UGANDA

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Abstract

The Cassava Diagnostics Project (CDP), 2008–2018, was implemented in Uganda through the National Crop Resources Research Institute (NaCRRI). A number of objectives were set, and the milestones prescribed were achieved. To meet our aim of assessing the prevalence of Cassava mosaic disease (CMD), Cassava brown streak disease (CBSD) and whiteflies, we surveyed 1320 cassava fields in 20 districts across the country. We collected 12,000 CBSD virus samples, 2880 CMD virus samples and 288 vials of *Bemisia tabaci* isolates – each vial containing approximately 50 isolates. These were used for molecular analysis with the aim of detecting the virus and whitefly species that occur in Uganda.

Analysis of the field data showed an increase in CMD incidence (18.2–32.5%), a slight decline in CBSD incidence (34–24%) and an increase in *B. tabaci* abundance (8.4–21 per plant). The survey results of 2017 showed that CMD incidence was highest in the western region (45.1%) and lowest in the north (26.3%). The CBSD incidence was highest in the central region (27.6%) and lowest in the western region (16.9%). These trends were observed throughout the project period.

Our characterization of viruses and vectors did not reveal any new species in Uganda. We found two cassava mosaic begomovirus (CMB) species: *African cassava mosaic virus* (ACMV) and *East African cassava mosaic virus* (EACMV). The predominant species among these was ACMV (80.9% of samples) and EACMV was present in 19.1%. Among the cassava brown streak viruses (CBSVs) detected, *Cassava brown streak virus* (CBSV) was more prevalent (50.8%) than *Ugandan cassava brown streak virus* (UCBSV) (49.2%). Full genome analysis of the CBSVs showed that CBSV was more variable than UCBSV. It had more positively-selected sites and was evolving five times faster than UCBSV. Seven species of *B. tabaci* were detected, among which SSA1-SG1 (66.3%) was dominant and widely distributed in the country. No new insect vector was identified among the suspect insects studied for potential transmission of CBSVs and CMBs.

Outreach activities to support conventional breeding efforts facilitated the release of two new varieties, NAROCASS1 and NAROCASS2, and the promotion of 374 clones to the next breeding levels. Twenty-five demonstration gardens were established, where 518 farmers were trained. In addition, 160 bags (80,000 mini-stem cuttings) of improved cassava planting materials sufficient to plant 20 ha were produced and distributed to farmers. Over 19,000 copies of various CMD and CBSD awareness materials were distributed to farmers and stakeholders at various fora within the country. In total, 112 extension workers and 419 students were trained on various aspects of the cassava value chain.

Seven project staff participated in five international and national fora, during which project results were disseminated.

The project aimed at strengthening Ugandan scientists, extension workers and farmers to conduct cassava disease surveillance and diagnostics. The CDP project enhanced the existing infrastructure of NaCRRI by constructing one screenhouse used for experiments – a facility which is being shared by other projects. Project staff attended five training visits and 12 meetings. The CDP team also hosted scientists from partner countries who came to monitor project progress and for consultation. As part of CDP, we also provided training to postgraduate students during their studies.

Acronyms and abbreviations

5CP	Cassava Varieties and Clean Seed to Combat CBSD and CMD Project
A2N	Africa 2000 Network Uganda Limited
ACMV	*African cassava mosaic virus*
BUCADEF	Buganda Cultural and Development Foundation
CBB	Cassava bacterial blight
CBSD	Cassava brown streak disease
CBSV	*Cassava brown streak virus*
CDP	Cassava Diagnostics Project
CMD	Cassava mosaic disease
CMB	Cassava mosaic begomovirus
EACMV	*East African cassava mosaic virus*
MAP	Months after planting
mtCOI	*Mitochondria cytochrome oxidase* gene
NaCRRI	National Crop Resources Research Institute
TARI	Tanzania Agricultural Research Institute
UCBSV	*Uganda cassava brown streak virus*
UNFFE	Uganda National Farmers Federation
UWA	University of Western Australia
WAVE	West African Virus Epidemiology project

Results summary: Uganda

Aim I: Understand the threat from evolving viruses and vectors	
Objective 1: Disease epidemiology	
Disease and whitefly prevalence surveys conducted	• Three surveys were conducted in 2013, 2015 and 2017 in which 400 cassava fields were surveyed in each year. • Mean Cassava mosaic disease (CMD) incidence (%) and severity were: 18.2 & 2.7, 21.6 & 2.6 and 32.5 & 2.8 in 2013, 2015 and 2017, respectively. • Mean Cassava brown streak disease (CBSD) incidence (%) and severity were 34.0 & 2.2, 21.0 & 2.4 and 24.0 & 2.4 in 2013, 2015 and 2017, respectively. • Mean whitefly populations/field during survey years were 8.4, 34 and 21 in 2013, 2015 and 2017, respectively.
Objective 2: Characterization of emerging viruses	
Cassava virus isolates in the project countries sequenced and analyzed	• Cassava brown streak virus (CBSV) isolates (50) were deep sequenced at Biosciences eastern and central Africa Research Institute, Nairobi, Kenya and the sequences analyzed at the University of Western Australia (UWA). • Three CBSV full genome sequences were published in Alicai et al. (2016).
Cassava virus distribution maps for partner countries, generated (incidence, severity, whitefly, viruses, sat)	• From the surveys conducted in 2009, 2013, 2015 and 2017, 27 different maps were produced. These included CMD and CBSD incidence maps (six), CMD and CBSD severity maps (six), CMD and CBSD prevalence maps (two), CMD infection type maps (three), whitefly abundance maps (four) and CMD and CBSD virus distribution maps (six).
Objective 3: Characterization of disease vectors	
Whiteflies characterized	• Sixty-four consensus sequences of *mitochondria cytochrome oxidase* (*mtCOI*) gene sequences were generated from the Uganda isolates. From these, seven species of whitefly (*Bemisia tabaci*) were identified and two papers published in 2012 and 2018. • Whitefly *mtCOI* data published in two papers by Mugerwa et al. (2012, 2018).
Potential insect vectors of CBSVs identified	• Seventy-three isolates (10 species) of insects screened for CBSVs and Cassava mosaic begomoviruses (CMBs). • None of the insect species confirmed with CBSVs or CMBs.

Aim II: Support clean seed systems for farmers	
Objective 6: Conventional breeding support	
Breeders' material monitored for disease and indexed for virus (CMBs and CBSVs) load at 3, 6, 9 and 12 MAP	• Out of the 675 genotypes tested, 607 had no CMD and were promoted for CMD management. • There were 248 genotypes with no CBSD and these were promoted for CBSD management. Virus loads were not determined.
Farmers trained on CMD and CBSD disease symptom recognition and management strategies	• There were 1034 farmers (547 females and 487 males) trained in the demonstration sites, agricultural shows and during 2013, 2015 and 2017 disease surveillance surveys and/or in workshops.
Demonstration plots for benefits of using virus-indexed planting materials established on-farm	• During 2014–2017, 25 demonstrations established on-farm, and persons trained totaled: farmers (905), extension workers (112) and students (419) trained at various fora across the country.
Information materials developed and disseminated	A total of 19,200 copies of dissemination materials printed in English, Luo, Luganda and Ateso languages. Of these: • 500 T-shirts on CBSD awareness printed and distributed to stakeholders • 16,700 brochures on CMD and CBSD disseminated to cassava farmers • 1500 posters on CMD and CBSD disseminated to cassava farmers • 500 copies of cassava seed manuals disseminated to stakeholders • Three project presentations made at sister research institutes and other stakeholders • During the project period, three manuscripts were published, one submitted for publication and three in preparation.
Aim III: Build sustainable regional capacity	
Objective 10: Strengthening stakeholder linkages	
Awareness on availability of diagnostic capacities created through training and different media	• Two awareness programs on the availability of diagnostics capacity and processes were produced and aired on URBAN and NBS TV in 2014 and 2016, respectively.

Objective 11: Strengthening human capacity and infrastructure	
Human capacity	
Project staff recruited	• A total of six project staff were recruited and remunerated: one Team Leader with roles of general project management; one Assistant Team Leader to assist with project management; two Research Assistants to plan, execute and supervise project activities in the field; and two Research Technicians to conduct laboratory diagnostics.
PhD and MSc trained on different aspects of cassava virus diseases	• One PhD and one MSc student trained at Greenwich University, UK, and Jomo Kenyatta University of Agriculture and Technology, respectively. Both completed in 2017.
Advanced specialized training and visits for project scientists (1-2 months) conducted	• Dr Titus Alicai visited Dr Laura Boykin at UWA for technical training on bioinformatics in December 2015 for one month.
Extension workers, crop inspectors and other stakeholders (1 week) training	• Four workshops conducted during 2014–2016. In 2014, 2015 and 2016, there were 24, 47 and 41 extension workers trained, respectively.
Infrastructure strengthening	
Greenhouses constructed/renovated	• One screenhouse completed and being used for conducting experiments that require keeping away unwanted insects or containment of wanted/introduced insects.

Background

Cassava (*Manihot esculenta* Crantz) is the second most important crop after bananas in Uganda. Some 500,000 hectares are under cassava cultivation and the most recent published information puts cassava production at 5.4 Mt, representing an average yield of 12 t/ha (FAO, 2014). The crop is grown by over 75% of households and contributes about 22% of cash income to rural farmers. The leading cassava producing areas are eastern, northern, central and western regions of the country. However, cassava production is constrained by several insect pests and diseases, the most important of which are cassava mosaic disease (CMD) and cassava brown streak disease (CBSD).

Following the severe outbreak of CMD in Uganda in the 1990s and CBSD in 2004, there have been efforts to counter their spread within the country. Cassava mosaic begomoviruses (CMBs) cause CMD, while CBSD is caused by cassava brown streak viruses (CBSVs). Both these major diseases are transmitted by the whitefly vector, *Bemisia tabaci*, and spread by widespread use of infected planting materials (Legg et al., 2015; Rey & Vanderschuren, 2017).

The epidemic of CMD associated with high abundance of *B. tabaci* reported in the 1980s in Uganda (Otim-Nape et al., 1994, 1998) has spread extensively within the country and beyond its borders, affecting other countries in the region – for example, Tanzania, Rwanda, DR Congo and South Sudan Kenya. The CMD epidemic was due to a virulent recombinant virus strain, the *East African cassava mosaic virus*-Uganda variant (EACMV-UG). In 2004, symptoms resembling CBSD were reported on cassava in central Uganda and tests on the diseased materials confirmed the presence of CBSD caused by CBSV (Alicai et al., 2007). Since then, CBSD has continued to spread widely in the country and our studies have shown that its prevalence in the country is at >90%, although incidence remains low.

As part of efforts to mitigate their effects and to guide control intervention, surveys have been conducted annually to monitor changes in the incidence, severity and spread of these major diseases and pests. Additional efforts during the course of the Cassava Diagnostics Project (CDP) project have included knowledge building by reaching farmers directly and through partners; working on the development and deployment of improved cassava varieties; and developing infrastructure and human resource capacity. To achieve the CDP project goals set for participating countries, studies were conducted within Uganda for eight years and were guided by the targets and milestones set by the CDP project. In this document, we report the findings, achievements and challenges of the project in Uganda during 2009–2017.

SECTION ONE: Understanding the threat from evolving viruses and vectors

Disease epidemiology in Uganda

Four pest and disease monitoring surveys were conducted in the cassava-growing regions in Uganda in 2009, 2013, 2015 and 2017. A total of 20 districts were surveyed: Apac, Lira and Pader (northern); Bugiri, Kamuli, Kaberamaido, Kumi, Mayuge, Pallisa and Soroti (eastern); Kayunga, Kiboga, Luwero, Mubende, Mukono, Nakasongola and Wakiso (central); and Hoima, Masindi and Kibaale (western) regions. During these surveys, a total of 1320 farmer fields were assessed.

The aim of the surveys was (1) to determine and map the incidence and severity of CMD, CBSD and whiteflies and (2) to determine the geographical distribution of CMBs and CBSVs and *B. tabaci* species in the surveyed areas. The survey results showed that CMD and CBSD were present in all districts surveyed, that they are still a threat in the country and that a concerted effort is needed for the effective management of these diseases and their vectors.

CMD and CBSD incidence

Overall CMD incidence was 25.7%, 18.2%, 10.6% and 25% in 2009, 2013, 2015 and 2017, respectively, indicating an increase in incidence (Figure 1). The CBSD incidence was 11.2% in 2009 and rose to 34% in 2013, reduced to 21% in 2015 and rose slightly to 24% in 2017. A rise in CMD and a reduction in CBSD incidence could be due to farmers paying more attention to CBSD, a new disease with more devastating effect than CMD.

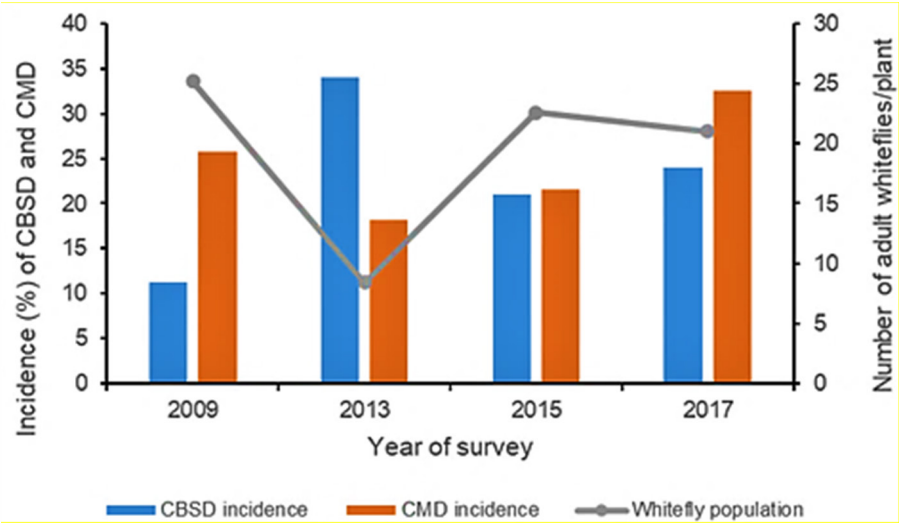

Figure 1 CMD and CBSD incidence and whitefly abundance trends, 2009–2017

CMD and CBSD severity

Symptom severity of CMD showed a slight increase from 2.2 (using a 1–5 scale, with 0 = no symptoms and 5 = very severe symptoms) in 2009 to 2.6 in 2017; however, CBSD severity was 2.4 in 2009, reduced to 2.2 in 2013, and slightly increased in 2017 to 2.4, indicating mild disease in the

surveyed years. In the four years of the survey, cutting-borne infection (52.6%) was higher than whitefly-borne infection (47.4%), showing that the disease was perpetuated mainly by infected planting materials. This was probably due to farmers' limited knowledge on how the disease spreads or due to lack of clean planting materials within communities that resulted in recycling of infected planting materials.

Whitefly abundance

Mean whitefly abundance was highest in 2009 at 25.2 adults per plant. This was lower in 2013 with 8.4 and increased in 2017 to 21.0 adults per plant (Figure 1).

Prevalence of improved cassava varieties in the surveyed areas

A number of improved cassava varieties and local varieties ('landraces') were cultivated across the surveyed areas. Overall, the prevalence of improved varieties was 68.7% in 2009, 70.0% in 2013, 62.5% in 2015 and 65.7% in 2017 giving a mean prevalence of 66.7% in the four years (Table 1). Despite the high prevalence of improved varieties, landraces were also preferred widely by farmers probably due to their good attributes and farmer preferred qualities.

Table 1 Prevalence of improved varieties 2009–2017

Year of survey	Improved variety prevalence (%)
2009	68.7
2013	70.0
2015	62.5
2017	65.7
Mean	**66.7**

Alternative hosts for CBSVs and CMBs and associated insect vectors identified

Work on alternative hosts of CBSVs and CMBs was not the mandate of CDP in Uganda; however, a survey was carried out in 2016 to collect wild plant species considered as potential virus reservoir hosts. This was a joint survey involving the CDP-Tanzania and CDP-Uganda teams, and participants from the National Crops Resources Research Institute (NaCRRI). The goal was to unravel virus diversity in reservoir plant species that may pose risks to cassava production and agriculture in general. During the survey, non-crop plants at 53 different sites were assessed for virus symptoms. A total of 235 symptomatic leaf samples were collected and taken by the CDP-Tanzania team for processing using molecular techniques.

Characterization of emerging viruses

Cassava virus isolates sequenced and analyzed

It is not known if CMBs and CBSVs have genetically changed, with possible emergence of more virulent strains. There was therefore a need for regular collection of CMD and CBSD virus samples from farmers' fields and to test them to identify the virus species present, with subsequent sequencing of the isolates in an advanced laboratory to characterize them.

During the monitoring surveys, virus samples were collected from each of the 1320 fields assessed in the country. A total of 1840 CMD and 9200 CBSD samples were collected in the four years of surveys. Representative samples were picked from each year's collection, from which DNA was extracted using a method described by Dellaporta et al. (1983), and RNA was extracted using the CTAB method (Lodhi et al. 1994). The samples were subsequently tested for the presence of CBSVs using primers, which simultaneously amplify *Uganda cassava brown streak virus* (UCBSV) and CBSV at 437 and 343 bp, respectively (Mbanzibwa et al., 2011), and CMBs by primers that amplify ACMV at 1000 bp and EACMV-UG at 1500 bp (Harrison et al., 1997). The samples that reacted positively to each of the above tests were selected and sequenced.

Detection of CMD and CBSD viruses

From the diagnostics results, there was random distribution of CMBs in the surveyed areas. The results further showed that in 2013, ACMV (70%) was the most common virus species; however, in 2015, mixed infections of ACMV and EACMV-UG2 (56%) were the most prevalent. The diagnostic results further revealed that UCBSV was the most common virus species in the country with an increase in prevalence from 48% in 2013 to 63.7% in 2015. However, this further changed in 2017 with CBSV being more predominant even on a regional basis: ACMV predominated except in the northern region where there was a shift from ACMV being predominant in 2013 to dual infection predominating in 2017. For CBSVs, there was a shift from UCBSV being the predominant virus in 2013 to CBSV predominating in 2017 (Figure 2). These results indicate a marked change from the situation in Uganda at the height of the CMD epidemic in the 1990s, when EACMV-UG2 was the most prevalent virus species/strain and had devastating effects on cassava production.

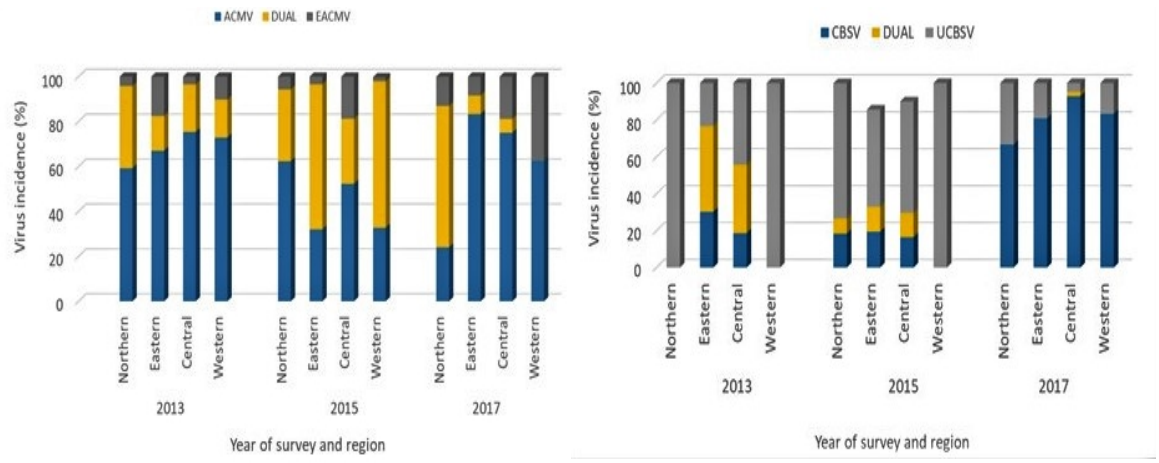

Figure 2 CMBs and CBSVs occurring in Uganda during 2013–2017

Sequence analysis of CMBs and CBSVs

From the 2013 and 2015 surveys, 133 CMB and 128 CBSV isolates were selected and sequenced at Macrogen (The Netherlands) using Sanger techniques. From these isolates, 146 CMB and 156 CBSV sequences were generated, *de novo* assembled and edited. From the edited sequences, 63 CMB and 57 CBSV consensus sequences were generated and phylogenetic trees constructed. A further 40 CMB isolates collected in 2015 were submitted for direct whole genome sequencing in South Africa in January 2016. Our CMB sequencing results revealed the presence of ACMV and EACMV-UG2. Analysis of the CBSV and UCBSV genomes showed that CBSV was more variable, had more positively-selected sites and was evolving five times faster than UCBSV (Alicai et al., 2016).

Cassava virus distribution maps for partner countries generated (incidence, severity, whitefly, viruses)

During the surveys conducted between 2009 and 2017, 26 maps from the survey results were produced and shared with Tanzania Agricultural Research Institute (TARI)–Mikocheni and partners. The various maps developed included the following: CBSD, CMD and Cassava bacterial blight (CBB) incidence maps; CBSD, CMD and CBB severity maps; CBSD and CMD prevalence maps; CMD infection types; whitefly abundance maps; CBSD and CMD virus distribution maps; and whitefly species distribution maps as shown in Figure 3 and Figure 4 below. These maps informed researchers on CBSD, CMD and whitefly hotspots. This information provided guidance on the strategic deployment of materials, especially where to test materials being developed by breeders, and where to set up seed multiplication blocks and demonstration gardens as farmer training sites.

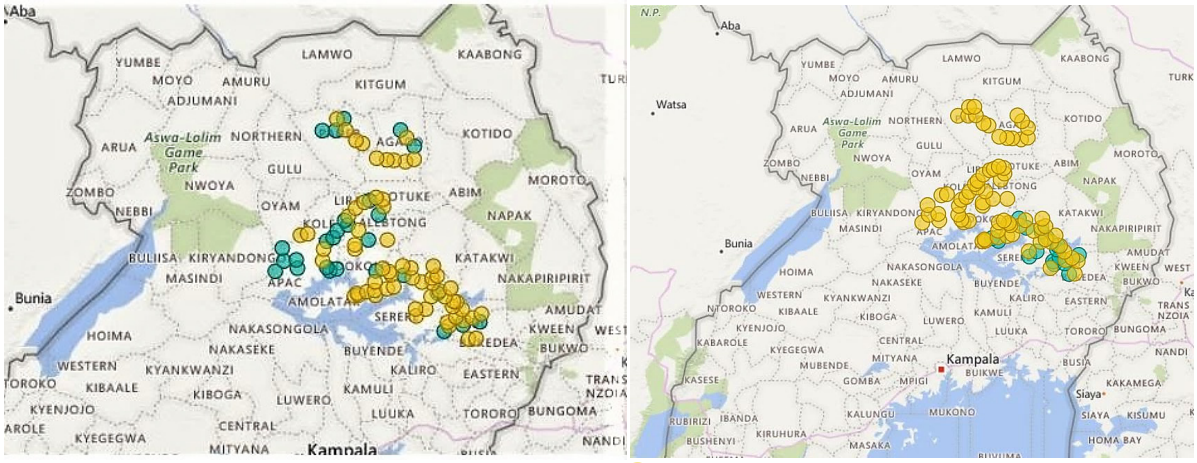

Figure 3 Disease incidence in locations surveyed in 2009 for CMD (left) and CBSD (right)

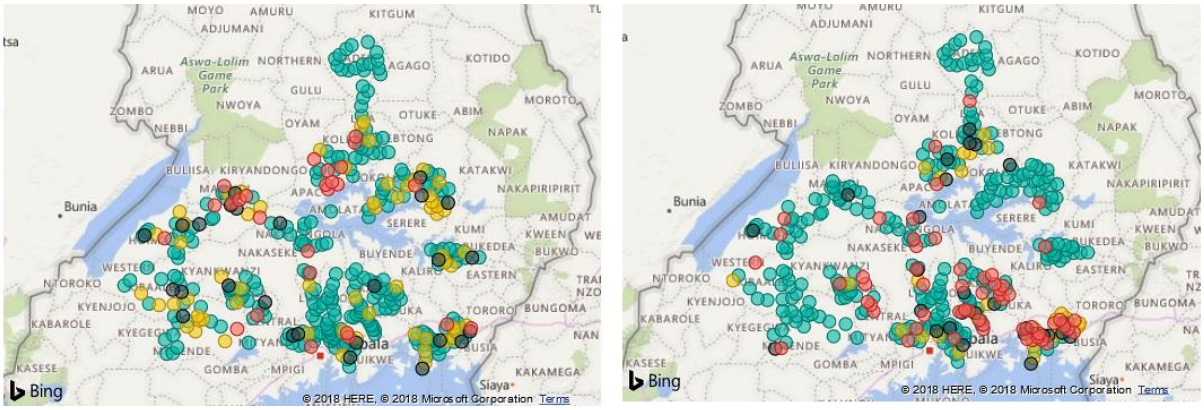

Figure 4 Disease incidence in locations surveyed in 2015 for CMD (left) and CBSD (right)

Characterization of disease vectors

Whitefly

A total of 320 vials, each containing about 50 adult (dead) whitefly samples, were collected on cassava during the surveys for characterization and determination of the genetic diversity of the mitochondrial cytochrome (*mtCOI*) gene through sequencing. The DNA was extracted from single

insects. The PCR amplification of the *mtCOI* gene fragment was achieved with the primer pair MT10/C1-J-2195 and MT12/L2-N-3014 (Simon et al., 1994) for a fragment of 850 bp. Altogether, 140 whitefly samples were sequenced by Macrogen Inc, The Netherlands, using the Sanger technique.

Sequence analysis

There were 230 sequences generated from the 140 isolates sequenced; 80 sequences were *de novo* assembled and edited. From the 80, 63 consensus sequences were generated, and one phylogenetic tree constructed. The results showed the occurrence of six *B. tabaci* species in Uganda: SSA1-SG1, SSA1-SG2, SSA2, Mediterranean, Indian Ocean and Uganda species (Table 2). The SSA1-SG1 (66.3%) was predominant on cassava; SSA2 comprised 29.4% of the species and was predominant in central and north eastern Uganda. The Mediterranean species was predominant on the weeds evaluated. One instance each of the Indian Ocean and the Ugandan species were also found on non-cassava plant species.

Table 2 Distribution of whitefly (*Bemisia tabaci*) species from the 2015 survey. '–' indicates not found

Region	Whitefly species					
	SSA1-SG1	SSA1-SG2	SSA2	Indian ocean	Mediterranean	Uganda
Northern	20.4	–	3.3	–	–	–
Eastern	20.4	–	19.6	–	–	1.0
Central	25.5	1.3	6.5	1.0	1.0	–
Western	–	–	–	–	–	–
Total	**66.3**		**29.4**	**1.0**	**1.0**	**1.0**

Potential insect vectors of CBSVs identified on cassava

The identity and diversity of other potential cassava virus vectors were studied using insect specimens collected in the major cassava-growing districts in each of the four regions of the country in 2014 and 2015. The surveys targeted and collected insects found feeding on cassava plants; which were picked and preserved in 80% ethanol.

There were 73 insect isolates collected and identified to species level by Dr Andrew Polaszek, an agricultural entomologist at the Natural History Museum in London, UK. The results from the 2014 survey showed that none of the insects collected could be virus vectors because most were generalist predators that include *B. tabaci* in their diet. The very small coccinellid beetles identified were specific whitefly predators that fed on *B. tabaci* (Table 3). In 2015, 360 vials containing different samples of insects were collected. The insects collected were grouped based on their morphological similarities.

Table 3 Insects identified and tested for potential to carry virus, 2014

Group number	Insects identified by group
1	*Camponotus* sp. (ants)
2	Coccinellidae (beetles)
3	Coccinellidae larvae
4	Tettigoniidae (bush crickets)

Group number	Insects identified by group
5	Spiders
6	Lymantriidae (caterpillars)
7	Forficulidae (earwigs)
8	*Trigona* sp.
9	Lygaeidae
10	Pentatomidae

SECTION TWO: Integrated pest management

Supporting clean seed systems for farmers

Conventional breeding support

Breeders' material monitored for disease and indexed for virus (CMBs and CBSVs)

Since the outbreak of the CMD epidemic in the country in the 1990s, and more recently the CBSD epidemic, several breeding efforts were initiated to develop resistant cassava varieties to manage the viral diseases affecting the crop. The CDP supported efforts for screening breeders' materials for cassava viruses and the virus titers. The data obtained were used together with the disease symptom assessments to guide and/or confirm resistance to viral disease.

In 2014, three breeding trials were monitored: (1) Uniform Yield Trials (UYTs) using four genotypes, (2) CBSD screening trials using 11 clones and (3) CBSD-resistance crossing block using 127 clones. In total, 324 CMD- and 1641 CBSD-symptomatic leaf samples were collected and analyzed using standard PCR protocols. The results were as follows: in the UYTs, all samples (100%) tested negative for CMD, and 57.8% of samples tested positive for CBSD viruses. In the CBSD screening trials, of the 11 clones, five (45.4%) tested negative for CBSD but all 11 (100%) tested negative for CMD viruses. In the CBSD crossing block of 217 clones, 83 (38.2%) had no visual CBSD symptoms, and 92 (42.4%) tested negative for CBSVs. From the same trial, 80 (36.9%) clones tested positive and 137 (63.1%) tested negative for CMD viruses.

From the CBSD screening trials, five clones (out of 11) were selected for multi-locational trials; from the CBSD-resistance crossing block, 85 clones were promoted to advanced seedling trial; and from the UYT trials, disease data supported the release of two genotypes, NAM130 and MM06/0130, as new varieties, named NAROCASS1 and NAROCASS2, respectively. The varieties with very low disease incidence or that tested negative to the viruses were selected for release or promotion to the next level of research.

In 2015, two genotype-by-environment (G×E) trials were monitored at two locations, where genotype performance was evaluated within a specific environment. The G×E trials under the NextGen project comprised 650 clones, while those under the Cassava Varieties and Clean Seed to Combat CBSD and CMD Project (5CP) project had 25 clones – thus, a total of 675 clones were monitored. From these trials, 94 CMD and 1308 CBSD virus isolates were collected and tested. Data from these trials showed that 607 (93%) clones exhibited no CMD symptoms and 248 (38%) exhibited no CBSD symptoms. The 248 clones without both CMD and CBSD symptoms were advanced to participatory variety selection trials for further evaluation. These are still being monitored, with promising results suggesting that they are candidates for resistance to CMD and CBSD and probable release.

Table 4 Breeders' materials monitored for disease and viruses in 2014 and 2015

Description	Number of trials monitored per year	
	2014	2015
No. of locations	4	4
No. of trials monitored	3	2
Type of trial	UYT (4 genotypes) CBSD screening trial (11 clones) CBSD resistance crossing block (127 clones)	G×E (NextGen) 654 clones G×E (5CP) 25 clones
No. of samples tested	CMBs: 324 CBSVs: 1641	CMBs: 94 CBSVs: 1308

Reaching farmers directly and through partners

Training farmers on CMD and CBSD disease symptom recognition and management strategies

It was a requirement of the project that farmers must either be reached directly or through partners such as extension workers. This was intended to increase farmers' knowledge on cassava pests and disease management as well as their access to quality planting materials to improve cassava production and productivity at the farm level.

Between 2014 and 2017, CDP-Uganda trained a total of 1034 farmers (487 male and 547 female) at five demonstration sites. The training covered good agronomic practices, pest and disease identification and management strategies, stem storage, weed management regimes, post-harvest handling and cassava value addition to prolong shelf-life of cassava and cassava products for better markets. The trained farmers are now using the acquired knowledge within their farming communities.

Table 5 Farmers trained from 2014 to 2017 – by gender

Year	Male	Female	Total
2014	28	33	61
2015	180	230	410
2016	30	15	45
2017	249	269	518
Total	**487 (47.1%)**	**547 (52.9%)**	**1034 (100%)**

Cultivating demonstration plots to underline the benefits of using virus-indexed plant material

Following the project protocol, demonstration gardens were created. In each location, improved cassava varieties were planted together with a local variety preferred by the farmers. This activity was intended to show farmers the benefit of using disease-free planting materials when establishing

their fields. These demonstration gardens also acted as farmer training centers. The CDP partners and sponsors in this endeavor included the Uganda National Farmers Federation (UNFFE), the Africa 2000 Network Uganda Ltd (A2N), OXFAM and the Buganda Cultural And Development Foundation (BUCADEF).

Between 2014 and 2017, in partnership with other stakeholders, a total of 25 demonstration plots were established in 11 districts across the country, 20 of which were harvested (Table 6). The demonstration plots were established with three improved virus-indexed cassava varieties (NAROCASS1, NASE14 and NASE19) and one farmer-preferred local variety as identified by the farmers in each location.

During the period of growth, the demonstration plots were monitored for CMD, CBSD and whiteflies at intervals of 2, 5, 8 and 12 months after planting (MAP); both researchers and farmers participated in monitoring the demonstration plots. All of the established demonstration gardens were evaluated and harvested. At harvest, the farmers were invited to participate in a 'sensory testing' exercise. This meant tasting raw and cooked cassava roots first to identify the sweet and bitter varieties and second to indicate other attributes that they may or may not have liked in a variety. This exercise was used to guide the breeders on how to improve the rejected variety.

Some 205,200 mini-stem cuttings were produced during 2014–2017 from the demonstration sites for distribution to farmers and their communities. These cuttings enabled the farming communities to plant approximately 20 ha of cassava (Table 6).

Table 6 Demonstration-plot experiments 2014–2017

Start of experiment	Number of plots created	Number of plots maintained to end of experiment	Sponsor	Partner
2014	2	2 (2015)	CDP	–
2015	4	4 (2016)	UNFFE	CDP
2015	8	8 (2016)	A2N/OXFAM	CDP
2016	6	6 (2017)	A2N/OXFAM	CDP
2016	5	Experiment not completed	CDP	BUCADEF
Total	**25**	**20**		

Figure 5 Participatory monitoring of demonstration gardens: researchers Geoffrey Okao-Okuja (fourth from left) and Lilliane Kiiza (second from right)

In the demonstration plot evaluations, NAROCASS1 performed best in terms of high yield and disease resistance, followed by NASE14. However, in Hoima, the landrace yield exceeded that of NASE14 and NASE19 (Figure 6), possibly due to the low disease pressure in the area. Generally, farmers had a very high perception of the improved varieties due to their disease resistance and high yield. They also believed that improved varieties together with the knowledge acquired would increase cassava production when they saw the yield gain resulting from improved varieties. Demonstration plots also positively changed farmers' attitudes toward growing cassava – a crop which was being abandoned by some communities due to poor yields. Yield examples from Oyam and Pader demonstration sites are shown in Figure 7.

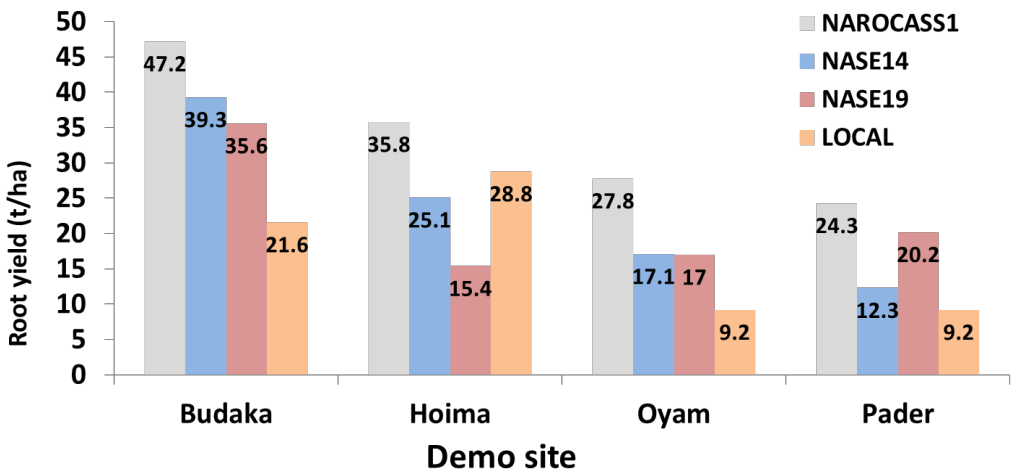

Figure 6 Yield of cassava varieties harvested from demonstration plots in 2016

Figure 7 NAROCASS1 and NASE19 yield at Oyam and Pader in 2016

Table 7 Incidence and symptom severity of CMD and CBSD in the demonstration plots, 2016. Inc = incidence; Sev = severity on a scale of 1–5 (1 = no symptoms and 5 = very severe symptoms)

Variety	Budaka		Hoima		Oyam		Pader	
	Inc (%)	Sev	Inc (%)	Sev	Inc (%)	Sev	Inc (%)	Sev
				CMD				
NAROCASS1	0	1	0	1	13.0	2.7	0	1
NASE14	0	1	0	1	0.5	2.0	0	1
NASE19	0	1	0	1	0	1	0	1
Local	86.2	2.3	0	1	73.0	3.2	52.5	3.0
				CBSD				
NAROCASS1	0	1	0	1	0	1	0	1
NASE14	1.5	2.0	0	1	0	1	0	1
NASE19	0	1	0	1	0	1	0	1
Local	2.3	2.0	0	1	0	1	0	1

Development and dissemination of information materials

Training

Eleven training sessions were carried out at demonstration sites at 2, 5, 8 and 12 MAP. Training was conducted on site selection, land preparation, selection and proper storage of planting materials, and cassava pest and disease symptom recognition and management. At harvest time, farmers were trained on post-harvest handling and management – as shown in Figure 8.

Figure 8 Mr Geoffrey Okao-Okuja training farmers in Lira 2014 (left) and in Oyam in 2015 (right)

Some 19,000 copies of various information materials – on cassava agronomy and cassava pests and disease symptom recognition and management – were developed and distributed to farmers. During the second training session at 2 MAP, a questionnaire was administered by the CDP-Uganda team and completed by farmers to assess the farmers' initial level of knowledge on cassava pests, diseases and management. A total of 681 farmers were trained, 50.8% (346) of whom were female (Table 8).

Table 8 Farmers trained in 2014–2017 by gender

Year	Male	Female	Total
2014	28	33	61
2015	180	230	410
2016	30	15	45
2017	97	68	165
Total	**335 (49.2%)**	**346 (50.8%)**	**681 (100%)**

Disease awareness

Information materials on CMD and CBSD were integral in imparting knowledge to farmers and their communities. To achieve this, 19,200 copies of several information materials were developed and disseminated to farmers and other stakeholders during 2014–2017 (Table 9). The materials included brochures, posters, seed manuals and T-shirts for the CMD and CBSD awareness campaign. The materials were printed in English, Luo, Luganda and Ateso. The themes of the awareness campaign were "Use of clean planting materials against viral diseases of cassava" and "Facts about CBSD and CMD". The materials were distributed at different fora within the country.

Table 9 Information materials developed and disseminated, 2014–2017

Year	Material type	Number of items
2014	Cassava seed quality manual	500
2014	T-shirts on CBSD awareness	500
2014	CBSD awareness brochure	15,000
2015	CBSD awareness poster	500
2016	CBSD awareness poster	500
2017	CBSD awareness poster	500
2017	CMD awareness brochure	200
2017	CBSD awareness brochure	1500
Total		**19,200**

Building sustainable regional capacity

Strengthening stakeholder linkages

Stakeholder engagement

From the start of CDP implementation in Uganda, a number of stakeholders were visited and contact maintained throughout the project. These interested parties ranged from university departments to research institutions and government departments (see Table 10).

Table 10 Partners and stakeholders visited during the impact assessment baseline study and monitoring and evaluation missions for the 'Disease diagnostics for sustainable cassava productivity in Africa' project, 2014

Institution	Location	Partnership/ Type of stakeholder	Respondent(s)	Role	Contact person(s)
National Crop Resources Research Institute (NaCRRI)	Namulonge	NARS (Project partner)	Dr Titus Alicai (Country Team Leader), Mr Geoffrey Okao Okuja (Assistant Team Leader), Ms Lillian Nanvubya (Technician), Mr Godfrey Sseremba (Research Assistant)	Hosting the project, breeding for resistance to CMD and CBSD and disease diagnostics	Dr Titus Alicai Mr Geoffrey Okao Okuja Mr Godfrey Sseremba
		Cassava Breeder	Dr Antony Pariyo	Breeding cassava for resistance to CMD and CBSD	Dr Antony Pariyo
		BMGF supported project on cassava seed systems	Dr Antony Pariyo (Project Coordinator)	Production and distribution of disease-free planting materials	Dr Anthony Pariyo
Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)	Entebbe	Government	Ms Florence Tumuboine (Assistant Commissioner)	Plant health, seed certification and regulation	Ms Florence Tumuboine
Nakasongola District Farmers Association (NADIFA)	Nakasongola	Non-governmental Organization (NGO)	Mr Joshua Ssebwato (Extension worker)	Seed multiplication and distribution	Mr Joshua Ssebwato

Institution	Location	Partnership/ Type of stakeholder	Respondent(s)	Role	Contact person(s)
Bio-Crops (U) Limited, Kampala	Kawanda	Private tissue culture laboratory	Dr David Talengera (Technical Director)	Production of disease-free planting materials using tissue culture	Dr David Talengera
Makerere University, Department of Agricultural and Environmental Sciences	Kampala	University (Collaborators)	Dr Ssetumba Mukasa, (Lecturer/ Acting Head of Department of Agricultural and Environmental Sciences), Dr Mildred Ochwo-Ssemakula (Lecturer), Dr Jeninah Karungi (Lecturer)	Training and student supervision	Dr Mildred Ssemakula
Farmer	Nakasongola	Farmer	Ms Justina Ssenku, Leader of farmer association NADIFA	Cassava production and seed multiplication	Ms Justina Ssenku

In order to strengthen stakeholders' linkages, awareness of NaCRRI's diagnostic capacity was created through television talk shows during 2014–2017. The television programs were aired on local TV stations after journalists visited NaCRRI and interviewed project scientists. The topics discussed included strategies such as selection of clean planting materials to establish new crop fields, early removal of diseased plants within established crop stands and the management of the major cassava diseases and pests prevalent in the country. They also included the diagnostic processes carried out in the molecular biology laboratory at NaCRRI. An interview on diagnostic processes was broadcast by URBAN TV on 2 July 2014, and an interview on the availability of diagnostics capacities was broadcast by NBS TV in January 2016.

During 2016–2017, NaCRRI continued to collaborate with UNFFE, A2N, Oxfam and BUCADEF to scale up farmer training, demonstration plots and the multiplication of improved and virus-tolerant or virus-resistant planting materials for viral disease management within the various communities.

Exchange visits between scientists in the CDP partner countries

In 2014, a team of scientists from TARI–Mikocheni visited Uganda to monitor project progress. In October 2016, the project team leader (Dr Titus Alicai) and his assistant (Mr Geoffrey Okao-Okuja) attended the CDP Annual General Meeting in Zambia. In December 2016, two scientists (Mr Phillip

Abidrabo and Mr Geoffrey Okao-Okuja) participated in the Data Entry and Assembly Workshop in Dar es Salaam, Tanzania.

Strengthening human capacity and infrastructure

Project staff recruited in 2013 and 2015

During the project duration, several staff were recruited to provide the project with a range of skills (Table 11).

Table 11 Staff recruitment 2013–2015

Name	Role	Year of recruitment
Titus Alicai	Team Leader	2013
Geoffrey Okao-Okuja	Assistant Team Leader	2013
Godfrey Sseremba	Research Assistant	2013
Lilliane Kiiza	Research Technician	2013
Resty Nanvubya	Research Technician	2013
Brian Kula	Accounts Assistant	2013
Phillip Abidrabo	Research Assistant	2015

Mr Godfrey Sseremba left the project to pursue PhD studies in Ghana and has now returned to work at the National Coffee Research Institute as a Research Officer.

Human capacity

Training for project staff 2013–2017

During 2013–2017, several project staff were trained on various aspects of the cassava value chain as part of the project objectives and goals. This training program included financial management, disease surveys and diagnostic techniques, bioinformatics and general project administration (Table 12).

Table 12 Project staff trained 2013 –2017

Date	Course title	Venue	Staff trained
May 2013	Financial management	Dar es Salaam, Tanzania	Brian Kula
Aug 2014	Disease surveys and diagnostics	Dar es Salaam	Lilliane Kiiza and Resty Nanvubya
Oct 2014	Bioinformatics basics	Kawanda, Uganda	Lilliane Kiiza, Resty Nanvubya and Godfrey Sseremba
Feb 2015	Biosafety	Serere, Uganda	Geoffrey Okao-Okuja
July 2015	Bioinformatics	Australia	Titus Alicai
Oct 2015	Intellectual property rights	Nairobi, Kenya	Geoffrey Okao-Okuja and Titus Alicai
Jan 2016	AgShare, scientific writing & communication	USA	Titus Alicai
Mar 2016	Mobile apps for cassava disease surveillance	NaCRRI, Uganda	Geoffrey Okao-Okuja and Phillip Abidrabo
Nov 2016	Data entry & assembly	Dar es Salaam	Geoffrey Okao-Okuja and Phillip Abidrabo
May 2017	Gender Action Learning Systems (GALS)	Lira, Uganda	Geoffrey Okao-Okuja

Training of students

In addition to project staff and government workers, the project facilities and staff at the molecular biology laboratory at NaCRRI were made available for training other stakeholders, especially students from colleges and universities in the country. During 2013–2017, students were trained for a range of academic qualifications (Diploma, Bachelors, Masters and PhD) on aspects of the cassava value chain with emphasis on molecular diagnostic processes.

A total of 419 students visited the laboratory for practical sessions of one day or longer (Table 13). In addition, in 2015, three project students were attached to the laboratory as part of their course requirement. During the student training, pest and disease symptom recognition, sample collection and storage and the laboratory detection of viruses in cassava samples were the major practical activities.

Table 13 Students trained, 2013–2017

Student category	Number of students
Diploma	16
Bachelors	346
Masters	52
PhD	5
Total	**419**

Extension staff, crop inspectors and other stakeholders (1 week) training

Agricultural extension workers, crop inspectors, district and Ministry of Agriculture staff, and Animal Industry and Fisheries staff were trained on various techniques relating to the cassava value chain. During 2013–2017, a total of 112 of these staff were trained on general cassava production including best agronomic practices, pest and disease management, cassava value-addition and laboratory diagnostic techniques. These training sessions were delivered at NaCRRI, and at Ngetta in Lira district in northern Uganda (Table 14 and Figure 9). These training courses were conducted in partnership with UNFFE and A2N.

Table 14 Extension workers and crop inspectors trained 2014–2017 by gender

Year	Venue	Country of origin	Gender		Total
			Male	Female	
2014	NaCRRI	Uganda	19	5	24
2015	NaCRRI	Uganda	38	9	47
2016	NaCRRI	Somalia	21	4	25
2016	Lira	Uganda	14	2	16
Total			**92 (82%)**	**20 (18%)**	**112 (100%)**

Figure 9 Titus Alicai (left: standing) and Geoffrey Okao-Okuja (right: third from right) at training sessions for extension workers at NaCRRI in 2015

Project staff trained on intellectual property rights, biosafety issues and communication strategies

During 2015–2017, two project staff members received training on intellectual property rights, biosafety issues and communication strategies in Uganda, the USA and in Nairobi, Kenya (Table 15).

Table 15 Staff trained on intellectual property, biosafety and communication strategies in 2015 and 2016

Date	Course title	Venue	Staff trained
Feb 2015	Biosafety	Serere, Uganda	G Okao-Okuja
Oct 2015	Intellectual property rights	Nairobi, Kenya	G Okao-Okuja and T Alicai
Jan 2016	AgShare – scientific writing and communication	USA	T Alicai

Advanced specialized training and visits for project scientists (1–2 months) conducted

Advanced specialized training was attended only by the Team Leader, Dr Titus Alicai, who received training on bioinformatics at the University of Western Australia for one month and also visited the Volcani Center, an agricultural research institute in Israel, for one week to become acquainted with laboratory diagnostic processes.

Project results and information disseminated

During 2013–2017, project staff presented project results and information nationally and internationally in various fora as indicated below.

In July and October 2015 in Jinja and Fort Portal, Kabarole district, two project staff participated in agricultural shows where they informed attendees on the availability of improved and resistant cassava varieties NAROCASS1 and NASE14. They also distributed various posters and brochures on disease awareness.

In June 2016, Titus Alicai and Phillip Abidrabo participated in a virus symposium conference in France where they presented a poster on the “Geographical and genetic diversity of cassava brown streak viruses” in Uganda.

In November 2016, three project staff participated in the NARO–Makerere University joint agricultural dissemination conference. These staff presented a paper and a poster on “CBSD virus diversity” and “Demonstration of the benefits of using virus-indexed cassava planting materials”, respectively.

Publications output from the project included work in the following disciplines: virology, entomology and molecular biology. This work was published in international journals such as Nature Scientific Reports (Alicai et al, 2016) and Systematic Entomology (Boykin et a, 2018), attesting to the quality of the science performed by the CDP-Uganda team.

From 2015 to date, project staff have participated in a monthly Root Crops Program seminar at NaCRRI and have occasionally presented information on the project results. Among the topics presented were the “Status of cassava mosaic disease, cassava brown streak disease and whitefly abundance in Uganda” and the “Genetic diversity of cassava brown streak viruses in Uganda” by Mr Geoffrey Okao-Okuja and Phillip Abidrabo, respectively.

Institute Director trained in leadership and management

In July 2014, the NaCRRI Director (Dr James Ogwang) participated in the Leadership and Management Skills training in Kigali, Rwanda.

Infrastructure strengthening

To strengthen infrastructure development, in 2014, one screenhouse was constructed at NaCRRI and is now being used. One plant growth chamber and one portable car freezer were procured. In addition, three laptop computers, one desktop computer and one printer were procured for the project and are being used by the NaCRRI community for various purposes (Table 16). Laboratory reagents and consumables were procured regularly when required.

Table 16 Inventory of infrastructure in Uganda, 2013–2017

Project item	Asset description	Serial no	Purpose	Status
1	Dell Computer OptiPlex 9010	8DN03W1	General office work	Working order
2	Dell Computer OptiPlex 9010	7JZKWX1	General office work	Working order
3	HP Envy Touch Smart 15 laptop	5CG3432XY2	General office work	Lost
4	HP Envy Touch Smart 15 laptop	5CG3433QGT	General office work	Lost
5	HP Envy Touch Smart 15 laptop	5CG3433TRD	General office work	Working order
6	HP LaserJet Printer	CNCXF7LOZP	Printing work	Working order
7	Insect Proof Screenhouse	Not available	Controlled experiments	Working order
8	Dell Computer OptiPlex 3020 MT	HF8S032	Accounts work	Working order
9	Plant Growth Chamber	AI15402701-6220V	Plant growth under controlled conditions	Working order
10	Campmaster Portable Freezer	45FYH13050126	Field sample collection, preservation and storage	Working order

SECTION THREE: Impacts, success stories and learning outcomes

Impacts

Impact area	Impact
How many students were trained by this project directly and indirectly?	419 students were trained: • 16 Diploma • 346 BSc • 52 MSc • 5 PhD.
No. of projects using the CDP facilities	Six projects at NaCRRI: • Mandi-Plus • GT4SP • African Whitefly Project • VIRCA-Plus • Double Haploid Project • ATAAS Other units at NaCRRI.
No. of students and/or staff using facilities and reagents of CDP	Twelve students and staff are using these facilities to run their experiments.
No. of people that have been inspired by the project	Some 750 people have been inspired by the project. These include most of the farmers trained, extension workers and some district leaders.
Institutional visibility	A number of tertiary institutions such as Makerere, Gulu and Nkumba Universities now apply to train their students at our facility. The National Fisheries Resources Research Institute generally use our ELISA plate reader for their work. The institute received 250 students in June 2018 from various institutes within the country as interns and volunteers. One student from Sierra Leone is being trained in molecular diagnostics. One student from Japan started an internship in July 2018. Twenty students, under the West African Virus Epidemiology project in West Africa, will come to NaCRRI in September 2018 for training on virus diagnostics and management.
Infrastructural capacity – helping student execute their project	Adequate infrastructure for studies such as efficient laboratory, research fields and a screenhouse.

	Two MSc students from Kyambogo University are doing their research at the facility with guidance from CDP staff.
New stakeholders interacting with the project	New stakeholders interacting with the project are OXFAM, A2N, UNFFE and BUCADEF.
Service the laboratory has provided	Diagnostics: 26,100 virus and vector samples Training: 422 scientist/students.
How many farmers have benefited either directly or indirectly	Some 5560 farmers have benefited. Directly: • 112 extension workers • 419 students • 681 farmers. Wider reach: Each trainee is assumed to have come from a household, and that each household comprises five people. This translates to 5560 people reached directly and indirectly by the project.
New collaborations/collaborative projects	Newly collaborated with "Cassava Applied Research for Food security in Northern Uganda" on demonstration gardens and farmer training, in which they invited us to train their farmers on the cassava value chain.
People using information generated by this project	Scientists: for cassava research work Students: for thesis write ups Policy makers: guide policy formulation Farmers: from the various information materials distributed and through training offered.
Benefits to the government – extension training, inspectors and regulators	Trained 112 extension workers and inspectors. These trainees work in various institutions such as Agricultural Research Stations and the Ministry of Agriculture across the country and their work includes guiding farmers in different communities.
Advocacy impacts on policy	The project advised the Uganda Government to put in place guidelines for certification and movement of planting materials across the country to limit the spread of CMD and CBSD.
Publications and other communications including other communication materials	Produced 19,200 communication materials and published two papers. These are being used by various communities and scientists.
Increase in crop yield and incomes (especially farmers who used clean materials)	Farmers' crop yields have increased due to knowledge gained and quality seed materials available to them for adoption.

Meetings and conferences attended – for the whole team	Three international conferences and two national meetings attended by project staff.
Support to breeders and other projects	Offered support to breeders in indexing their materials for viruses and diagnostics and this led to the release of new cassava varieties NAROCASS1 and NAROCASS2 in October 2016.
Involvement of vulnerable groups	Farmers are now selling cassava planting materials from stems obtained from the varieties grown in demonstration plots.
Change of farmers perceptions	Some members of the communities worked with vulnerable individuals such as the physically disabled, the elderly, youths, the poorly educated and those with limited access to land.
Other universities requesting to use the facilities/equipment	Farmers' perceptions of diseases in their crop changed; in particular, they saw the need to select clean planting materials and adopt new disease management strategies.
Minimizing/arresting brain drain	Most people trained by the project (i.e. staff, extension workers and crop inspectors) are working at various institutions within the country, hence contributing to the national economy and development.
Building a network of scientists	The project trained local and foreign scientists and collaborated with many local and foreign scientists. This resulted in a good network of knowledge. We continue to receive invitations to inspect private cassava farms for disease and training/guiding farmers on disease management.

Success stories

The reach of CDP in Uganda can be seen both within the country and abroad. Notable achievements are summarized below.

High profile at governmental level

NaCRRI released two varieties of cassava, one of which, NAROCASS1, is in very high demand in the country. The Uganda Government is procuring it and supplying it free to farmers under the program "Operation Wealth Creation" – a presidential initiative to create wealth through agriculture. Similarly, the Republic of Rwanda procured NAROCASS1 for distribution to its citizens.

Benefit to science and disease management

The project benefited Uganda by providing trained and qualified scientists within the country. One MSc and one PhD student were trained and have completed their studies successfully.

Trained scientists, extension workers and farmers can now deploy their knowledge and experience to work toward arresting the spread of cassava viral diseases in the country.

Benefit to farmers

The Genbadi Farmer Group was established in Pader district where a demonstration plot was set up in 2015. This group has been selling cassava planting materials to the Kitgum District Administration. This has enabled them to purchase one ox that they intend to use for plowing their land.

Most interacting farmers said they were willing to pay for disease-free planting materials because they have seen the benefits of such planting materials from colleagues within their communities.

Legacy of CDP

The long-term benefit of CDP is that farmers and other stakeholders are using the knowledge and seed materials given to them to improve production and productivity. This is shown by the increase in the area and percentage of improved cassava varieties grown by the various communities within the country.

Learning outcomes

This section summarizes events – whether advantageous or deleterious – which triggered a change from previous protocols, resulted in administrative changes or caused a task to be re-evaluated. It is intended to assist researchers at all levels when setting up or implementing similar projects in the future.

Value of project interaction with farmers

The demonstration gardens increased farmers' knowledge in general cassava production techniques with emphasis on pest and disease management to increase production and productivity. The seed multiplication plots increased farmers' access to high-quality cassava planting materials, which were lacking within the different communities.

This changed farmer practices, especially concerning the selection of planting sites, selection of good planting materials, planting time, spacing, size of stem cuttings to plant, removal of diseased plants within crop stands to remove virus inoculum source, mode of spread of the disease and farming as a business.

Value of project interaction with extension workers

The training of extension workers and crop inspectors improved the researcher–extension–farmer linkages in the country, which had previously been weakened due to lack of resources for training.

This revival enables extension workers to use their recently acquired knowledge within their communities. They can now assist farmers by inspecting fields for diseases as well as recommending sources of seed to potential buyers.

Improved knowledge of researchers on disease management

The surveys helped researchers to identify pest and disease hotspots in the country.

The knowledge has given researchers, breeders and pathologists the tools to determine where to deploy materials, where to test new varieties being developed, where to multiply seed materials and where to have farmers trained on disease management. This will assist with efforts to minimize disease spread.

Increased knowledge about the viruses and the vectors that spread cassava diseases

The characterization of viruses and disease vectors has improved researchers' knowledge on the species of viruses and pests infecting cassava in the country.

This is currently being used by researchers and students in experiments to determine the vector species that transmit particular virus species. This will guide future control interventions and the management of pests and diseases.

Refinement of procedures and protocols to aid similar tasks in future

The project improved on the techniques of sample collection, storage and analysis by developing sample collection techniques using the plant press method for CBSD laboratory materials. Samples used to be placed in ice – a method which led to the deterioration of samples prior to processing. The improved method has the advantage that researchers can maximize their time in the field for sample collection.

Importance of research collaboration

The project shared its data with valuable stakeholders locally and internationally and this has enhanced research collaborations with local and international partners – this can be seen in our collaboration with the West African Virus Epidemiology (WAVE) Project.

Enabling Uganda to assist other countries

Our experience on CDP now enables us to assist projects outside the country. For example, we are testing assorted West African cassava germplasm in our CBSD and CMD aggressive virus hotspots. This collaboration will help the WAVE regions to deal with potential outbreaks of CMD and CBSD.

Implications of our work at country level

The sharing of knowledge with collaborators enabled the Government of the Republic of Rwanda in 2016 to procure 11,000,000 pieces of cassava planting materials of varieties NAROCASS1 and NASE14 for their farmers. The variety NAROCASS1 was released as a result of giving conventional breeding support to breeders in Uganda by the project.

Forging new collaborations with NGOs

As a result of CDP, NaCRRI was approached by OXFAM, A2N and BUCADEF. NaCRRI was requested to assist with setting up farmer participatory demonstrations in their project areas to help farmers manage cassava viral diseases to increase yields.

Influencing administrative procedures at governmental level

The project's input has guided policy on the movement of cassava planting materials within the country. Plant materials are no longer allowed to move from disease hotspots to low disease pressure areas, but the reverse is possible. Moreover, materials must now have a movement permit proving that the source field was inspected by a competent authority and a certificate of quality issued.

Procurement procedures

Through their experience on CDP, researchers now know that they must plan their requirements in good time and to build in contingency to cope with delays or failure to receive materials ordered.

Effective presentation of our work in publications

Through joining the AgShare community, writing skills were improved and enabled the team to publish their work in well-regarded journals (see 'Publication of research findings'). Further manuscripts are due to be submitted for publication by the end of 2018.

Conclusions

The pest and disease surveys conducted by the NaCRRI team have determined the incidence, virus severity and whitefly species in the cassava-growing region of the country. Our studies have further shown that CMD and CBSD are the most important constraints to cassava production in Uganda.

Our work has directly benefited Uganda's cassava growers. The farmers gained knowledge on cassava production with an emphasis on pest and disease management. Additionally, they now have increased access to high-quality cassava varieties. Another important outcome is that researchers are now better informed about the hotspots of CMD and CBSD and this knowledge has guided the strategic deployment of materials by government and partner NGOs.

The high occurrence of improved varieties found in our surveys suggests that farmers have been able to obtain CMD-resistant and CBSD-tolerant cassava varieties. It also demonstrates that they appreciate the yields and level of resistance obtained from the improved varieties. The accepted use of improved varieties is the most important tool in the fight against viral diseases of cassava.

The CDP targets set at the start of the project were met. It is hoped that another phase of this work can take place to address the current gaps, such as limited market access by farmers for seed and the need to reach other communities with knowledge and quality seed.

Publication of research findings

Published by the project

Alicai, T., Ndunguru, J., Sseruwagi, P., Tairo, F., Okao-Okuja, G., Nanvubya, R., Kiiza, L., Kubatko, L., Kehoe, M. and Boykin, L. (2016). Cassava brown streak virus has a rapidly evolving genome: implications for virus speciation, variability, diagnosis and host resistance. *Nature Scientific Reports*, 6:36164.

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Manuscripts in preparation

The following papers are expected to be submitted for publication by the end of 2018:

1. Prevalence of cassava brown streak disease and associated viruses in Uganda over ten years: 2008–2018
2. Prevalence of cassava mosaic disease and associated viruses in Uganda over ten years: 2008–2018
3. Experiences in promotion and adoption of virus-indexed planting materials in management of cassava virus diseases in Uganda
4. Evaluation of elite cassava progenitors for virus resistance in Uganda
5. Screening promising cassava germplasm for resistance to cassava brown streak disease by graft inoculation and field screening under high inoculum.

Acknowledgements

This work was supported by Tanzania Agricultural Research Institute (TARI)–Mikocheni with joint funding from the Bill & Melinda Gates Foundation (BMGF) and UK Department for International Development (DFID) through the 'Cassava disease diagnostics for sustainable productivity in Africa' project (Grant no. 51466).

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