ZAMBIA

Patrick Chiza Chikoti[1], Mathias Tembo[1], Miriam Chisola[1], Hilda Mwaba[1], Rabson Mulenga[1], Suwilanji Sichilima[1], Mathews Matimelo[1], Joseph Ndunguru[2], Fred Tairo[2] and Peter Sseruwagi[2]

[1] Zambia Agriculture Research Institute, Mt. Makulu Central Research Station, Private Bag 7, Chilanga, Zambia
[2] Tanzania Agricultural Research Institute (TARI)–Mikocheni, P.O. Box 6226, Dar es Salaam, Tanzania

Abstract

The Cassava Diagnostics Project (CDP) project (2008–2018) was implemented in Zambia through the Zambia Agricultural Research Institute (ZARI). In the 10 years of its implementation, several objectives set in three main aims were successful implemented and their milestones accomplished. Four countrywide surveys were conducted in seven provinces. During the surveys, the prevalence of cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) and whiteflies were assessed using a standardized disease surveillance protocol and representative samples collected for laboratory analysis and identification.

Results of field data showed moderated CMD incidence (47%, 51% and 49%) with no significant differences among 2009, 2013 and 2015 surveys, respectively. The severity of CMD symptoms was also moderate with means on the 1–5 severity scale of 3.25, 2.65 and 3.35, respectively. For the first time in Zambia, CBSD was observed in the 2017 survey with incidence of 32% in North-Western Province. Molecular detection and characterization of the representative samples showed that *African cassava mosaic virus* was predominant (65.4%) followed by *East African cassava mosaic virus* (25%) and *Uganda cassava brown streak virus* was the only species causing CBSD, which was closely related to Ugandan isolates by 94% nucleotide sequence similarity. Whitefly biotyping using mitochondrial *COI* gene sequencing showed the predominant species was sub-Saharan Africa 1 sub-groups 1 and 2.

The seed system was supported by enhancing the capacity of the Seed Control and Certification Institute and a private seed multiplication company to certify cassava planting materials. Monitoring of breeders' crossing and yield performance trials enabled screening of 30 parent materials for viruses and their response to CMD.

Outreach activities built the capacity of 430 cassava farmers through training on cassava agronomic and integrated disease management practices. Over 200,000 cassava farmers across the country were reached directly and indirectly by received information on CMD and CBSD through two television programs produced and aired in 2015 and 2016.

The country's capacity to manage virus diseases was strengthened through human resource and infrastructure capacity enhancement. In the 10 years of CDP implementation, a total of six ZARI staff members were upgraded to MSc level and three research assistants retooled on advanced molecular

diagnostic techniques and bioinformatics in short-term tailor-made training. Infrastructure was enhanced through refurbishment of one screenhouse, acquisition of a project vehicle and several items of laboratory equipment and consumables. ZARI's visibility was enhanced through collaboration with project partners in the country and within the region through participation in exchange visits, training visits and in 12 scientific meetings.

Acronyms and abbreviations

ACMV	*African cassava mosaic virus*
CBSD	Cassava brown streak disease
CBSV	*Cassava brown streak virus*
CDP	Cassava Diagnostics Project
CMD	Cassava mosaic disease
CTL	Country Team Leader
EACMV	*East African cassava mosaic virus*
FAO	Food and Agriculture Organization of the United Nations
IITA	International Institute of Tropical Agriculture
JKUAT	Jomo Kenyatta University for Agriculture and Technology
MAP	Months after planting
mtCOI	Mitochondrial cytochrome oxidase gene
NAIS	National Agriculture Information Service
SCCI	Seed Control and Certification Institute
TARI	Tanzania Agricultural Research Institute
UCBSV	*Uganda cassava brown streak virus*
UNZA	University of Zambia
ZARI	Zambia Agricultural Research Institute

Results summary: Zambia

Aim I: Understand the threat from evolving viruses and vectors	
Objective 1: Disease epidemiology	
Disease and whitefly prevalence surveys conducted	• Four countrywide surveys were conducted in 2009, 2013, 2015 and 2017, respectively. • Mean cassava mosaic disease (CMD) incidence (47%) and severity of 3.2 in 2009, 51% and 2.6 in 2013 and 49% with severity of 3.55 in 2015, respectively. • Mean whitefly populations were 3.6, 1.8 and 11.3 in 2009, 2013 and 2015, respectively. • In 2017, cassava brown streak disease (CBSD) was surveyed in 29 fields, with incidence 32.2% and symptom severity 2.3.
Objective 2: Characterization of emerging viruses	
Cassava virus isolates in the project countries sequenced and analyzed	• Cassava brown streak virus (CBSV) isolates collected in 2017 were sequenced. • Sixty samples were partially sequenced for cassava mosaic begomoviruses from 2013 and 2015 surveys.
Cassava virus distribution maps for partner countries, generated (incidence, severity, whitefly, viruses, sat)	• Maps were produced from the surveys of 2009, 2013, 2015 and 2017. These included 100 CMD as well as CBSD incidence and severity maps.
Objective 3: Characterization of disease vectors	
Whiteflies characterized	• Forty samples were *mtCOI*-PCR amplified and sequences.
Potential insect vectors of CBSVs identified (if any)	• No alternative host was found with CBSVs.
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	• Thirty parents were screened for CMD and CBSD.
Farmers trained on CMD and CBSD disease symptom recognition and management strategies	• There were 430 farmers trained in the demonstration sites, agricultural shows and disease surveillance surveys and/or workshops or field days during 2013–2017.
Demonstration plots for benefits of using virus-indexed planting materials established on-farm	• Two demonstrations and 45 farmers, extension workers and NGOs trained.

Information materials developed and disseminated	• Three-hundred flyers for CMD and CBSD copies of dissemination materials printed in English and local languages. • Three-hundred brochures disseminated to cassava farmers. • Three radio programs. • Three TV programs. • One documentary. • Eight papers published in peer-reviewed journals.
Aim III: Build sustainable regional capacity	
Objective 10: Strengthening stakeholder linkages	
Awareness on availability of diagnostic capacities created through training and different media	• Three radio programs produced and aired. • Two TV programs. • Two demonstration plots initiated.
Objective 11: Strengthening human capacity and infrastructure	
Human capacity	
Project staff recruited	• Two research assistants. • One Assistant Country Team Leader (CTL). • One vehicle driver. • One MSc student.
PhD and MSc trained on different aspects of cassava virus diseases	• The CTL, and one PhD and one MSc student.
Advanced specialized training and visits for project scientists (1-2 months) conducted	• Dr Patrick Chikoti worked with the Modelling Group in Rothamsted and Cambridge University, UK, to learn how to model disease spread.
Extension workers, crop inspectors and other stakeholders (1 week) training	• Two workshops were conducted and extension officers trained on cassava viral diseases and their management. • Twelve crop inspectors trained in the same workshop.
Infrastructure strengthening	
Greenhouses constructed/renovated	• One screenhouse completed.

Background

Cassava is one of the most important root crops in Zambia. It is the second most important food crop after maize with an annual production of 1,010,298 t/year (FAOSTAT, 2016). An estimated 30% of the 16 million Zambians consume cassava as part of their daily carbohydrate diet. Cassava is mostly grown by small-scale farmers on fields of less than 1 ha and mainly in the cassava belt, which includes Luapula, Northern, North-Western and Western Provinces (Figure 1). The crop is also increasingly important in Central and Lusaka Provinces. Cassava is used in various ways including as raw material for livestock feed and the starch for paper making and brewing. However, its cultivation is hampered by several abiotic and biotic constraints. Abiotic stresses include low soil fertility, acidic and alkaline soils, drought and low temperatures, especially during winter (May–August). Biotic stresses include cassava green mites (*Mononychellus tanajoa* Bondar), cassava mealy bugs (*Phenacoccus manihoti* Matile-Ferrero), whiteflies (*Bemisia tabaci* Gennadius) and termites (*Cubitermes tenuiceps*). Cassava is also affected by diseases, such as cassava bacterial blight (CBB), cassava mosaic disease (CMD) and cassava brown streak disease (CBSD).

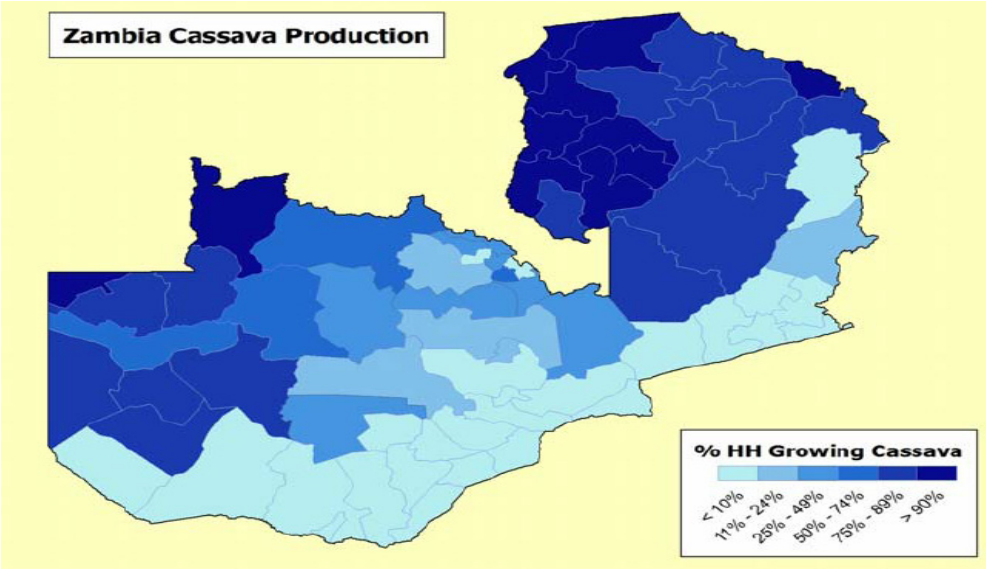

Figure 1 Major cassava-growing zones in Zambia (source Haggblade and Nielsen, 2007)

Whitefly, *B. tabaci*, is the vector of CMD and CBSD. These two diseases are of great economic importance for cassava and cause significant yield losses of over US$1 billion annually worldwide. *Bemisia tabaci* has been associated with CMD in the virus pandemic-affected parts of East and Central Africa (Legg et al., 2014). The CMD is widespread in all key cassava-growing areas of the country (Chikoti et al., 2013) and its incidence was 40.8% in 1996 (Muimba-Kangolongo et al., 1997) and 46% in 2006 (Legg and Chikoti, unpublished). It is currently the most devastating disease of cassava in Zambia (Chikoti et al., 2013) and accounts for 50–70% of cassava yield losses countrywide (Muimba-Kankolongo et al., 1997), with recent estimated annual losses of US$52 million (Tembo et al., 2017). Strategies to control CMD were initiated in the early 1990s and included the release and distribution of CMD-resistant cassava varieties to smallholder farmers. However, efforts to control the disease are limited by lack of sufficient quantities of planting materials of resistant varieties.
To mitigate the negative effects of CMD, the Zambia Agriculture Research Institute (ZARI) implemented a ten-year regional project 'Disease diagnostics for sustainable cassava productivity in Africa' that was coordinated by Tanzania Agricultural Research Institute (TARI)–Mikocheni in Tanzania and conducted in seven African countries in east and southern Africa. The project had

three aims: (i) to understand the threat from evolving viruses and vectors, (ii) to support clean seed systems for farmers and (iii) to build sustainable regional capacity. This report presents the activities implemented in Zambia and the achievements during 2008–2018.

SECTION ONE: Understanding the threat from evolving viruses and vectors

Disease epidemiology in Zambia

Four comprehensive field disease diagnostic surveys were conducted in 2009, 2013, 2015 and 2017 in the seven provinces of Zambia. The aims of the surveys were to (1) determine and map the incidence and symptom severity of major cassava viral diseases and abundance of associated insect vectors and (2) determine the geographical distribution of the causal viruses and vectors in the survey areas. The surveys were carried out in Lusaka, Northern, Central, Luapula, Eastern, North-Western and Western Provinces. Cassava leaves with viral disease symptoms were sampled from plants of 3–6 months of age following the standardized survey protocol (Sseruwagi et al., 2017 in the CMD/CBSD survey manual available on the CDP intranet on the Agshare.Today platform).

In addition, asymptomatic cassava leaves were collected in each field to confirm absence of viruses. Sampling was done at intervals of 10–50 km in areas where cassava growing was less intense, but in areas with intense cassava cultivation, fields were sampled at intervals of ≤10 km along main motorable roads. Cutting- and whitefly-CMD infections were distinguished as plants expressing symptoms on all the leaves and those expressing disease symptoms on only the uppermost leaves, respectively.

Cassava mosaic disease

CMD incidence

The overall CMD incidence was 47%, 51% and 49% for 2009, 2013 and 2015, respectively (Figure 2). Generally, the trend of CMD incidence showed the disease was moderate with no significant changes between years. Among provinces, Lusaka was the most affected with CMD incidence increasing from 67% in 2009 to 83% in 2015, followed by North-Western Province with similar increasing incidences across years Although the least affected province was Muchinga Province, in the northeast of the country bordering with Tanzania, the incidence still increased from 27% in 2013 to 30% in 2015. The main source of CMD infection across years and provinces showed that 42.6%, 49.6% and 44.5% in 2009, 2013 and 2015 was cutting borne, and whitefly infection was the least.

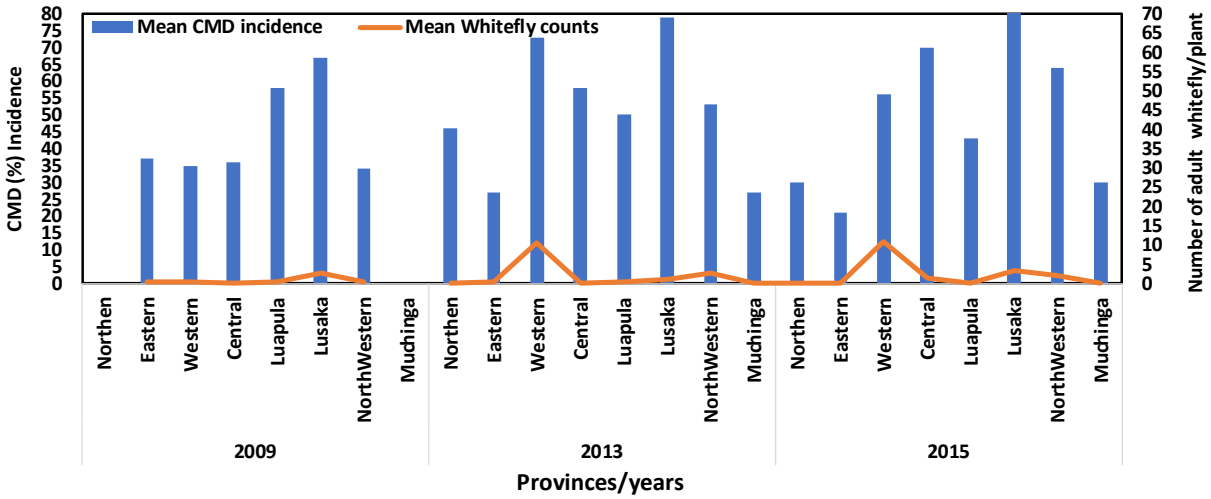

Figure 2 CMD incidence and whitefly abundance trends, 2009–2015

CMD symptom severity

Overall symptom severity across years and provinces was mild to moderate. The CMD symptom severity ranged from 3.2 in 2009 to 3.35 in 2015.

Adult whitefly abundance

Whitefly abundance was low in all provinces. The mean whitefly counts ranged from 0.03 in 2009 to 10.3 in 2015 with slightly higher counts in Western Province both in 2013 (10.5) and 10.8 in 2015 (Figure 2).

During the surveys of 2009–2015, several disease maps were generated and shared with cassava stakeholders in Zambia. The maps were used to enable key stakeholders to make decisions on where to multiply cassava plant materials, and thus govern movement of cassava planting materials within the country. The generated maps include distribution of CMD disease across provinces, the prevalent CMD species and abundance of whitefly (Figure 3 and Figure 4).

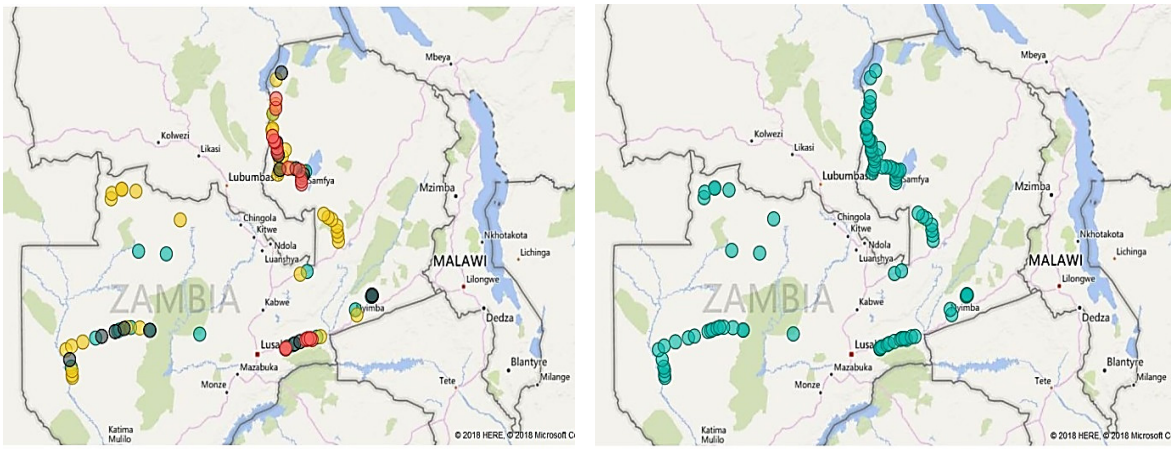

Figure 3 Disease incidence 2009 survey: (left) CMD and (right) CBSD

= 0–25% (Low) >25–50% (Medium) >50–75% (High) >75–100% (Very high)

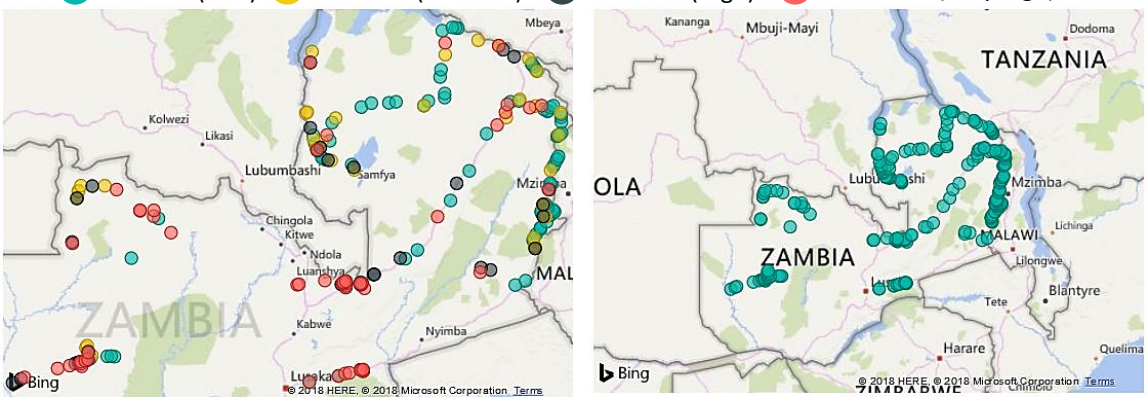

Figure 4 Disease incidence 2015 survey: (left) CMD and (right) CBSD

CBSD incidence

During the surveys conducted in 2009, 2013 and 2015, CBSD was not detected in Zambia. However, in March 2017, CBSD symptoms were observed in North-Western Province. Twenty-nine cassava fields were surveyed and cassava leaf samples collected from 116 plants (92 symptomatic and 24 non-symptomatic). The CBSD prevalence was ~79% (23/29) across fields. Mean CBSD incidence varied across fields but averaged 32.3% and mean disease severity was 2.3 on a 1–5 scale.

Prevalence of improved cassava cultivars

In the surveys conducted, farmers recalled cultivar names, which differed among provinces and years. The most frequently recalled cultivar was Manyokola in all surveys (10 responses) in 2009, 65 in 2013 and 56 in 2015 (Table 1). However, in all provinces and all surveys, the majority of farmers could not recall the name of the cultivar they were growing; therefore, we referred to them as 'unknown'.

Table 1 Predominant cultivars growing in seven provinces in Zambia during 2009, 2013 and 2015 surveys

Cultivar name	2009	2013	2015
Bangwela	6	11	7
Manyopola	10	65	56
Nalumino	14	11	15
Total cultivars recalled	**19**	**39**	**29**

Characterization of emerging viruses

Detection of cassava viruses (CMBs and CBSVs)

CMB analysis

In line with disease surveys, a total of 156 representative cassava leaf samples with CMD-like symptoms were collected for virus detection and genetic characterization to determine genetic diversity of cassava mosaic begomovirus (CMB) species prevalent in Zambia. The PCR results using virus species-specific primers with representative samples from 2009 and 2013 surveys both showed that *African cassava mosaic virus* (ACMV) was the predominant CMB species followed by *East African cassava mosaic virus* (EACMV). Of the 156 tested samples, ACMV was detected in 65.4%, EACMV in 25% and a small proportion of samples (9.6%) were dually infected with ACMV + EACMV (Table 2).

Table 2 Occurrence and geographical distribution of CMBs in seven provinces of Zambia, April–May 2009. Adapted from Chikoti et al. (2013)

Province	CMBs			No. of samples
	ACMV	EACMV	ACMV + EACMV	
Lusaka	13 (52/12.7)	12 (48/30.8)	0 (0/0)	25 (16.0)
Luapula	23 (46/22.5)	17 (34/43.6)	10 (20/66.7)	50 (32.1)
Northern	18 (100/17.6)	0 (0/0)	0 (0/0)	18 (11.5)
North-Western	12 (100/11.8)	0 (0/0)	0 (0/0)	12 (7.7)
Central	8 (80/7.8)	0 (0/0)	2 (20/13.3)	10 (6.4)
Western	16 (84.2/15.7)	0 (0/0)	3 (15.8/20)	19 (12.2)
Eastern	12 (54.5/11.8)	10 (45.5/25.6)	0 (0/0)	22 (14.1)
Totals	**102 (65.4)**	**39 (25.0)**	**15 (9.6)**	**156**

In addition to PCR results, total of 60 PCR products were directly sequenced by Sanger method. Phylogenetic analysis of all the partial sequences with similar sequence identity resulted in four clades that included isolates *ACMV*-UG Mild Uganda (AF126800.1), *ACMV-UG*Svr Uganda (AF126802.1), *ACMV*-[MG:MG310A1] Madagascar and *ACMV*-CM39 Cameroon (AY211462.1)

(Mulenga et al., 2016). The Zambian isolates showed substantial homology with clade members, with sequence identities ranging within 97–98%. Within the *EACMV* species, however, isolates showed greater variability, with a wide sequence divergence (77–99%).

In a separate analysis of 41 core coat-protein nucleotide partial sequences (550 bp), obtained from the 2014 sample isolates (KT869078–KT869118), the Zambian isolates clustered with several global isolates of the seven begomovirus species, albeit several Zambian isolates did not clearly resolve into specific clades (Figure 5A). However, complete DNA-A genome sequences of 19 CMBs (KT869119–KT869131 and KP890349–KP890354) obtained from a selected number of isolates formed elaborate clades with specific groups of virus isolates obtained from GenBank (Figure 5B). Sequence identity among similar species of the Zambian isolates was within 98–100% compared with 95–97% for other members of the phylogroup.

CBSV analysis

Laboratory analysis confirmed the presence of *Cassava brown streak viruses* (CBSVs) in Zambia in a separate field assessment carried out in July 2017 in Luapula (Chienge and Nchelenge districts) and Northern (Kaputa district) Provinces, following observations of plants with CBSD-like symptoms there. Using RT-PCR and sequencing, *Uganda cassava brown streak virus* (UCBSV) was detected in the samples (Mulenga et al., 2018). A comparative analysis of the isolate with the National Center for Biotechnology Information (NCBI) revealed its nature as a sequence variant of UCBSV sharing 94/96% maximum complete polyprotein nt/amino acid identities with isolates from Malawi (MF379362) and Tanzania (FJ039520).

Characterization of disease vectors

Although *B. tabaci* has previously been observed in farmers' cassava fields in Zambia, the population has always been generally low (<1 per plant). However, surveys conducted in Northern, Luapula, Western, Lusaka, North-Western, Eastern and Central Provinces in 2013 and 2015 showed an increase (>1 to 5 per plant) in adult whitefly abundance in some farmers' fields. This was attributed to the presence of the species sub-Saharan Africa 1 sub-group 1 (SSA1-SG1), which is currently associated with high populations in East Africa (Legg et al., 2014). We studied the diversity of *B. tabaci* on cassava in Zambia using specimens collected in the 2015 survey.

A total of 42 samples were used to study the molecular diversity and distribution of *B. tabaci*. The *B. tabaci* sequences grouped within the SSA1 clade when compared with other species in NCBI. Sequence alignment followed by phylogenetic analysis grouped the Zambian sequences in two major clusters, supported by high bootstrap values (>50): SG1 and SG2. The *B. tabaci* samples from Western and North-Western Provinces comprised SG1 and SG2, respectively, whereas most samples from Eastern Province were clustered within SG2.

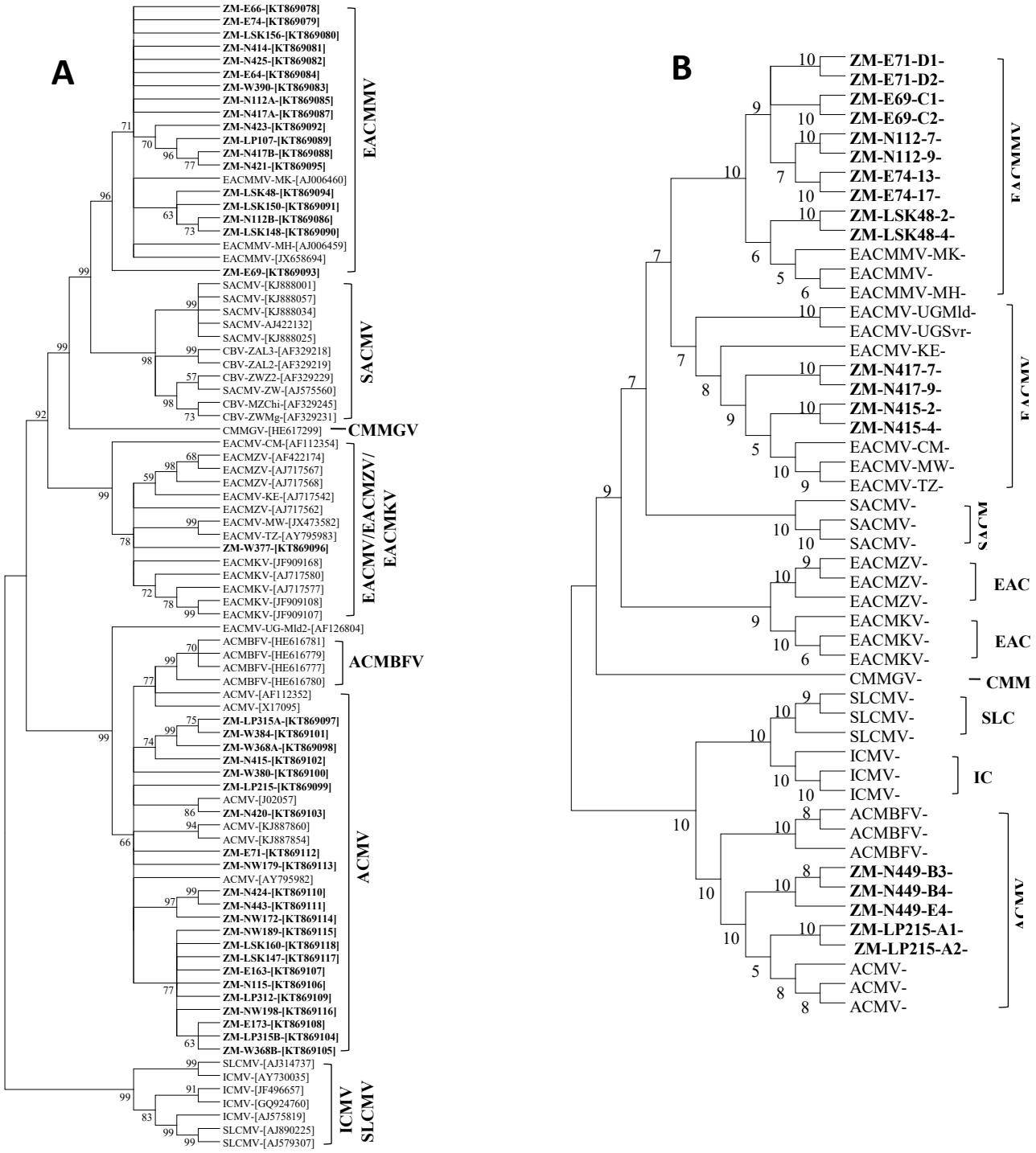

Figure 5 Phylogenetic relationships between cassava mosaic geminiviruses from Zambia (in bold) and global virus isolates based on analysis of aligned core coat protein (A) and complete DNA-A genome nucleotide sequences (B). Adapted from Mulenga et al. (2016)

SECTION TWO: Integrated pest management

Conventional breeding support

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

Among the various strategies for management of CMD, planting virus-free cuttings is the most effective for minimizing disease spread. However, for effective management of CMD, it is impracticable to use a 'one-size-fits-all' strategy. Therefore, the management efforts promoted included supporting clean seed systems for farmers, conventional breeding and reaching farmers directly.

Support clean seed systems for farmers

Supporting certification systems

Figure 6 Seed inspectors at the Seed Inspector Training, Mt. Makulu Research Station, Chilanga (left) and Mansa Research Station (right)

To improve the quality of cassava seed, the Cassava Diagnostics Project (CDP) embarked on training of personnel in charge of regulating the seed industry with advanced skills in recognizing cassava viral disease symptoms. Twelve inspectors, comprising three senior staff and nine technicians from the Seed Control and Certification Institute (SCCI), a government department that regulates the seed industry in Zambia, were trained in 2014 at Mansa Research Station (Figure 6). The training covered the following topics: (i) recognition of CMD and CBSD symptoms, (ii) assessment of disease incidence and symptom severity and (iii) how to collect samples for laboratory testing of virus diseases.

At present there is no formal cassava seed system in Zambia. Although several individual farmers are multiplying and selling cassava planting materials, checking for diseases and the causal viruses is not routine. For this reason, CDP-Zambia monitored the cassava multiplication fields and offered technical backstopping to Arulusa Farm (Figure 7) in Central Zambia, which is approximately 60 km from Lusaka and has 54 ha of cassava grown only for seed.

Following building a successful partnership with Arulusa, CDP-Zambia has provided technical advice on the management of both cassava and sweet potato viruses to the company, which enabled them to maintain a low CMD threshold (4%) in the planting materials they sell.

Figure 7 CDP scientists (Drs Ndunguru, Sseruwagi and Chikoti) visit Arulusa Farm with the General Manager (in checked shirt) to provide technical advice on inspection of plants for cassava viral diseases (left) and the ZARI staff testing of planting materials for CMD status at Mt. Makaula Laboratory in Lusaka (right)

Support to cassava breeders

Breeders' material monitored for disease and indexed for CMBs and CBSVs

Support to breeders was strengthened through increased monitoring of research trials consisting of crossing blocks and preliminary yield trials. These efforts were aimed at creating partnerships and common agreement on CMD evaluation in terms of disease rating. Two cassava breeders within the ZARI, Root and Tuber Improvement Program had their trials evaluated for CMD. The trials included a preliminary yield trial in Mansa (Figure 8), and seedling trials (three sites) in Western, Lusaka and Luapula Provinces.

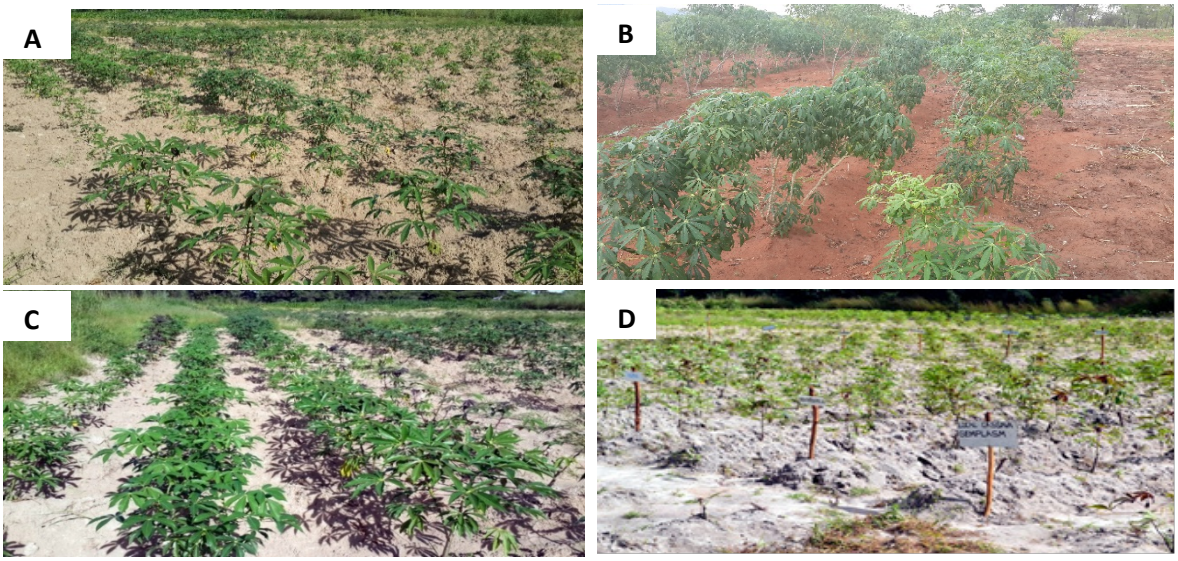

Figure 8 Cassava preliminary yield trials at Manza (A and B) and Rufunsa (C and D) assessed by CDP

Reaching farmers directly and through partners

Interaction with cassava farmers during sample collection in field surveys

Since 2013, ZARI scientists have interacted directly with farmers during biannual surveys in their cassava fields. A total of 430 farmers were directly contacted: 180 in 2013 and 250 in 2015 (Figure 9). Farmers were asked what cultivars they grew and what they knew about cassava pests and

diseases, specifically CMD, CBSD and whiteflies. The interaction lasted 10–20 minutes per farmer. Regardless of whether they knew CMD or CBSD, the farmers were educated on how to recognize the diseases. In addition, management strategies were also highlighted to farmers. The farmers were also given brochures and leaflets as extra information (Figure 9). The brochures were more pictorial for easier understanding.

Figure 9 Researchers interacting with farmers directly during cassava diagnostic surveys in Mansa district, Luapula Province

Farmers trained on CMD and CBSD disease symptom recognition and management strategies

Reaching farmers through agricultural shows

One mode of information dissemination to the cassava community in the project was through participating in district and national agricultural shows. Participation in the shows aimed to (1) inform the general public about the CDP, (2) educate farmers on how to recognize and manage cassava diseases, particularly CMD and CBSD, and (3) showcase different technologies that ZARI is developing. More than 6500 farmers passed through the agricultural show stands at district, provincial and national shows during 2013–2017 (Figure 10). Among the high-ranking show participants who visited the stand in 2016 at the National Agricultural and Commercial Show included Mr Roland Msiska (Secretary to the Treasury), Ms Dora Siliya (then Minister of Agriculture), Mr Shawa (Permanent Secretary for Agriculture) and The Honourable Davis Mwila (Minister of Defense). The exhibits included healthy and CMD-infected plants (Figure 10), cassava roots and information products on cassava disease management (leaflets and brochures). More than 1000 information products were given out to farmers and those with an interest in growing cassava.

Figure 10 Visitors to the ZARI stand in 2017: (A) CDP Assistant Country Team Leader (Assistant CTL, Mathias Tembo, in light blue suit) showing the Secretary to the Cabinet, Rolland Msiska, (B) CDP Assistant CTL showing the Minister of Agriculture, Dora Siliya (left), Minister of Defense, Davies Chama (second left) and the Deputy Director exhibits (C) of CMD-infected cassava and tissue culture plantlets and (D) harvested stool of cassava from the virus-free improved cassava variety

Training of women farmers

A training workshop on 'Cassava Diseases and Management' was held at Mount Makulu Research Station, Lusaka, in 2016, under the auspices of the Plant Pathology Unit. The workshop was attended by 22 women farmers growing cassava from Chilanga district (Figure 11). The criterion used in the selection of participants was that the women were required to have a field of cassava, so that techniques learned could be immediately put into practice. The participants were trained on cassava diseases and their management. A participatory framework was created, and the participants had the opportunity to present their views and knowledge on cassava management and challenges. The challenges were discussed during the plenary session and advice was offered by experts.

Figure 11 Cassava farmers attending training at Mt. Makulu Research Station on cassava diseases and management in 2016

The workshop was structured around two main processes. The first was an experience sharing process, mostly theory, on the first day – this included group discussions and presentations by the participants. The second day consisted of field visits, in which participants were presented with diseased samples and asked what they thought about the cassava diseases.

The participants were of the view that such training should continue and be given more time, especially with regard to symptom identification and management of cassava diseases. In addition to identification and management of cassava diseases, the participants and facilitators agreed to consolidate the partnership for the farmers to realize their full potential in cassava production.

Information materials developed and disseminated

Information products on CMD and CBSD were produced for various stakeholders. The materials were in the form of brochures and leaflets (Table 3). Over 10,000 of the information products were distributed to farmers during 2013–2017.

Table 3 List of information products developed under the CDP 2013–2017 on cassava diseases and their management

SN.	Material	Topic	Type	Target audience	Quantity issued
1	Brochure	Recognition of CMD and CBSD and management	3	Farmers, extension agents	5000
2	Leaflet	Recognition of CMD and CBSD and management	2	Farmers, extension agents	5000
3	Radio messages	About CDP, importance of cassava diseases and how to manage them	2	Farmers, extension agents	3
4	TV interviews	Importance of CMD and CBSD in Zambia, outbreak of CBSD in Zambia and interventions required	3	General public (farmers, extension agents, policy makers)	3
5	TV documentary	About CDP, importance of cassava diseases and how to manage them	1	General public (farmers, extension agents, policy makers)	1
6	Prevalence maps	Distribution and incidence and severity of CMD in Zambia	2	Seed multipliers, seed regulator, farmers, extension agents	100
7	Research journal articles	Distribution and incidence and severity of CMD in Zambia		General public (farmers, extension agents, policy makers, scientists)	9
8	Advisory note	Spread of CBSD in Zambia	1	Policy makers	1

Cassava documentary

A documentary on cassava was produced in September 2016 in partnership with the National Agriculture Information Service (NAIS). The NAIS is a Department within the Ministry of Agriculture and is responsible for disseminating agriculture information to the farming community. The

documentary covered (i) an overview of the CDP, (ii) how to recognize CMD and CBSD symptoms and (iii) the importance of managing CMD and CBSD.

Figure 12 NAIS personnel with Zambia CTL Dr Patrick Chikoti (A and B) during the production of CDP documentary at Three Sisters Farm, Rufunsa, in 2016

During production, one of the demonstration sites (Three Sisters Farm, Rufunsa) was used to highlight the CDP activities (Figure 12). The documentary was produced by a public broadcaster, the Zambia National Broadcasting Corporation, and was broadcasted in all 10 provinces of Zambia. The same documentary was also aired by the two privately owned Muvi and Prime TV stations which target mainly major towns. Each channel made more than one broadcast and over 200,000 members of the public viewed the documentary. The estimated viewership was based on NAIS projections.

Demonstration plots for benefits of using virus-indexed planting materials established on-farm

On-farm demonstration plots were established to show the benefits of growing virus-indexed cassava planting material compared with unindexed material. The demonstrations were established at three sites: Rufunsa on the Three Sisters Farm (Figure 13), Kaoma on Shandy's Farm, and Mansa on the Mansa Research Station. Rufunsa and Kaoma are located in region II and experience annual rainfall of 800–1000 mm. Mansa is in agro-ecological region III, and has annual rainfall of >1000 mm. The farmers were also trained in good agricultural practices, including the following:

i) benefits of using clean indexed planting material
ii) planting density
iii) weeding
iv) recognition and management of CMD and CBSD
v) scouting for CMD and CBSD.

In all three sites, planting to harvesting was done with the farmers. More than 60 farmers benefited directly by learning how to plant, recognize and manage CMD, CBSD and CBB. These demonstration plots provided farmers with skills that will enable them to increase productivity in their cassava fields.

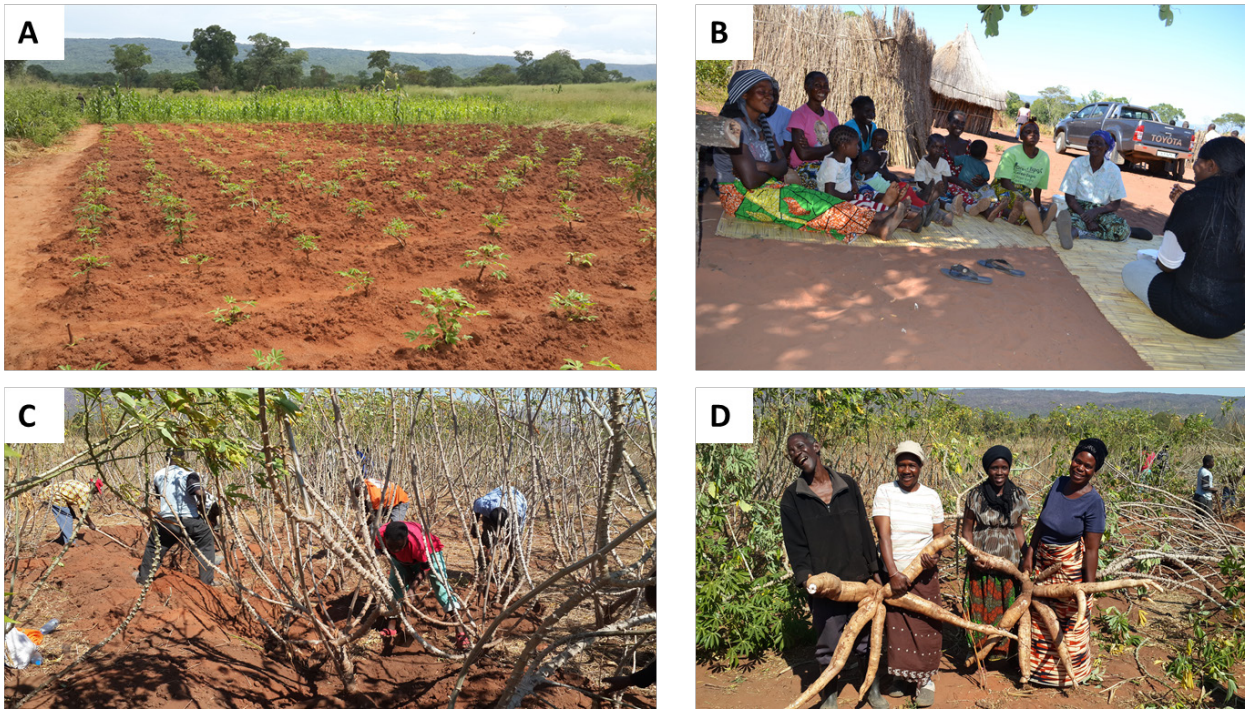

Figure 13 CDP activities in Rufunsa at Three Sisters Farm: (A) a cassava field planted with disease-free cassava stems, (B) CDP Research Assistant gathering farming practices from the farmers, (C) farmers harvesting cassava from the demonstration plot and (D) farmers showcasing their harvested cassava from the demonstration plot planted using virus-free improved cassava

Strengthening stakeholder linkages

Project inception and consultative meeting with stakeholders

During the first phase, one awareness meeting was held at Annias Lodge in Chilanga. Among the organizations represented were ZARI scientists, senior extension officers, seed regulators and a Food and Agriculture Organization of the United Nations (FAO) representative (Table 4 and Figure 14). The objective of the meeting was to introduce the CDP to the partners that were working on cassava-related activities.

Table 4 List of participants to the inspection workshop

SN	Name of Participant	Organization	Position	Gender
1	Dr Kamona	ZARI	Director	Male
2	Dr Joseph Ndunguru	TARI-Mikocheni	Director	Male
3	Mrs Monde Zulu	ZARI	Chief Agriculture Research Officer	Female
4	Mr Mulonga	FAO		Male
5	Mr Isaac Sichilima	SCCI	Seed Inspector	Male
6		NAIS		
7	Mr Arundile Sakala	ZARI – Plant Quarantine and Phytosanitary Service	Principal Agriculture Research Officer	Male
8	Mr Kenneth Msiska	ZARI – Plant Quarantine and Phytosanitary Service	Principal Agriculture Research Officer	Male

SN	Name of Participant	Organization	Position	Gender
9	Dr Chiona	Ministry of Agriculture – Extension Service	Principal Agriculture Research Officer	Male

Before the start of the second phase, further awareness about the project was made at the University of Zambia (UNZA) and ZARI – Mt. Makulu Research Station. At UNZA the awareness meeting was attended by lecturers from the School of Natural Sciences, including Professors Kapooria, Nkunika and Mbata, and Drs Kaimoyo and Katongo. At Mt. Makulu, awareness was increased of researchers from the Plant Protection and Quarantine Division.

Figure 14 Participants at the first phase project awareness meeting, Chilanga, Zambia in 2010

Stakeholders engagement

Since the CDP inception, the Zambian team has developed local partnerships in Zambia. To consolidate the partnerships, the project helped to build capacities through various training sessions. The institutions whose capacities were increased included UNZA, Mulungushi University, SCCI, Arulusa Farm and the Extension Service (Ministry of Agriculture). The skills enhanced included identification of CMD symptoms and laboratory molecular techniques (Table 5 and Figure 15).

Table 5 Local partners and the capacities increased by CDP in Zambia 2013–2016

SN	Institution	Skill	Number of personnel
1	UNZA	Molecular techniques	6
2	Mulungushi University	Molecular techniques	4
3	SCCI	Molecular techniques, CMD identification, management strategies	12

SN	Institution	Skill	Number of personnel
4	Extension Service (Ministry of Agriculture)	CMD identification, management strategies	20
5	NAIS	Production of TV and radio documentaries on project activities	2
6	Arulusa Farm	CMD identification, management strategies	1

Figure 15 Partnering with stakeholders: (A) Mr Mathews Matimelo in Katete district, Eastern Province training farmers on management of plant diseases, (B) extension officers having hands-on in a farmer's cassava field in Kaoma district, Western Province, (C) extension officers in a training workshop in Kaoma and (D) CDP scientists examining cassava planting material at Arulusa Farm

Table 6 List of partners and stakeholders

Institution	Location	Partnership/ Type of stakeholder	Respondent(s)	Role	Contact person(s)
ZARI	Chilanga	NARS (Project partners)	Dr Patrick Chikoti (CTL), Mr Mathews Matimelo (Assistant CTL)	Hosting of the project and CMD diagnostics	Dr Patrick Chikoti, Mr Mathews Matimelo
ZARI	Chilanga	NARS	Dr Mweshi Mukanga (Chief Agric Research Officer), Ms Mulonda Sakajila (Technical Research Assistant), Mr Mathias Tembo (Senior Agric Research Officer), Ms Judith Malumo (Agric Research Officer)	Research and improvement of cassava	Dr Mweshi Mukanga
ZARI	Chilanga and Misamfu	NARS	Ms Maimuna Abass Luangala (Agric Research Officer), Dr Martin Chiona (Cassava Breeder)	Plant health, and breeding for CMD resistance and general improvement	Ms Maimuna Luangala, Dr Martin Chiona
Zambia Agricultural Research Institute	Chilanga	Collaborator	Mr Ivor Mukuka (National Coordinator) Cassava Mechanization and Agro-Processing Project (CAMAP)	Processing and value addition	Mr Ivor Mukuka
International Institute of Tropical Agriculture (IITA), Zambia	Lusaka	Collaborator	Dr Pheneas Ntawuruhunga (Project Coordinator), Feed the Future Project	Breeding and promotion of cassava to improve food security	Dr Pheneas Ntawuruhunga
SCCI	Chilanga	Seed Certifier	Mr Richard Chanda (Principal Seed Officer and Biotechnology Department Head)	Seed certification and control	Mr Richard Chanda
UNZA	Lusaka	University	Dr Langa Tembo	Training and supervision of students	Dr Langa Tembo
Arulusa Farm	Chisamba	Private seed producer	Mr John Kimani (Farm Manager)	Production of cassava seed materials	Mr John Kimani
Farmers	Kalundu, Rufunsa District	Farmer	Ms Margaret Kamusasa, Ms Monica Chitabala, Ms Agness Mukoma and Mr Damus Lungu	Cassava production	Ms Margaret Kamusasa

Exchange visits between scientists in the project countries

One scientific exchange visit between project countries was held in Zambia during 16–20 May 2016. The aim was to share and exchange views and ideas on project operations. Among the participants were the CTLs and the project management teams from Tanzania, Malawi, Kenya, Rwanda, Uganda and Mozambique (Figure 16). During the scientific exchange visit, a field visit was made to farmers' fields in Rufunsa, 160 km from Lusaka (Figure 16). In addition, a visit was made to the UNZA, a key local partner of the CDP ZARI team. Dr Joseph Ndunguru made a key note address on the project overview and achievements. From the exchange visit the scientists learned:

i) how Zambia was closely working and sharing information with cassava farmers in Rufunsa
ii) how the project was utilizing infrastructure such as screenhouses and laboratory facilities in understanding the viruses affecting cassava in Zambia. Within the first year of the project Zambia had built the screenhouses and procured the laboratory equipment.

Figure 16 (A) CDP scientists with farmers in Rufunsa, (B) scientists looking at a cassava plant infected with CMD at Three Sisters Farm in Rufunsa, Lusaka Province

Hosting of cassava diagnostic annual meeting

Zambia hosted the 7th Annual Meeting of the Disease Diagnostics for Sustainable Cassava Productivity in Africa Project at Radisson Blu Hotel, Lusaka, during 10–12 October 2016. The meeting was attended by 58 participants from the UK, Australia, USA and Africa.

The objectives of the meeting were to:

i) review research activities for the past year and plan future activities
ii) share scientific knowledge generated from project activities
iii) strengthen existing collaboration with scientists from different projects working on cassava.

The meeting was officially opened by Mr Moses Mwale, Director of ZARI. In his address, he thanked the Project Managers for convening the meeting in Zambia. He also applauded the Zambia CDP team for their many successes.

In his introductory remarks, the Project Coordinator, Dr Joseph Ndunguru, reminded the participants of the significance of the project. He stated that availability of reliable and affordable capacity to diagnose CMBs and CBSVs accurately and effectively in the major cassava-growing countries is a key to effective management of CMD and CBSD. He further mentioned that through the collaboration, robust standardized molecular diagnostic tools for sensitive and rapid detection of viruses infecting cassava had been developed and shared among scientists in the network countries. Virus characterization and disease surveillance were conducted in all project countries, generating both

disease prevalence and virus distribution maps that are being used for informed decision making especially by extension agents.

Cassava virus disease epidemiological modelling: a visit to Rothamsted and University of Cambridge (UK)

Dr Patrick Chikoti and Professor Elijah Ateka [Jomo Kenyatta University for Agriculture and Technology (JKUAT)] visited Rothamsted Research and Cambridge University to learn how to model disease spread. The key objectives of the study visit were to (i) develop and advise on sampling strategies for CBSD in Zambia and (ii) develop predictive models for CBSD spread to new areas. Thus, while in the UK, the disease surveillance and whitefly abundance data collected in 2009 and 2013 were utilized to model disease spread in unsampled areas and predict the future spread of disease and identify where, when and how disease monitoring programs should target areas where cassava viruses have been detected or areas likely to be affected.

A sampling strategy was developed with Rothamsted Research and used in the 2015 countrywide survey (Anna et al., unpublished). Using the designed strategy, CBSD was detected in the 2017 survey in Luapula (Chienge and Nchelenge districts) and Northern Provinces (Kaputa district) (Mulenga et al., 2018). The other significant outputs of the four-week study visit that contributed to the CDP success were (i) sampling protocols and methods strengthened, (ii) intervention strategies for monitoring and mitigation and (iii) knowledge sharing and transfer between collaborating institutions which resulted in the contribution to publication of a paper 'Spatial Dynamics and Control of a Crop Pathogen with Mixed-Mode Transmission' and 'Advice for cassava brown streak disease (CBSD) sampling strategy in Zambia'.

Technical backstopping

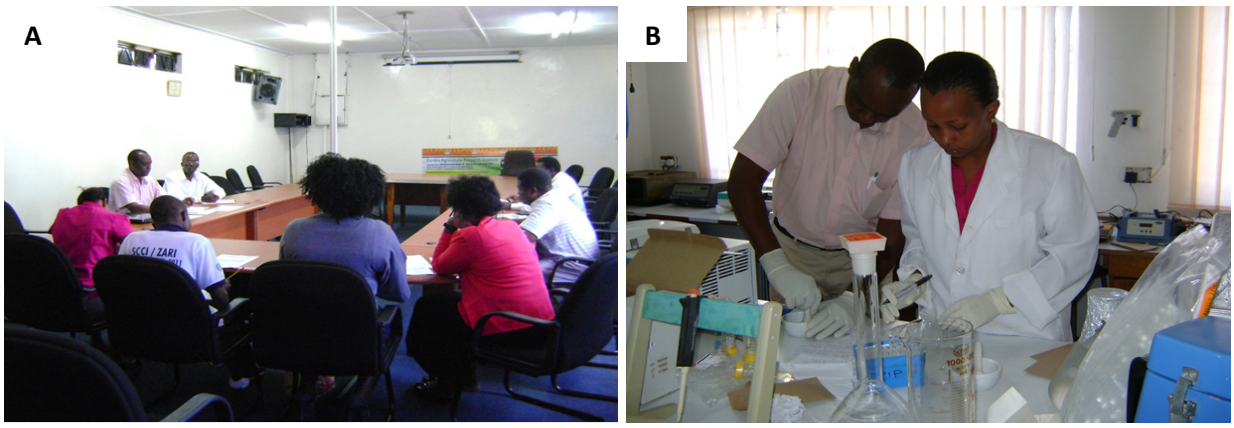

Figure 17 Technical back stopping: (A) members of CDP-Zambia conferring with Dr Fred Tairo at Mt. Makulu and (B) Dr Fred Tairo and Ms Catherine Gwandu training Zambian CDP research assistants on molecular diagnostic method for cassava viruses at Mt. Makulu Laboratory in 2014

In 2014, scientists from TARI-Mikocheni visited ZARI for technical backstopping in deep sequencing methods for virus detection and characterization. The objective of the visit was twofold: (i) familiarization with CDP-Zambia operations and (ii) imparting knowledge on deep sequencing to Zambian scientists. The visit involved collection of diseased cassava samples from the field and laboratory extraction of nucleic acids and analysis using a deep sequencing technique (Figure 17).

Strengthening human capacity and infrastructure

Prior to commencement of project activities, a team of scientists was constituted from among the members of ZARI with the exception of research assistants (Table 7).

Table 7 List of project staff recruited

No of staff recruited	Position	Name
1	CTL	Dr Patrick Chiza Chikoti
1	Assistant CTL	Mr Mathias Tembo
1	Research Assistant	Mrs Miriam Chisola Goma
1	Laboratory Technician	Ms Sichilima Suwilanji
1	Driver	Mr Vincent Mwanza

PhD and MSc trained on different aspects of cassava virus diseases

Six students (five MSc and one PhD) received support either directly or indirectly through use of CDP project equipment and reagents in their research studies (Table 8). To date, four students have graduated.

Table 8 List of students trained under CDP-Zambia

S/No.	Name	Research topic	Degree*	Status
1	Rabson Mulenga	Multiplex polymerase chain reaction for the simultaneous detection of CMBs in Zambia	MSc – full support by CDP	Completed
2	Mathias Tembo	Molecular epidemiology of CMD in selected cassava-growing provinces of Zambia	MSc – partial support by CDP	Completed
3	Tiuzeyani Zulu	Characterization of cassava (*Manihot esculenta* Crantz) varieties resistant to Cassava mosaic virus in Zambia	MSc	Completing in 2018
4	Batisba Tembo	Development of wheat (*Triticum aestivum*) germplasm resistant to spot blotch disease for summer rain-fed conditions in Zambia	PhD	Completed
5	Joseph Banda	Response of sweet potato to sweet potato viruses on beta carotene content, yield and yield components	MSc	Completing in 2018
6	Siankuku Munsaka	Molecular characterization of selected rice varieties in Zambia	MSc	Completed

***Degree program and nature of support**

Training of technicians from local partner institutions

The training workshop on 'Cassava Viruses: Biology, Diagnostics and Management' was held at Mount Makulu Research Station, Lusaka, during 6–10 February 2012 (Figure 18), under the auspices of ZARI and IITA. The workshop was attended by 14 participants from UNZA, SCCI and ZARI. The topics included:

i) cassava pests
ii) cassava viruses, symptoms and epidemiology
iii) CMD incidence and severity assessments
iv) collection of diseased samples
v) nucleic acid extraction
vi) analysis of PCR products and interpretation of results.

Training outcome

Most of the participants felt that strong collaboration was required, and that ZARI needed to come up with training materials suitable for farmers to understand and recognize CMD symptoms both in the multiplication plots and farmers' fields. The participants suggested that future training should be given more time, especially concerning symptom identification and management of cassava diseases. In addition to identification, testing and management, the participants from SCCI suggested that the certification protocol for cassava multiplication fields required revision.

Figure 18 Participants from local research institutions attending a one-week training course at the virology laboratory at ZARI in collaboration with IITA

Bioinformatics training of CDP staff in Kenya

The CDP staff from Zambia for bioinformatics training included Mr Mathias Tembo, Mr Rabson Mulenga and Ms Miriam C. Goma. The training workshop (Figure 19) 'Bioinformatics Tools for Species Identification' with special focus on whitefly and CBSD genomic datasets was held during 7–10 June 2016 at JKUAT, Kenya. The workshop was hosted by Dr Laura Boykin and Prof. Elijah Ateka. The training focused on how to use programs such as Geneious (alignment and basic analyses of NGS data), JModelTest (determining correct model of evolution of the dataset), PAUP (generating a robust phylogeny) and TextWranger (Mac) or Notepad++ (Windows) to enable analysis of multiple sequence alignments (whiteflies and cassava viruses), interpretation of phylogenetic trees, identifying species of viruses and vectors and designing diagnostic primers based on genetic variability. The training contributed to analyzing the generated virus subsequences and three papers have been published (see 'Publications and conference participation' in Section 3).

Figure 19 (A) Participants at bioinformatics tools for species identification training at JKUAT, Kenya, and (B) Laura Boykin (facilitator) with participants

Data entry and assembly training in Tanzania

The CDP conducted a 'Data Entry and Assembly Workshop' for the surveys conducted in the CDP participating countries since 2009 from 28th November to 2nd December 2016. The workshop involved participants from Kenya, Malawi, Mozambique, Uganda, Zambia and Tanzania (Figure 20). Zambia was represented by Mr Mathias Tembo and Ms Miriam C. Goma. The workshop was hosted by Dr Peter Sseruwagi, Dr Fred Tairo and Dr Joseph Ndunguru of TARI-Mikocheni and facilitated by Dr Anna Szyniszewska from Rothamsted Research and Mr David Godding from the University of Cambridge, UK. The purpose of the workshop was to ensure that all paper forms from the previous CDP surveys of 2009–2015 were scanned and digitized for easier analysis and retrieval. The participants were trained on coordinated entry and general techniques of scientific data entry. Metadata were also collected on the exact protocol used for the different surveys. The objectives of the training were to:

i) maximize the amount of verified correct survey data
ii) establish links between digitized survey forms and original paper survey forms
iii) train data entry clerks to independently enter data to specified standards.

The 2009–2017 survey data are now accessible through Agshare.Today for participating partner countries under the CDP project. Agshare.Today is a platform in which information is shared among project members.


Figure 20 CDP staff having data entry discussions (left), David Godding, facilitator, scanning hard copies in Dar es Salaam, Tanzania in 2016 (right)

Infrastructure strengthening

To support implementation project activities, several pieces of infrastructure were either procured or refurbished.

Motor vehicle

Prior to the second phase (2008–2012), the Plant Pathology Team did not have reliable transport to carry out the project activities including procurement, disease surveillance and collection of samples for laboratory analysis. The vehicles that were then available were constantly breaking down and contributing to delays in implementing project activities. In the second phase of the project, a brand-new Toyota Hilux was procured.

Screenhouse

One screenhouse was constructed at ZARI with the support of the CDP. The screenhouse is used for biological studies to maintain field-collected cassava plants with unique symptoms for further study.

Laboratory equipment

To achieve the set objectives of the project, i.e. surveillance of insect pests and diseases and virus and vector identification, various items of equipment were procured during 2009–2016 (Table 9).

Table 9 CDP equipment procured during 2015–2016

S/N	Structure	Equipment	Serial No.	Number	Status
1	Vehicle	Toyota Hilux 4WD double cabin	ALP 5476	1	Functional
2	Greenhouse equipment	Ventilation system	N/A	1	Functional
3		Watering system	N/A	1	Requires some repairs
4	Diagnostic laboratory	Clifton water bath	85610	1	Requires some repairs
5		Stuart BioCote vortex mixer	R000107349	1	Functional

S/N	Structure	Equipment	Serial No.	Number	Status
6		Hettich refrigerated centrifuge (MIKRO 200)	MIKRO 200R D-78532	1	Requires some repairs
7		Hettich micro-centrifuge	MIKRO 120	1	Functional
8		Ultra-freezer (–20°C)	Bosch	1	Functional
9		Techne PCR Machine	TC-5000	1	Requires some repairs on the display panel
10		Stuart hotplate stirrer	SB 302	1	Functional
11		Stuart stirrer	SB 161	1	Functional
12		Thermal shaker	TS-100	1	Functional
13		Geno grinder	MINI-G 16002; SN: 10091	1	Functional
14		PCR workstation (UVT-8AR)	SN: 0401071606086	1	Functional
15		PIKO 96 thermal cycler	PK961300715	1	Functional
16		VWR electrophoretic tank	SN: 700-0056	1	Functional
17		VWR electrophoretic tank	700-01136/30044283	1	Functional
18		VWR electrophoretic tank	700-0136/30044280	1	Functional
19		Laminar flow		1	Functional

Tissue culture facility

A new facility was established at Mt. Makulu with funds obtained from the Finnish Government. The facility has attracted much interest from various stakeholders. The facility is now being used for micropropagation for the rapid generation of 'clean' plantlets for a number of running and upcoming project activities. The projected increase in cassava demand among small and emerging farmers and the need to produce clean planting material cannot be overemphasized. The demand for clean planting material is projected to increase because of industries being set up to produce beer, starch and ethanol. One such project is the 'Establishment of a decentralized and sustainable pipeline for the production and deployment of disease-free cassava planting materials in Zambia (2016–2020)', being spearheaded by ZARI. The equipment in the virology laboratory procured under the CDP has the capacity to index cassava plantlets and other crops.

SECTION THREE: Impacts, success stories and learning outcomes

Impacts

For the duration of the project, several impacts have been registered, including strengthening human and infrastructure capacity, generating information on disease spread and building new linkages with local and international organizations.

Impact area	Impact
No. of students trained by this project directly and indirectly	For long-term training (2–4 years), one MSc student was trained directly and five students (one PhD and four MSc) received indirect training. Twenty-seven students received short-term training (up to 2 weeks).
No. of projects using the CDP facilities	Five projects currently use the greenhouses and laboratory equipment (see section on equipment).
No. of students and/or staff using facilities and reagents of CDP	Five ZARI staff members and three students (UNZA and University of KwaZulu-Natal) are currently using the CDP facilities.
No. of people that have been inspired by the project	More than 100 individuals – from UNZA, the National Institute for Industrial and Scientific Research (NISIR), Mulungushi University, Copperbelt University, the National Biosafety Authority and SCCI – have been inspired through the level of investment and the results generated (see sections for infrastructure and publications).
Institutional visibility	Locally and internationally, ZARI's increased standing in terms of credibility and diagnostic capacity has improved. This can be attested in the joint supervision of students and use of the facilities by individuals from other organizations including University of KwaZulu-Natal, UNZA, IITA and Mulungushi University.
Infrastructural capacity – helping student execute their project	With the available infrastructure, seven students received local long-term training.
New stakeholders interacting with the project	Two: National Biosafety Authority and NISIR.
Service the lab has provided	GMO detection (one), indexing of sweet potato (one) and cassava viruses (one).
People using information generated by this project	Extension agents are using information to advise farmers on disease management, and college and university students are using it for their research purposes.

Benefits to the government - extension training, inspectors and regulators	The knowledge generated has enabled extension agents to utilize information on CMD and CBSD occurrence, and how to manage the two diseases.
Advocacy-impacts on policy	One advisory note on the spread of CBSD in Zambia was drafted and submitted to the Ministry of Agriculture. The government is now putting in place stringent measures to contain the disease.
Publications and other communications including other communication materials	Information products including brochures, leaflets, journal articles and DVDs on awareness were produced and distributed. The information material is being utilized by different stakeholders.
Meetings and conferences attended – for the whole team	Several meetings and conferences were attended, and project activities presented at these fora.
Support to breeders and other projects	Support to breeders was provided in form of joint scoring of breeders' trials: crossing blocks, yield trials and parent trials.
Other universities requesting to use the facilities/equipment	Mulungushi, Copperbelt and Zambia Open Universities and UNZA.
Building a network of scientists	With the setting up of CDP a good network of scientists locally and internationally has been built including Dr Evans Kaimoyo (UNZA), Professors Susan Seal and John Colvin (University of Greenwich), Professor Chris Gallighan (University of Cambridge), Professor Van den Bosch (Rothamsted Research) and Dr Laura Boykin (University of Western Australia).

Success stories

ZARI has research stations in all provinces of Zambia and includes Mount Makulu Central Research Station. This is the hub of crop research innovations in Zambia, covering many aspects of crop husbandry. This research station has specialized laboratories in soil and water management and plant protection. The Plant Protection Unit hosts the Plant Pathology Section from where the CDP was administered in Zambia. The plant pathology laboratory has been the central laboratory providing crop disease diagnostic services to farmers and research units in Crop Improvement and Agronomy as well as Plant Protection and Quarantine.

Prior to CDP's introduction in 2009, and the successor project in 2013, diagnosis of crop diseases of virus etiology was largely based on symptomatic determination and to lesser extent enzyme linked immunosorbent assays (ELISA). This was because (i) the laboratories had few and incomplete pieces of equipment for molecular-based detection and identification of pathogens affecting crops and (ii) human capacity and skills to diagnose the diseases using molecular-based tools were limited. This hampered efforts to generate technologies suited for managing crop diseases. With the advent of the CDP, the situation changed. The laboratory has a complete molecular workbench necessary to conduct advanced molecular studies. Using such molecular techniques, the laboratory has identified

specific species of CMBs and CBSVs affecting cassava in Zambia. Before the CDP, CMD was only detected through foliar symptoms. To augment the equipping of the laboratory, several laboratory techniques and laboratory safety training sessions were conducted involving 22 project and non-project staff at various levels. Training in practical laboratory skills has increased the competence of ZARI staff to identify different pathogens by molecular means and they can now conduct research previously deemed impossible.

With the increased human and infrastructure capacity, the laboratory is now collaborating with UNZA and Copperbelt and Mulungushi Universities, who have sent their students and laboratory technicians for training in molecular-based diagnostics. Using the same facilities and competencies attained during the duration of the CDP, we were able to identify ACMV, EACMV, *East African cassava mosaic Malawi virus*, *East African cassava mosaic Zanzibar virus* and *South African cassava mosaic virus* from samples collected countrywide. Further, we reduced the turnaround time between sample collection and dissemination of results to stakeholders from the previous 10 days to 2 days depending on availability of required laboratory reagents.

A total of 20 extension staff were trained in CMD symptom identification, most of whom could not identify CMD symptoms prior to the CDP project. This has potential to increase awareness of CMD beyond the reach of research staff thereby making farmers aware of the negative effect of the disease on yields. Further, through establishing demonstration plots, targeted farmer training and interactions with farmers during surveys, more than 2000 farmers were reached and information on CMD and its management shared. Additionally, two TV and three radio programs were aired on four channels with national coverage. The additive effects of these efforts are now evident. Farmers who previously could not differentiate a diseased from a healthy plant can now do so, and some are practicing disease management. This resulted in a marginal decline in CMD incidence across Zambia during 2013–2017.

Capacity has also been built in scientific communication through training in scientific writing and communication. The positive impact of the training is evident from the publications produced within the duration of the CDP project. Overall, the CDP project has increased the research capabilities of ZARI researchers, and this is beneficial to the country both in the short and long term. The positive impact of the CDP project will have lasting impact on the Zambian farming community and improve livelihoods of the Zambian populace in more ways than one. For Zambia, CDP was a success and contributed greatly to the economy.

Learning outcomes

During the duration of the project, lessons were learned either through day-to-day operations or through training provided by TARI-Mikocheni.

Procedures

Laboratory procedures for handling of samples, analysis and data storage have been enhanced. The procedures in handling of samples included traceability from field to results. We learned that obtaining good results does not only depend on getting to the laboratory but also on the procedures that all the team players follow.

Sharing knowledge

We learned that sharing information with all key stakeholders including farmers, seed regulators, university students and extension agents is key to changing people's perceptions of cassava

diseases. Prior to the start of phase two, very few farmers knew what CMD was in Luapula Province (Chikoti et al., 2016) and certainly not how to manage the disease. With the generation of information, and sharing it with farmers and extension agents, knowledge of the farmers concerning CMD has greatly improved. However, how packaging of information was critical. For farmers, simple illustrations in the form of leaflets with pictures of diseased plants helped considerably and this may have contributed to reduction of CMD in Zambia from highs of 52.0% in 2009 (Chikoti et al., 2013) to 48.9% in 2015 (unpublished).

Training at all levels

Training at all levels is key to meeting set objectives especially with the CDP. Empowering project implementers with necessary skills is critical in achieving targets. Under the CDP, we learned that if you train people charged with implementing the project it is easier to register successes. Equally if the recipient of the information is adequately trained then there is more chance that the information received will be put to good use. One example was during each round of surveys in Zambia, farmers were trained for 10–15 minutes on symptom recognition of CMD and CBSD and how to manage the disease.

Tasking responsibilities

Previously, the CTL was responsible for most of the activities under the CDP and this contributed to slow completion of targets. After attending the leadership training in Uganda in 2015, the CTL changed the approach to tasking responsibilities equitably among team members. For this to happen, it was ensured that all members were competent in their assigned area through in-house training or training organized by TARI-Mikocheni. This new approach saw the team achieving targets on time and more efficiently. From this, the team learned:

i) efficiency was achieved by sharing responsibilities
ii) a sense of belonging for each team member.

Challenges

Surveys – owing to Zambia's land area of 752,000 km^2, conducting surveys in one month proved difficult. Consequently, the surveys generally took more than three months. In addition, surveys were often conducted during the rainy season as this is the only time when disease symptoms are fully expressed on cassava plants. Zambia experiences one rainy season during November–April and the roads can become impassable especially in the countryside. Depending on weather conditions, on a day when it was raining, not more than three fields could be assessed; however, if it was not raining then 8–10 fields could be assessed.

The other challenge was that if the owner of a field was available then the more time was spent assessing the field because, after collecting data, the farmer was interviewed on what he or she thought about diseases. The scientists could then advise the farmer on how best to manage the crop concerning CMD.

Conclusions

The CDP in Zambia has scored many successes as highlighted in this monograph. The successes include investment in infrastructure both human and physical. The investment in this area has contributed to detection of cassava viruses in more detail than previously possible – the first time for

Zambia. As a country, we now know where different virus species are found. This is important as organizations supporting cassava production are now using this information to distribute clean materials, as opposed to buying infected materials from farmers and distributing the same. The seed regulator (SCCI) has also strengthened its capacity for seed inspection of cassava because of receiving direct training from CDP. Most importantly, CDP enabled close interaction with key stakeholders – mainly farmers and extension agents, local universities and international research institutes (IITA and Rothamsted Research) on joint research. Despite these successes there are still more challenges. The detection of CBSD in Zambia poses a major threat to cassava production for small-scale farmers. More and urgent investment is needed to contain the disease if the farmers are to remain productive. A formal seed system in cassava needs to be developed to ensure that farmers engaged in cassava production use clean seed as planting material. Awareness of CBSD needs to increase to reach all local partners: extension agents, farmers, NGOs and seed multipliers.

Publications and conference participation

In order to share the results generated by CDP-Zambia with the local and international scientific community, several articles have been published. The articles mainly focused on viruses and disease vectors occurring in Zambia. These include:

Chikoti, P.C., Ndunguru, J., Melis, R., Tairo, F., Shanahan, P. and Sseruwagi, P. (2013) Cassava mosaic disease and associated viruses in Zambia: occurrence and distribution. *International Journal of Pest Management*, 59:63–72.

Chikoti, P.C., Tembo, M., Chisola, M., Ntawuruhungu, P. and Ndunguru, J. (2015) Status of cassava mosaic disease and whitefly population in Zambia. *African Journal of Biotechnology*, 14:2539–2546.

Legg, J.P., Shirima, R., Tajebe, L.S., Guastella, D., Boniface, S., Jeremiah, S., Nsami, E., Chikoti, P. and Rapisarda, C. (2014) Biology and management of *Bemisia* whitefly vectors of cassava virus pandemics in Africa. *Pest Management Science*, 70(10):1446–1453.

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