and targeted recruitment of existing  
147 connections: new members submitted an online form providing individual professional  
148 characteristics including country of work, institution, gender, level of experience/progression, and  
149 expertise. The initial membership emerged from strong existing connections with key academics,  
150 researchers, and stakeholders via the professional networks of the project leads.

151 Early in the project, the Network established an actor-centred linear Theory of Change approach to  
152 guide the programme of activities towards long-term impact on smallholder farming contexts in SSA  
153 via building capacity in VBPV research (Figure 1). This was enabled by expertise within the  
154 Management Board, with key elements emerging from the UK and Uganda launch conferences. The  
155 Theory of Change focused the activities of the network into three overarching themes: pump-priming  
156 new collaborative research projects, training, and networking opportunities.

157 The Theory of Change was underpinned by a monitoring, learning and evaluation (MLE) system to  
158 track progress: this used surveys, case studies, and web-based analytics to monitor event  
159 participation, learning and development outcomes, digital resource utilisation and reach. Outreach,  
160 engagement and publicity to researcher and stakeholder audiences were managed via a

161 communications strategy: project website including news blog, social media channels, monthly e-  
 162 newsletters, and bespoke internal/external relations.

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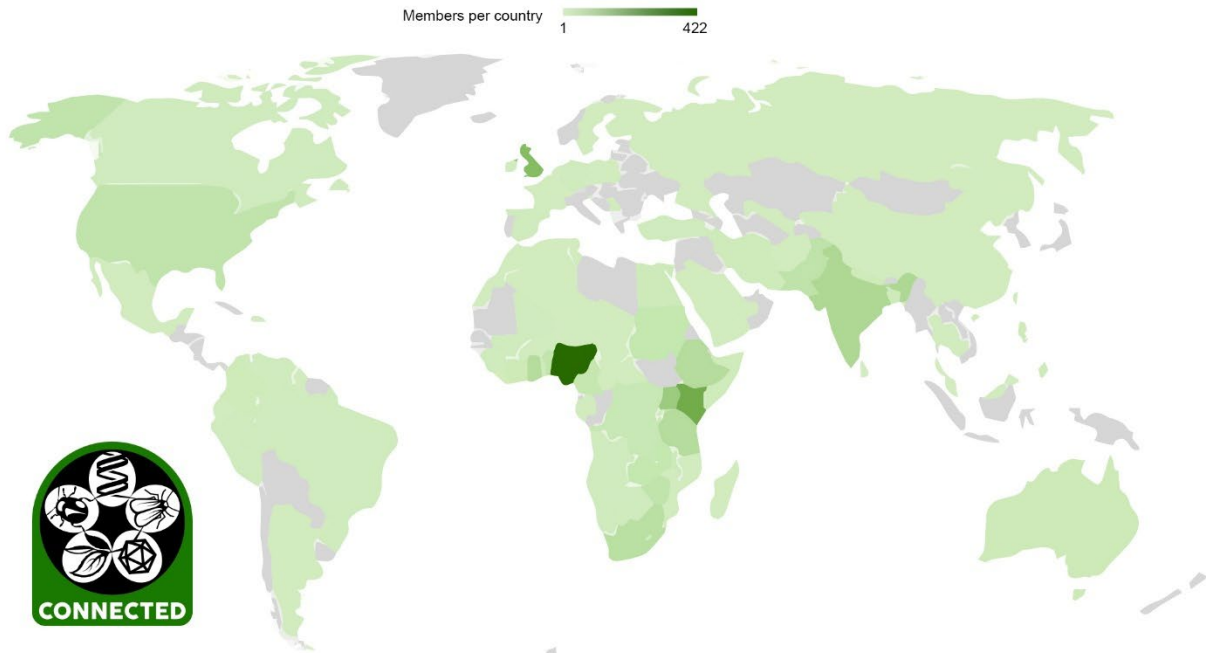
165 Figure 1: Actor-centred linear Theory of Change developed for the CONNECTED Network. From left  
 166 to right this shows the three themes of activities designed to achieve network objectives and the key  
 167 actors to whom these activities are relevant. It then identifies the outputs and outcomes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

172

173 By the conclusion of CONNECTED’s UK-based hosting, the network community comprised 1675  
 174 members across 97 countries – a truly global research community (see Figure 2). At least 79% of the  
 175 community was composed of ECRs, the vast majority of whom were based in OECD DAC-list  
 176 countries. Membership represented actors from across the agricultural impact value chain,

177 including research organisations and higher education institutions, industrial/commercial  
178 organisations, public and voluntary sector organisations, and others (including media organisations,  
179 think tanks, consultants).

180



181

182 Figure 2: Global membership of the CONNECTED Network (derived from a network membership data  
183 export in March 2023).

184

### 185 The CONNECTED Network activities programme

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

193 Initial outreach and engagement activities focused on accruing new membership in target sectors,  
194 bringing the early membership together for two in-person launch conferences, the first in the UK, the  
195 second in Uganda. These initial in-person meetings identified community needs and co-produced  
196 research priorities which were communicated to the entire network membership and around which  
197 the ensuing programme of activities was designed. These meetings also surfaced important regional  
198 differences in the routes by which research findings reach end users (farmers and growers) in SSA: in  
199 some cases, researchers may communicate directly with farmers and extension services, or only to  
200 extension services who then share it with end users. In other cases, research findings are first shared  
201 with policymakers, then extension services and then end users.

202 The ensuing programme of network activities is outlined in Table 2. These include: PPF funding calls  
203 and research project delivery; in-person and online conferences, workshops, research/special  
204 interest seminars, training courses; training grant schemes (for attending third-party training courses  
205 or conducting educational visits to other research groups), a hybrid training offering co-creation  
206 event, and a publication mentoring programme. Network activities were supplemented by provision  
207 of digital resources (e.g. infographics) and member-only services (e.g. ‘matchmaking’ research  
208 interests for future collaboration). The CONNECTED website provided a virtual space/hub of  
209 information, resource and service provision via a news blog, and access-restricted member-only  
210 resources including training materials, membership directory, and other useful support resources for  
211 VBPV research. The backbone of communications campaigns was a monthly e-newsletter providing  
212 news, information, resources and opportunities for members to connect, alongside a Twitter(X)  
213 channel and Facebook page which shared network resources and opportunities, relevant research-  
214 related online content, and connected members with other relevant accounts of individuals or  
215 organisations.

216 Various training and career development opportunities were provided for members. New  
217 interdisciplinary training offerings arose as deeper Africa-facing partnerships developed via regular  
218 discussions within the Management Board, and were supported by the acquisition of supplementary  
219 quality-related GCRF funding from within the University of Bristol. Responsiveness and adaptability  
220 to external funding opportunities and constraints, combined with seeking updated community needs  
221 enabled many events and activities to be pivoted to widely accessible online platforms. Adopting  
222 accessible virtual meeting platforms (primarily Zoom) generated recordings that were adapted into  
223 lasting resources accessible to members via the website.

224 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	32 team members						
PPF2 projects	Collaborative projects	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 members						
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						

225

226 Networking opportunities

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

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

251 Analysis of interviews with members indicated that the network represented a space that members  
252 could forge and deepen connections, and that the in-person conferences were generally considered  
253 as spaces of meeting. For ECRs, the network enabled building professional and personal networks  
254 that supported career progression, researcher collaboration, and research impact and  
255 dissemination. Being a member enabled ECRs to gain access to relevant research they could not  
256 otherwise access and provided a space to receive vital training. As one participant, a PhD student

257 based in Kenya exemplified when asked ‘*Can you tell me about your interactions with CONNECTED*’,  
258 they explained that by attending the virtual conferences: “*I’ve benefited by getting information that I*  
259 *could not [have otherwise accessed], [attending the conferences has improved] the way I do my work*  
260 *and my PhD objectives.*”

261

#### 262 New pump-primed research projects

263 CONNECTED ran two pump-prime funding (PPF) calls, which opened immediately following the  
264 launch conferences, enabling international teams to bid for small awards (£30,000-£90,000). The  
265 previous experience of Management Board members indicated that sums of approximately £30,000  
266 and of 1-2 years duration are effective at generating momentum, impact and follow on funds. These  
267 two, two-stage calls (expressions of interest followed by invited full submissions) led to a funded  
268 portfolio of 20 strategically relevant research projects involving 55 researchers from 33 institutions  
269 across 14 countries (see Supplementary Information Table S3 for details). While the funded projects  
270 represent operational international collaborative projects, the expression of interest stage was an  
271 important precursor stage to full scientific collaboration: 56 teams coalesced around priority  
272 research questions to submit project outlines as expressions of interest, the drafting of which  
273 necessitated online interactions following the in-person conferences.

274 Of the 20 funded PPF projects: 15 included ECRs, 15 included women, 11 included women ECRs, 15  
275 included ECRs in leadership roles, 11 included women ECRs in leadership roles. 18 of the 20 PPF  
276 project teams completed reports on the outputs and outcomes of their project. Data from these  
277 reports demonstrate that the projects undertook research on a wide variety of crops (African  
278 eggplant, banana, beans, butternut squash, cabbage, cassava, cocoa, cowpea, cucumber,  
279 groundnut, maize, peppers, plantain, pumpkin, quinoa, sweet potato, tobacco, tomato, watermelon,  
280 yam) and insect vectors (aphids, beetles, cassava green mites, leafhoppers, mealybugs, red spider  
281 mites, thrips, whiteflies).

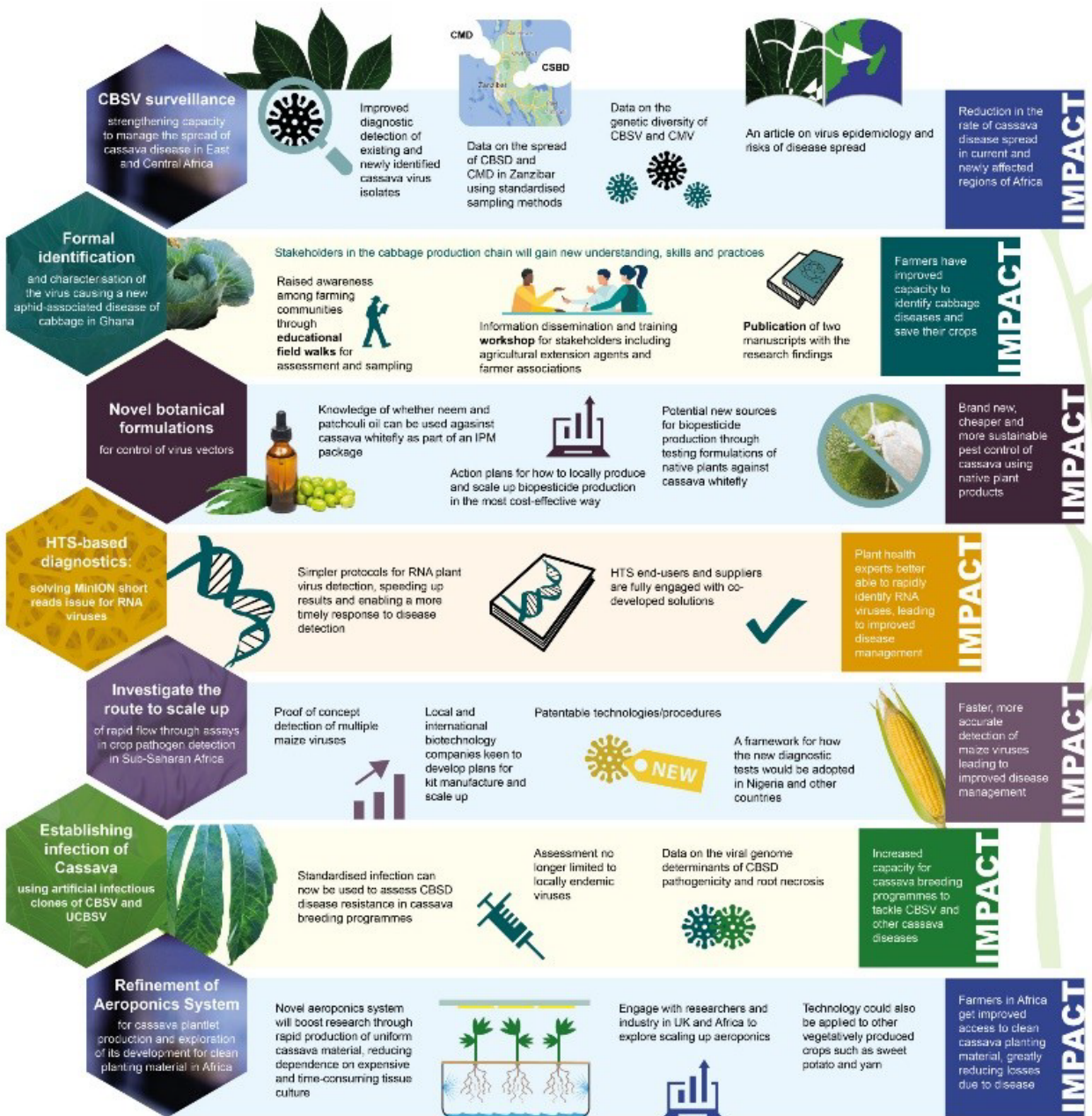
282 The reports also highlight the benefits the PPF schemes generated for UK-SSA collaborative research.  
283 Importantly, 16 of the collaborations between UK and SSA research organisations were new: these  
284 arose either from the bid development process or through CONNECTED events. 12 projects  
285 developed new collaborative connections in OECD DAC-list countries directly involved in the project.  
286 Of these, the majority were with farmers. The remainder were with researchers, extension workers,

287 technicians, and policy makers/government departments. Eight projects developed new  
288 international connections in non-OECD DAC-list countries, some of which were interdisciplinary in  
289 nature: the majority were with policy makers/government departments, others included farmers,  
290 researchers, technicians, extension workers.

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

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297



298

299 Figure 3: CONNECTED infographic describing the PPF projects that were taken forward into “impact  
300 projects”: aims, approaches and outcomes.

301

302 The projects funded by CONNECTED were pivotal for creating links between disciplines and research  
303 topics within the network, enabling members to form productive collaborative relationships that

304 accessed, integrated and implemented new knowledge and skills, often bridging plant pathology and  
305 entomology. This was clearly exemplified by one participant, an ECR based in South Africa. In  
306 response to being asked about how CONNECTED enabled them to share their work, they explained  
307 that *“through the PPF the work that I was doing got more exposure and through those interactions I*  
308 *got ideas on stuff that I could do. So, the guys helped through those interactions via the people that I*  
309 *met so that has helped my research”*. The PPF was pivotal for this participant to access other experts  
310 in their field to get feedback and disseminate the work they were doing.

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

325 The projects led, directly and indirectly, to various academic outputs including pilot data sets,  
326 scientific presentations, reports, a policy paper, and peer-reviewed publications (Fening et al. 2020;  
327 Wamonje, Tungadi, et al. 2020; Wamonje, Donnelly, et al. 2020; Forchibe et al. 2023; Poon et al. 2020;  
328 James et al. 2021; Nanyiti et al. 2023; Tembo et al. 2020; Academy of Scientific Research and  
329 Technology in Egypt and UK Universities Climate Network 2022; Robson et al. 2024; Folarin and Asala  
330 2022; Avedi et al. 2020; Du et al. 2020; Carr et al. 2020; Avedi et al. 2021; Adenka et al. 2021). Four  
331 teams successfully applied for further funding, being awarded a collective total of £312,753 from  
332 varied sources (Royal Society, British Society for Plant Pathology, National Institute of Agricultural  
333 Botany, Research England GCRF QR funding). 10 projects generated valuable VBPV capacity  
334 outcomes: seven projects generated new experimental methods and/or protocols, three generated

335 new DNA constructs, and four projects generated new products. Notable examples include the  
336 establishment of a new (to our knowledge the first) licensed entomopathogenic fungi laboratory in  
337 Nigeria, at Wesley University. One project developed a new diagnostic protocol to detect the  
338 episomal form of badnaviruses infecting yam. Another developed a mobile phone app for improved  
339 in-field detection of maize lethal necrosis/atypical maize lethal necrosis for farmers and extension  
340 staff.

341

#### 342 Training

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

352 The bespoke training courses developed by CONNECTED focused on interdisciplinary skills for plant  
353 virologists and entomologists – enabling these two groups to develop sufficient knowledge and  
354 awareness of key concepts, technical terminology and methods in each other’s field to be able to  
355 productively collaborate on VBPV research projects. To maximise interdisciplinary integration and  
356 reciprocity within the research community, the Network Team sought to ensure participants of all  
357 training awards comprised a balanced mix of plant pathologists and entomologists where possible.  
358 Bespoke courses comprised plant virus and insect vector molecular identification and diagnostics  
359 (named “Introduction to Virus and Vector Diagnostics”) and an associated Train the Trainer  
360 programme, enabling delegates to deliver the training in their home institutions. Both courses were  
361 actively co-created through key partnerships between the UK-based leadership team (University of  
362 Bristol, Newcastle University working with the Natural Resources Institute, University of Greenwich)  
363 and key agricultural research institutions in SSA (the Biosciences for Africa (B4A) – International  
364 Livestock Research Institute (ILRI) Hub, Kenya, and the International Institute for Tropical Agriculture,  
365 IITA, Nigeria). Course content and training materials evolved through consecutive in-person training

366 instances at each of these SSA-based institutions and with additional input from senior experts from  
367 African National Agricultural Research System (NARS) organisations, integrating the SSA agricultural  
368 context, updating priorities and needs. These partnerships were facilitated by connections to these  
369 institutions through members of the CONNECTED Management Board. Online training resources  
370 were created from these courses and made available to members via the CONENCTED website.

371 The Introduction to Virus and Vector Diagnostics course programme was augmented with leadership  
372 and personal development training for a two-week in-person course delivered from the University of  
373 Bristol's School of Biological Sciences (named Virus-Vector-Vice-Versa, or V4). Training content was  
374 delivered by researchers and practitioners from several national and international organisations,  
375 including Harper Adams University, Fera Science Ltd, University of Cambridge, Natural Resources  
376 Institute - University of Greenwich, Defra, University of West of England, University of Bristol, West  
377 African Virus Epidemiology (WAVE) - Cote d'Ivoire, North Carolina State University USA, National  
378 Crops Resources Research Institute - Uganda, Celia Knight Consulting, and CABI. All the trainers  
379 freely gave their professional time to benefit CONNECTED members, with many contributions arising  
380 via the Management Board. This demonstrates the widespread support for the network leveraged by  
381 the Network Team, and highlights the value of establishing an expert governing board (Parry et al.  
382 2020). Reflecting on the V4 training event, one delegate reported "*I found the hands-on experience  
383 with the latest molecular techniques in plant virology and entomology especially useful. I also  
384 gathered good communication and networking techniques, and have been using my new skills to  
385 develop new project ideas and prepare for grant applications*".

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

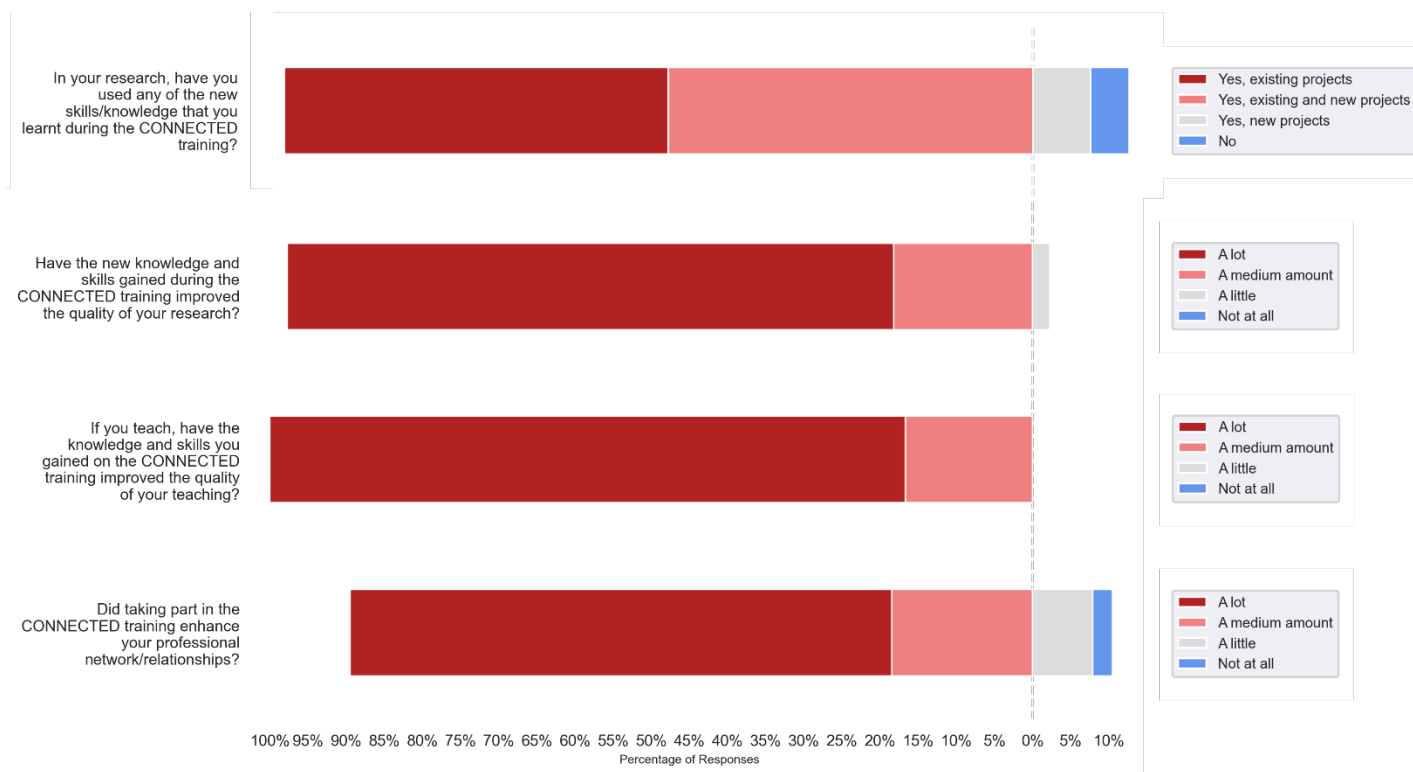
395 Further training and mentoring activities were included throughout the programme (Table 2). Grant  
396 writing workshops were provided to ECRs (by third party providers Scriptoria). The Network Team's

397 Communications Officer provided online training in communication skills and all network members  
398 were encouraged to present at the regular online seminars to enhance their scientific  
399 communication skills. An online academic publication mentoring scheme was delivered which  
400 paired senior academics with ECRs.

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

408 The value of the learning and networking experiences provided by CONNECTED training courses or  
409 training awards is demonstrated by the results of event follow-up surveys (Figure 4; see  
410 Supplementary Information Table S4 for example survey questions). 100% of delegates said they  
411 have shared the new skills/knowledge they gained with others, resulting in the new skills/knowledge  
412 being shared with between approximately 500 and 900 people. Trainees made over 470 new  
413 professional connections and strengthened more than 330 existing professional relationships. Since  
414 the training, delegates reported being in contact with these connections for varied purposes  
415 including research collaborations (71%), networking events (43%), and funding applications (32%).

416



417

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

421

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

434 referenced various in-person and online training events as being impactful for accessing new  
435 knowledge and developing members' research skills.

436

437 The CONNECTED Network website as a virtual hub for connection

438 The network website, social media accounts, and e-newsletter provided virtual mechanisms by  
439 which members could connect and interact. The CONNECTED website ("CONNECTED Network"  
440 2017) was visited by 26,280 people across 185 countries, with over 143,000 pageviews. This included  
441 an online resources hub for members offering a combination of signposting and downloadable web  
442 resources for members, including a membership directory, links to data sharing tools,  
443 sequencing/genome analysis tools, animated infographics, videos and animations (see  
444 Supplementary Information, Movies S1-S3).

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

451 By the end of the UK-based hosting, the CONNECTED Twitter(X) account (@CONNECTED\_Virus) had  
452 2608 followers and the Facebook account had 783 followers. Each year, the links shared on Twitter(X)  
453 typically received 1000+ clicks and approximately 700 retweets. However, interviews cited WhatsApp  
454 as being used by majority of event participants to facilitate connection and collaboration. For ECRs  
455 and PhD students especially, the connections formed through the PPF projects and education  
456 training visits have been developed and nurtured via WhatsApp groups. For some participants, these  
457 groups continue to act as essential spaces to share their work, ask subject-related questions, offer  
458 peer-support and career development opportunities. For one participant, these WhatsApp groups  
459 enable the facilitation of connection and collaboration. As they explained when responding to the  
460 types of collaboration that have come from being involved with the network, "*I was able to meet  
461 people of like minds at the training and up to now we still communicate [via WhatsApp]... some of us  
462 have collaborated but I have not collaborated with any of them. But I usually send messages to them,  
463 or I usually communicate with them whenever I need any information concerning my area. I am the*

464 *editor in chief of a journal in my country so invited two of them, as members of the editorial board and*  
465 *they obliged me so currently they are members of the editorial board of that journal”.* Although this  
466 individual does not observe inviting members onto the editorial board as collaboration, this can be  
467 seen as a productive outcome of a connection formed via the CONNECTED training and maintained  
468 via WhatsApp.

469 The ownership and management of CONNECTED’s virtual infrastructure (website and associated  
470 resources, e-newsletter mailing list, social media accounts) were handed over to an Africa-based  
471 partnership between IITA, Nigeria and the B4A-ILRI Hub, Kenya at the end of the UK-funded phase.  
472 This was achieved following a competitive call for applications from suitable organisations/consortia  
473 and collaborative hand-over process.

474

## 475 DISCUSSION

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

487 Transferring the management responsibility of CONNECTED over to long-term Africa-based partners  
488 represents an important legacy benefit of the investment that supported the network. It ensured that  
489 the future of CONNECTED became embedded within the continent the network intended to serve.  
490 The partnership that took this forward was led by key members of the CONNECTED Management  
491 Board who had played pivotal roles in the co-development and co-delivery of CONNECTED’s novel  
492 interdisciplinary ‘Introduction to Virus and Vector Diagnostics’ training courses and the associated  
493 ‘Train the Trainer’ programme. The organisations involved (IITA, Nigeria; B4A-ILRI Hub, Kenya) exert

494 significant influence in both supporting capacity across African National Agricultural Research  
495 System (NARS) organisations and in international plant health research.

496 The approach used by CONNECTED demonstrates how it is possible to intentionally develop an  
497 international community with interdisciplinary expertise across the ‘research with impact’ value  
498 chain. This supports the transitioning from knowledge heterogeneity towards knowledge integration  
499 which is necessary to generate interdisciplinarity and innovation (Zhang 2023). This study adds  
500 valuable insight regarding the effectiveness and operation of collaborative research networks,  
501 particularly regarding engaging researchers in the Global South. It complements recent work  
502 illustrating the increasing diversity and equity in co-authoring that can arise from long-term  
503 collaborative networks (Bailie et al. 2021). While CONNECTED aimed to co-create the approach  
504 taken with the Africa-based research community and redress inherent inequalities in international  
505 collaborative research, particular aspects of the network activities programme remained  
506 constrained by factors including funding terms and conditions. Future similar initiatives should  
507 actively integrate principles for transformative partnership working with LMICs (Aboderin et al. 2023).

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

524

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536

## 537 AUTHOR CONTRIBUTIONS

538 NOP: Co-led the design, delivery and evaluation of the CONNECTED Network activities  
539 programme as Network Co-Manager (2017-2023), conducted data collection, analysis, and  
540 interpretation, wrote the majority of the manuscript, edited and prepared all materials for  
541 submission, and completed the manuscript submission process.

542 DH: Co-led the design, delivery and evaluation of the CONNECTED Network activities  
543 programme as Network Co-Manager (2017-2023), conducted data collection, analysis, and  
544 interpretation, wrote sections of the manuscript, and edited throughout.

545 AB: Designed, conducted, analysed and interpreted the qualitative study reported in this  
546 manuscript, and wrote sections of the manuscript.

547 HTH: Oversaw the completion of the qualitative study reported in this manuscript, and  
548 interpreted qualitative findings in the context of the Network aims, objectives and operation,  
549 edited the manuscript.

550 NB: Obtained funding to initiate the CONNECTED Network and oversaw all operational  
551 delivery of the Network and the Network Team as Co-Director from 2017 to 2022, edited the  
552 manuscript.

553 GF: Obtained funding to initiate the CONNECTED Network and oversaw all operational  
554 delivery of the Network and the Network Team as Director from 2017 to 2022, edited the  
555 manuscript.

556 BC: Provided interpretation of the impact of the design and delivery CONNECTED's phased  
557 programme on network development and impact, wrote and edited sections of the  
558 manuscript.

559 AMB: Oversaw all operational delivery of the CONNECTED Network and the Network Team  
560 as Director from 2022 to 2023, oversaw completion of and edited the manuscript.

561

## 562 DATA AVAILABILITY STATEMENT

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

565

## 566 CONFLICT OF INTEREST STATEMENT

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

569

570 REFERENCES

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