# RWANDA

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## Abstract

The Cassava Diagnostics Project (CDP) aimed to (a) understand the threat from evolving viruses and vectors, (b) reach farmers directly and through partners, and (c) build sustainable regional capacity. The occurrence and distribution of cassava virus diseases – cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) – and the causal viruses in Rwanda were determined through three surveys in 2013, 2015 and 2017. The surveys were conducted in 10 major cassava-producing districts including: Bugesera, Kayonza, Kirehe and Nyagatare (Eastern Province), Kamonyi, Ruhango, Nyanza and Gisagara (Southern Province), Rusizi and Nyamasheke (Western Province) Districts. A total of 410 smallholder cassava fields were assessed for CMD and CBSD incidence and symptom severity, and adult whitefly abundance.

Mean CMD incidence ranged within 6.7–81.7% across the provinces sampled, and mean CBSD incidence within 0–20.5%. Molecular analysis results of the cassava mosaic begomoviruses (CMBs) affecting cassava in Rwanda indicated that *African cassava mosaic virus* (ACMV) and *East African cassava mosaic virus* (EACMV) occurred at very low levels – 0% and 1.18% of the samples, respectively. No co-infections of ACMV + EACMV were detected. The RT-PCR analysis showed the presence of two viruses causing CBSD: *Cassava brown streak virus* (CBSV) and *Uganda cassava brown streak virus* (UCBSV).

Farmers, extension staff and stakeholders were trained in 'training of trainers' workshops. Demonstration plots were established to show the benefits of using disease-free planting materials in pest and disease management. There were 1400 cassava stems distributed to smallholder farmers. With respect to raising awareness, leaflets were developed in the local language (Kinyarwanda) to help farmers gain a better understanding of the messages and information on cassava viral diseases, the whitefly vector and the management strategies.

Capacity was strengthened considerably in Rwanda through the training of one PhD and three MSc students. In addition, the Country Team Leader, her assistant and a Research Assistant received short-term training in a number of areas to enhance their performance of project activities. Training was provided for stakeholders including extension staff, agricultural officers, private company staff and smallholder farmers on field diagnosis and management of cassava viral diseases. Infrastructural capacity was enhanced though the acquisition of laboratory equipment and reagents to conduct molecular diagnostics.

# Acronyms and abbreviations

| | |
|---|---|
| ACMV | *African cassava mosaic virus* |
| CBSD | Cassava brown streak disease |
| CBSV | *Cassava brown streak virus* |
| CDP | Cassava Diagnostics Project |
| CMB | Cassava mosaic begomoviruses |
| CMD | Cassava mosaic disease |
| CTL | Country Team Leader |
| EACMV | *East African cassava mosaic virus* |
| ISAR | Institut des Sciences Agronomiques, du Rwanda |
| MAP | Months after planting |
| RAB | Rwanda Agricultural Board |
| SOP | Standard Operating Procedure |
| TARI | Tanzania Agriculture Research Institute |
| UCBSV | *Uganda cassava brown streak virus* |

# Results summary: Rwanda

## Aim I: Understand the threat from evolving viruses and vectors

### Objective 1: Disease epidemiology

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|---|---|
| **Disease and whitefly prevalence surveys conducted** | • Four surveys conducted in 2009, 2013, 2015 and 2017, covering 410 fields in 14 districts.<br>• Survey data for 2009, 2013 and 2015 were cleaned and validated by Tanzania Agriculture Research Institute (TARI)–Mikocheni and Cambridge modeling teams during the data entry and assembly workshop held from 27 November to 3 December 2016 in Dar es Salaam, Tanzania.<br>• A new SOP for 2017 countywide survey developed and used to collect 2017 data.<br>• Cassava leaf samples with Cassava mosaic disease (CMD) and Cassava brown streak disease (CBSD)-like symptoms, were collected for laboratory analysis. |
| **Relationship between CBSVs presence/load and disease symptom development determined** | • One manuscript published by Esperance Munganyinka from her PhD research (Munganyinka et al., 2018).<br>• Participated in the AgShare.Today Scientific Writing Workshop in Lusaka, 2–7 October 2017.<br>• Currently engaged on Objective 2 to quantify the viral loads of *Cassava brown streak virus* (CBSV)-infected plants in the DSMZ laboratory under the supervision of Dr Stephan Winter in Germany. |
| **Spread of CBSD within and between cassava fields** | • Ms Jeanine Umfuyisoni defended her MSc dissertation successfully in 2018 at Makerere University. |
| **Alternative hosts for CBSVs and CMBs and associated insect vectors identified** | • CBSV whole genome sequences obtained from non-cassava shrubs in Rwanda as part of Ms Jeanine Umfuyisoni's MSc research.<br>• One manuscript by Ms Umfuyisoni is in preparation to report on her MSc research. |

### Objective 2: Characterization of emerging viruses

| | |
|---|---|
| **Cassava virus isolates in the project countries sequenced and analyzed** | • CBSV and *Uganda cassava brown streak virus* (UCBSV) whole genomes were obtained and their genetic diversity studied. |
| **Cassava virus distribution maps for partner countries, generated (incidence, severity, whitefly)** | • Disease distribution maps produced and distributed to stakeholders. |

### Objective 3: Characterization of disease vectors

| TASKS | RESULTS |
|---|---|
| **Whiteflies characterized** | • Whitefly samples were collected and characterized – identifying the Rwanda species as SSA1. |

| | |
|---|---|
| **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 months after planting (MAP)** | • Twelve genotypes were indexed for cassava mosaic begomoviruses (CMBs) and CBSVs. These were promoted for disease management. |
| **Objective 9: Reaching farmers directly and through partners** | |
| **Farmers trained on CMD and CBSD disease symptom recognition and management strategies** | • Thirty farmers trained in CMD and CBSD symptom recognition and management at workshops. |
| **Demonstration plots for benefits of using virus-indexed planting materials established on-farm** | • Two demonstration plots were set up to train farmers in best practices to manage cassava diseases. Clean planting materials (1400 stems) distributed to farmers. |
| **Information materials developed and disseminated** | • There were 150 leaflets relating to cassava diseases and management printed and distributed to farmers and extension officers.<br>• Two radio programs on cassava diseases and their management were aired. |
| **Aim III: Build sustainable regional capacity** | |
| **Objective 10: Strengthening stakeholder linkages** | |
| **Team leader meeting to develop country-specific milestones** | • Rwanda Country Team Leader (CTL) and Assistant CTL participated in the development of country-specific milestones. |
| **Project inception and consultative meeting with stakeholders conducted** | • Rwanda CTL and Assistant CTL participated in project inception and consultative meetings. |
| **Exchange visits between scientists in the project countries conducted** | • Ms Marie C. Kanyange (CTL) and Assistant CTL, Mr Gervais Gashaka, participated in the first exchange visit to Zambia Agriculture Research Institute during 15–21 May 2016.<br>• The team visited the Cassava Diagnostics Project (CDP) research activities in Zambia including the new screenhouse and laboratories, and farmers' fields to assess the disease situation. |
| **Awareness on availability of diagnostic capacities created through training and different media** | • Awareness in diagnostic capacity was provided by CDP researchers to Rwanda Agricultural Board (RAB) scientists, university students and private-sector companies. |

| Objective 11: Strengthening human capacity and infrastructure | |
|---|---|
| **Human capacity** | |
| **Project staff recruited** | • Seven staff: one driver, one PhD and two MSc students, one Research Assistant, one Assistant CTL and one CTL. |
| **PhD and MSc trained on different aspects of cassava virus diseases** | • One PhD and one MSc student trained. |
| **Advanced specialized training and visits for project scientists (1–2 months) conducted** | • One staff member, Ms Marie C. Kanyange (CTL) together with other CTLs and TARI–Mikocheni project management team visited the Agricultural Research Organisation of Israel during 2–8 February 2014.<br>• CTL visited Rutgers University, USA, to learn analysis of begomoviruses in Rwanda in June 2015 with the instruction of Prof Siobain Duffy. |
| **Project staff trained on IP, biosafety issues and communication strategies** | • CTL attended training in intellectual property and communication strategies during 27–31 October 2014 at the World Agroforestry Center (ICRAF), Nairobi, Kenya. |
| **Project results and information disseminated** | • One manuscript published in 2018 by PhD student Esperance Munganyinka – on relationship between CBSV presence and disease development.<br>• One manuscript published in 2018 by MSc student Concilie Nyirahorana on influence of CBSD control measures on cassava production in Bugesera and Ruhango Districts<br>• Four annual meeting reports. |
| **Institute Directors trained in Leadership and management** | • One Director of RAB attended the 'Leadership Skills for Institutional Directors' conducted in July 2014 in Entebbe, Uganda, and Kigali, Rwanda. |
| **Infrastructure strengthening** | |
| **Greenhouses constructed/renovated** | • One screenhouse renovated at Rubona and is in use. |
| **Vehicles, laboratory equipment and consumables procured** | • One project vehicle procured and in use.<br>• Various equipment procured and in use. |
| **Project management** | • One RAB Institute Accountant, participated in the workshop on accounting package TALLY, during 14–17 May 2013 in Dar es Salaam, Tanzania.<br>• The CTL, Ms Marie C. Kanyange, participated in the financial management training workshop in Kigali, Rwanda, in 2015.<br>• CTL and two students attended the AgShare.Today training and scientific report writing skills in January 2016 in San Diego, USA. |

# Background

Cassava was introduced to Rwanda around 1932 and is grown across the country in North Province, East Province and West Province (Figure 1). It is an important staple food and is currently being promoted as a cash crop through the establishment of cassava processing plants. In addition to its tuberous root, its leaves are treated as a vegetable called isombe, which is rich in protein and vitamins. Cassava is consumed in various forms (raw, paste/bread or ugali, boiled for breakfast, mixed with beans, vegetables, etc.) and its cooking and preparation methods vary from one individual to another. Although cassava is a major food crop, its production is threatened by the two most devastating viral diseases: cassava brown streak disease (CBSD) and cassava mosaic disease (CMD). Since 2015, cassava yield has declined considerably, due to the pandemic of CBSD and CMD, a collapsed seed system and supply mechanism, low productivity, poor market linkage between producers and processors, and poor agricultural practices and processes.

The CBSD poses a serious threat to cassava productivity in East and Central Africa – it was first reported in 1936 in Tanzania and currently occurs in almost all East and Central African countries. In Rwanda, the disease was first reported by the Institut des Sciences Agronomiques du Rwanda (ISAR) in 2009 (ISAR, 2009 unpublished data) and has since been reported by the Rwanda Agricultural Board (RAB) to have spread widely in the main cassava growing areas of the country: Southern and Eastern Provinces (RAB, 2012 unpublished data).

Little work has been done in Rwanda to document the distribution, incidence and severity of CBSD; hence there is limited knowledge on the viruses responsible for the disease and their genetic diversity and distribution in the country. In East Africa, some epidemiological studies on CBSD have been undertaken, but significant knowledge gaps exist due to the variability in patterns of disease symptom expression. In addition, it is not clear whether symptom development is dependent on the virus species – *Uganda cassava brown streak virus* (UCBSV) or *Cassava brown streak virus* (CBSV) – or virus load or virus localization. There is a need to raise the level of knowledge on the disease, since this is crucial for developing effective and efficient diagnostic and management tools – this was achieved in one PhD student's research.

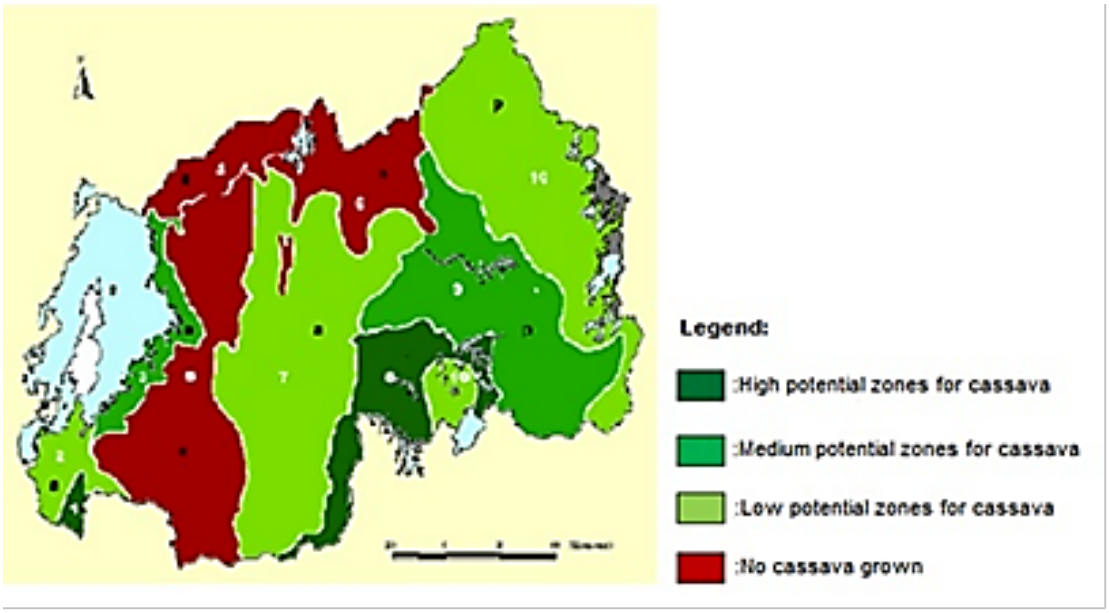


Figure 1 Major agro-ecological zones in Rwanda (adapted from Bazarusanga et al., 2011)

Under ideal growing conditions, disease-free cassava can yield more than 30 t/ha. However, despite attributes such as drought tolerance and low input requirements, yield is poor in Rwanda with 8–10 t/ha.

# SECTION ONE: Understanding the threat from evolving viruses and vectors

## Disease epidemiology

Four countrywide disease monitoring surveys were carried out in 2009, 2013, 2015 and 2017. In 2009, fields were assessed 3–6 months after planting (MAP) for CMD and after 6 MAP for CBSD. The 2013 survey was conducted during July–August in seven cassava growing districts: Kayonza, Kirehe, Nyagatare and Bugesera (Eastern Province); and Ruhango, Nyanza and Gisagara (Southern Province). A total of 67 and 137 fields were surveyed for CMD and CBSD, respectively, and 612 samples were collected for virus analysis. In 2015, a countrywide survey was conducted during May–June, with a total of 100 and 193 fields surveyed for incidence and severity of CMD and CBSD, respectively. About 879 samples were collected for virus analysis from 10 districts: Kayonza, Kirehe, Nyagatare and Bugesera (Eastern); Kamonyi, Ruhango, Nyanza and Gisagara (Southern); and Rusizi and Nyamasheke (Western). Another countrywide survey was conducted in June 2017. A total of 100 and 137 fields were surveyed for incidence and severity of CMD and CBSD, respectively. A total of 705 samples were collected for virus analysis from Kayonza, Kirehe, Nyagatare and Bugesera (Eastern); Kamonyi, Ruhango, Nyanza and Gisagara (Southern); and Rusizi and Nyamasheke (Western). The whitefly population was assessed by counting numbers of adult whitefly on the five upper fully expanded apical leaves and samples collected in 80% ethanol for species identification and genetic diversity analysis. Geo-coordinate points for each field were taken using a GPS receiver to produce distribution maps for cassava diseases and whitefly abundance in Rwanda.

### CMD incidence and symptom severity

In 2009, CMD incidence in Eastern districts ranged within 30.8–42.2%; in Southern districts it was 11.7–81.7% and in Western districts was 6.7–44.0% (Figure 2). Incidence and severity distribution maps from this survey are shown in Figure 3.

In 2013, CMD incidence was moderate (20.7%) in Nyagatare District, but low in the remaining districts (<10%). The moderate incidence in Nyagatare was probably due to the predominant use of local varieties susceptible to CMD. The CMD severity was severe (>3) in all districts except Gisagara (2.8). Cassava fields with high CMD incidence were more prevalent in the south and north than in the east. The distribution of cassava fields with severe CMD followed a similar trend.

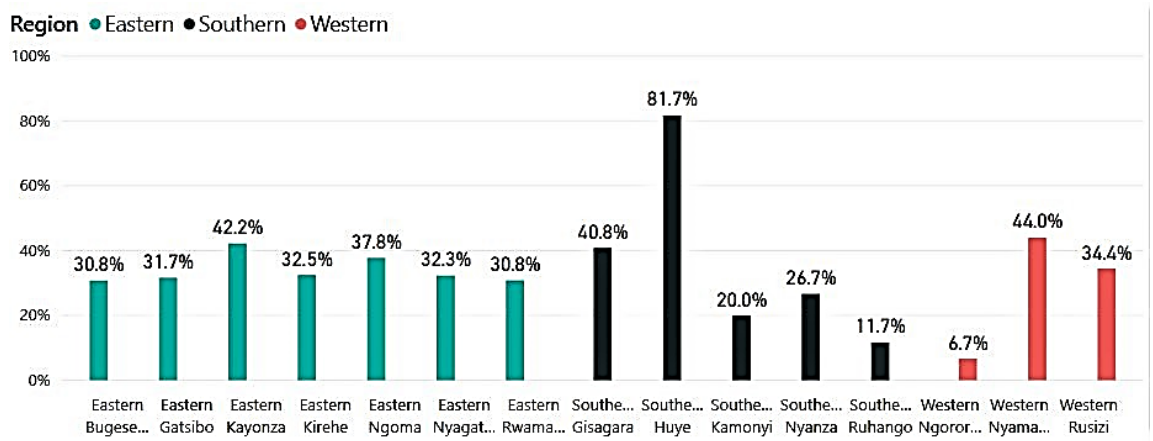


Figure 2 CMD incidence in districts – 2009 survey

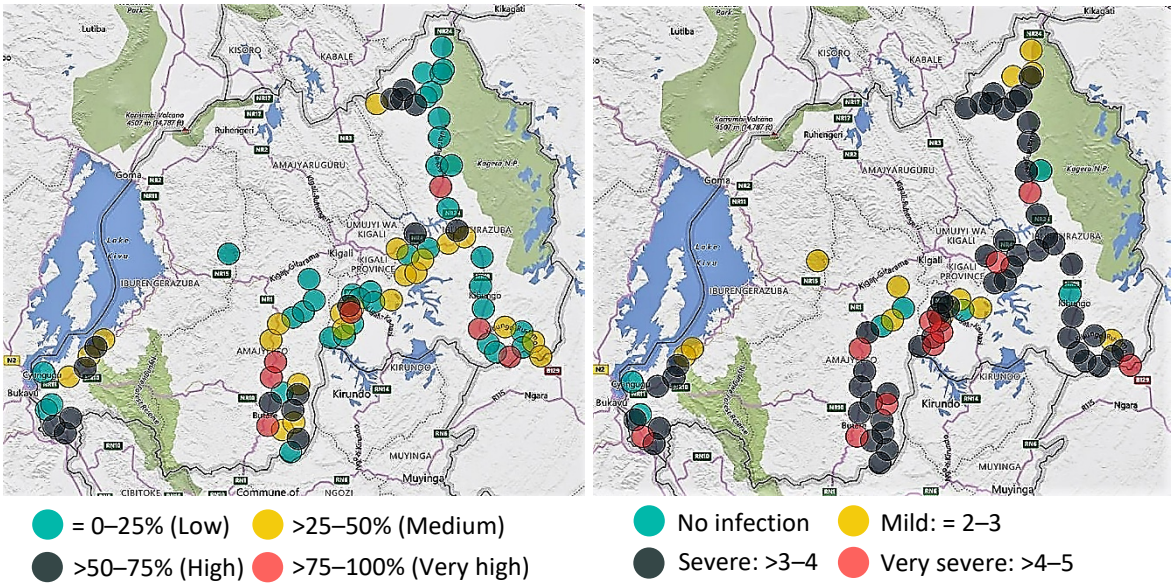


Figure 3 CMD – 2009 survey: (left) incidence and (right) severity

In 2015, CMD incidence in Eastern districts ranged within 0–33.8%, in Southern districts it was 0–9.6% and in Western districts was 4.2–10% (Figure 4). Incidence and severity distribution maps from this survey are shown in Figure 5. CMD incidence was high (>50%) in Nyagatare District, and moderate (20–40%) in Kayonza and Kirehe Districts but was low in the remaining districts (<20%). The CMD severity was severe (>3) in all Eastern districts, and in Nyamasheke District of Western Province. Most cassava fields had low to moderate disease incidence and mild symptoms in the surveyed areas.

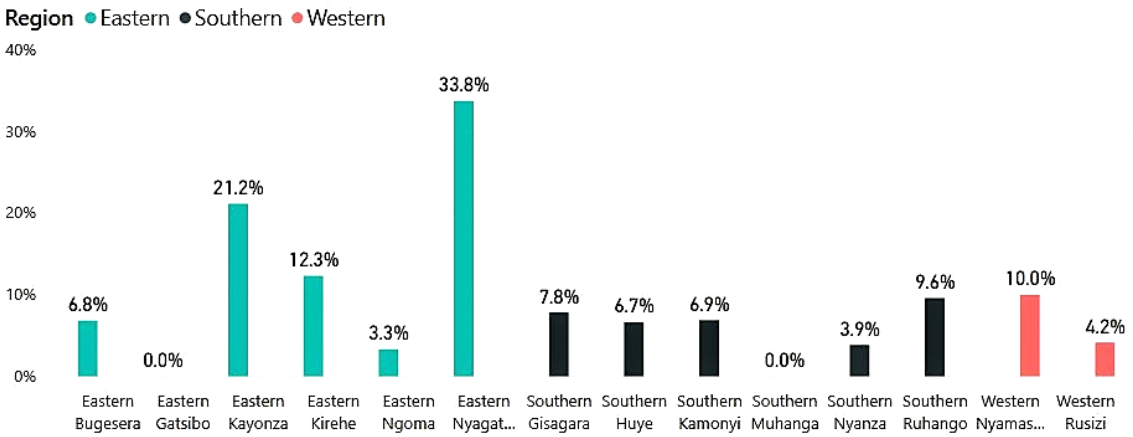


Figure 4 CMD incidence in districts – 2015 survey

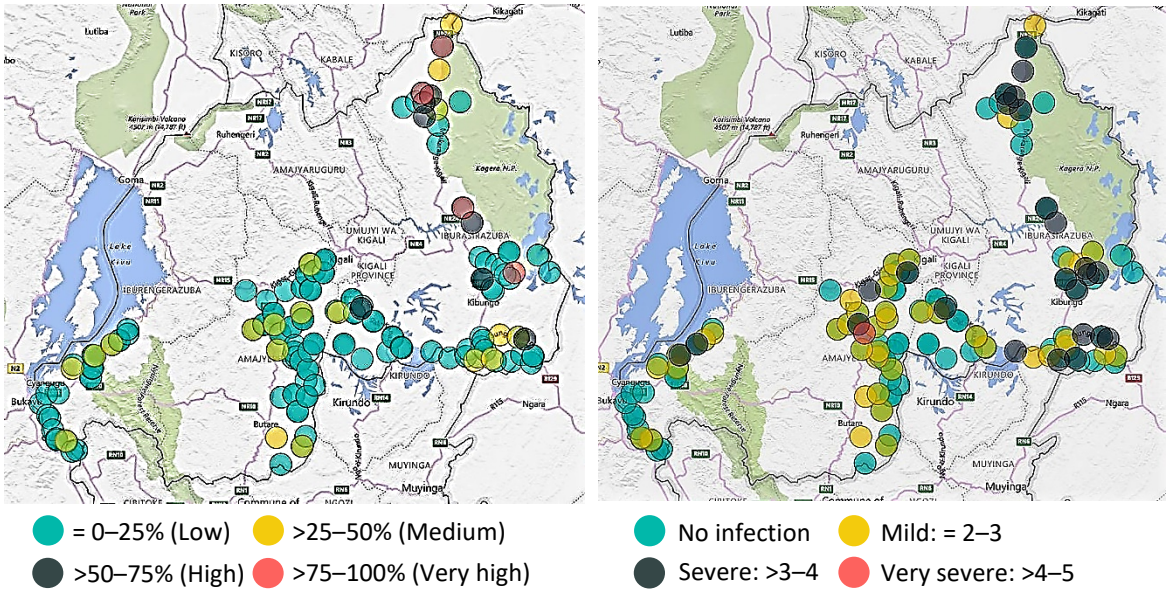


Figure 5 CMD – 2015 survey: (left) incidence and (right) severity

## CBSD incidence and severity

In 2009, CBSD incidence in Eastern districts ranged within 0–20.5%, in Southern districts was 0–10% and in Western districts was 0–1.1% (Figure 6). Incidence and severity distribution maps from this survey are shown in Figure 7.

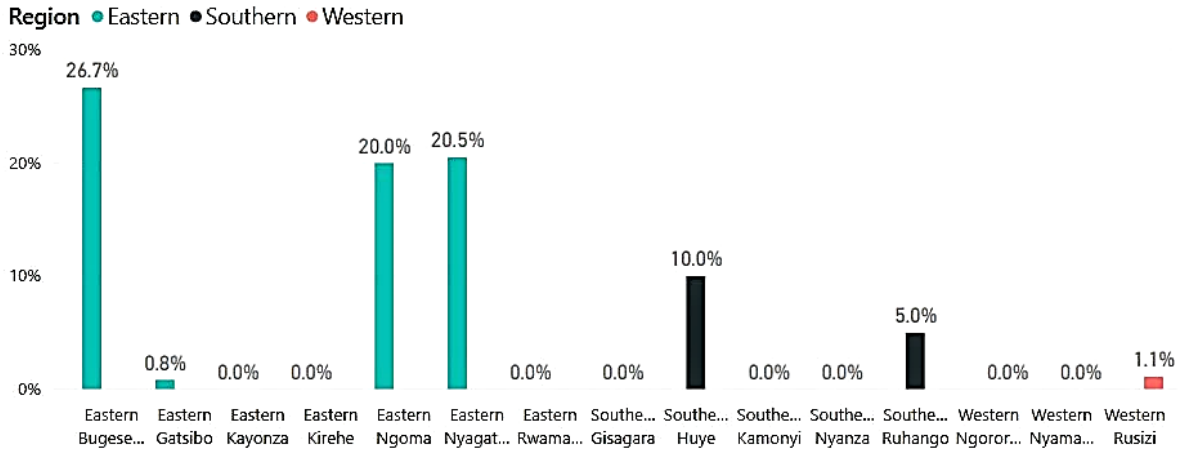


Figure 6 CBSD incidence by district – 2009 survey

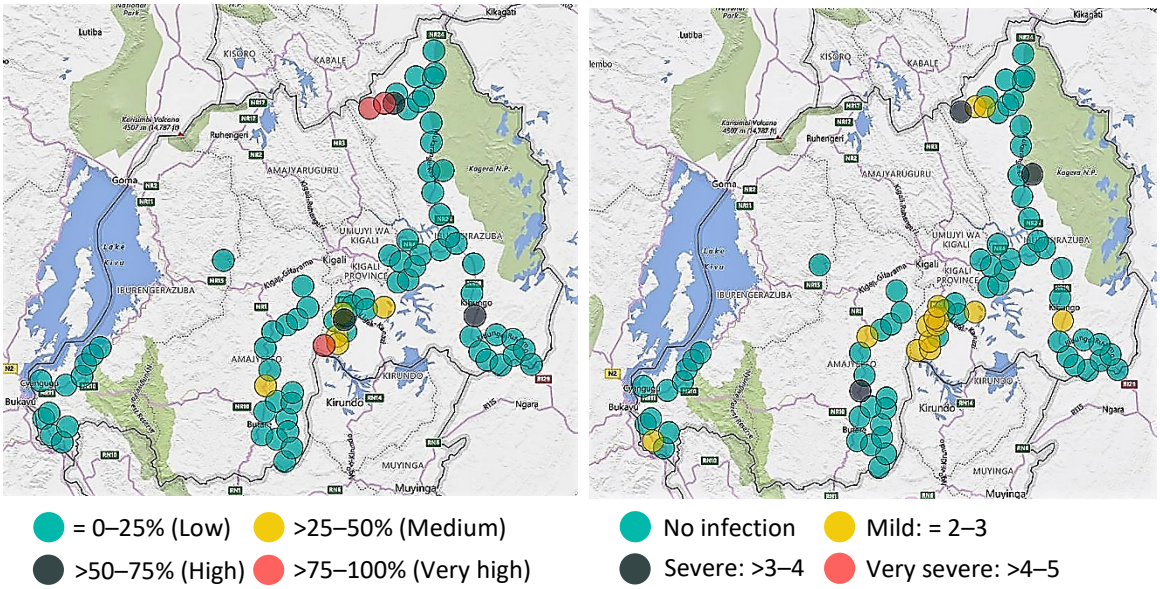


Figure 7 CBSD – 2009 survey: (left) incidence and (right) severity

In 2013, mean CBSD foliar incidence was very low (4–12%) in all districts; however, mean root incidence was high (52–66.6%) in Bugesera, Kirehe, Nyagatare and Ruhango Districts. The CBSD symptom severity was assessed on foliage, stems and roots. There were no symptoms on stems in all districts. The CBSD severity on foliage was in the range of 2.0–2.5 in Bugesera, Kirehe, Nyagatare, Ruhango and Nyanza. The severity on roots was moderate and ranged within 2.1–2.5 in all districts.

In 2015, CBSD incidence in Eastern districts ranged within 0–37.7%, in Southern districts was 20–77.8% and in Western districts was 4.2–10.8% (Figure 8). Incidence and severity distribution maps from this survey are shown in Figure 9. Foliar incidence of CBSD was high (>40%) in Kamonyi, Ruhango, Nyanza Gisagara and Bugesera. The CBSD root necrotic symptoms were high (>30%) in Bugesera, Kamonyi, Nyanza, Ruhango and Gisagara Districts. The CBSD leaf symptoms were severe (3–4) in Nyamasheke and Gisagara. The CBSD root necrosis was severe (>3) in Kirehe, Kamonyi, Ruhango and Nyanza.

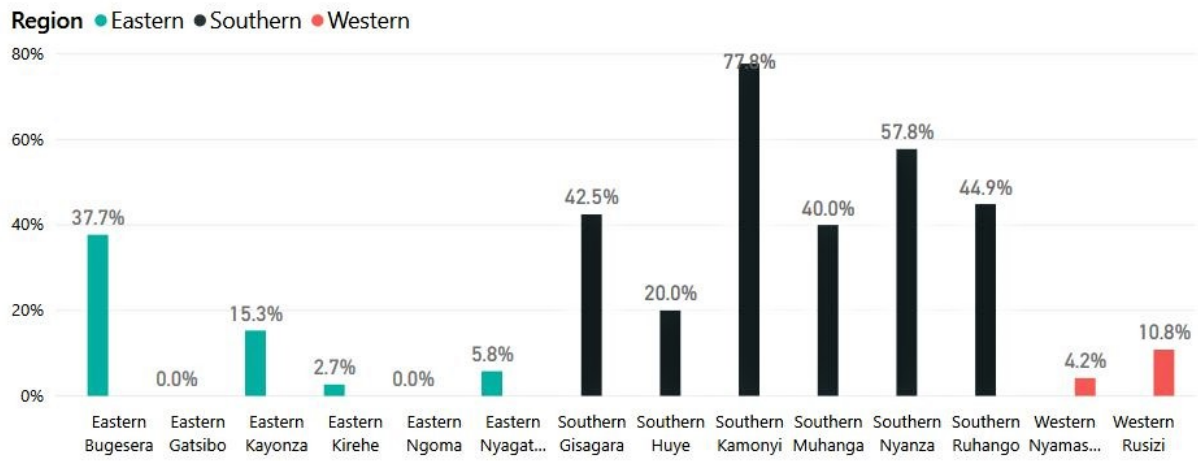


Figure 8 CBSD incidence by district – 2015 survey

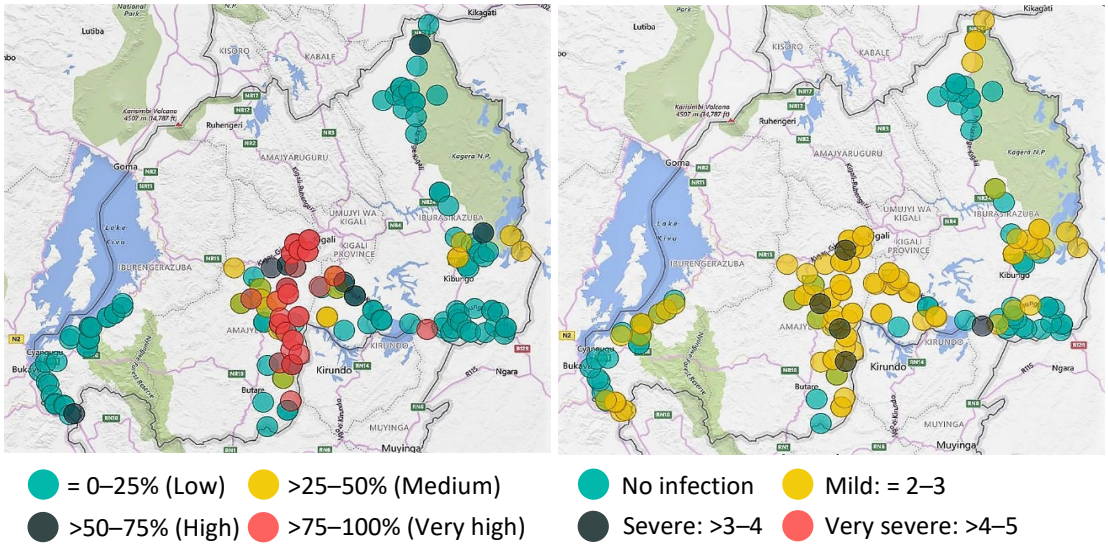


Figure 9 CBSD – 2015 survey: (left) incidence and (right) severity

In 2009, mean whitefly abundance was 2.77 (52 fields), 0.46 (18 fields) and 1.04 (12 fields) in Eastern, Southern and Western provinces, respectively. In 2013, the mean whitefly abundance was 31.64 (62 fields) and 61.24 (41 fields) in Eastern and Southern Provinces, respectively. In 2015, mean whitefly abundance was 29.63 (73 fields), 23.07 (61 fields) and 0.52 (28 fields) in Eastern, Southern and Western Provinces, respectively.

# Characterization of emerging viruses

## Cassava virus isolates sequenced and analyzed

Plant material from the countrywide field surveys were subjected to molecular tests using primers defined in Mbanzibwa et al. (2009). Molecular characterization of CBSVs was done for 300 samples. Analyses revealed the presence of CBSV and *Uganda cassava brown streak virus* (UCBSV). The RT-PCR analysis for CBSVs showed high levels of CBSV infection (10%) followed by UCBSV (9.67%) and 1.67% co-infected plants. Co-infection was found in Southern Province (Nyanza and Gisagara Districts) and Eastern Province (Bugesera District) (Table 1).

Table 1 Detection of CBSVs in Rwanda, 2015

| District | Number of samples | CBSVs | | | Total |
|---|---|---|---|---|---|
| | | CBSV | UCBSV | CBSV + UCBSV | |
| Kayonza | 30 | 3 | 0 | 0 | **3** |
| Kirehe | 30 | 0 | 0 | 0 | **0** |
| Nyagatare | 30 | 0 | 0 | 0 | **0** |
| Bugesera | 30 | 2 | 4 | 1 | **7** |
| Kamonyi | 30 | 9 | 1 | 0 | **10** |
| Ruhango | 30 | 6 | 2 | 0 | **8** |
| Nyanza | 30 | 7 | 9 | 3 | **19** |
| Gisagara | 30 | 3 | 8 | 1 | **12** |
| Nyamasheke | 30 | 0 | 0 | 0 | **0** |
| Rusizi | 30 | 0 | 5 | 0 | **5** |
| **Total** | **300** | **30** | **29** | **5** | **64** |
| **Percent** | | **10.0** | **9.7** | **1.7** | **22.9** |

Two cassava mosaic begomovirus (CMB) species: *African cassava mosaic virus* (ACMV) and EACMV were detected in the samples tested in 2013 and 2015. No co-infections were found in 2013; however, in 2015, co-infections were detected (approximately 1%; Table 2). The 2013 survey showed the presence of EACMV in all districts except Ruhango and Kayonza. In 2015, the survey indicated both EACMV and ACMV in different districts, with EACMV present in all districts except Nyanza, Rusizi and Nyamasheke, and ACMV present in Nyanza and Nyamasheke.

**Table 2 Summary of CMB detections in 2013, 2015 and 2017 in Rwanda**

| Year | ACMV | EACMV | ACMV+ EACMV | Total |
|---|---|---|---|---|
| 2013 | 0 | 18 (1.18%) | 0 | 152 |
| 2015 | 6 (2.15%) | 25 (8.96%) | 3 (1.07%) | 279 |

## Epidemiology and distribution of CBSD in Rwanda

In Rwanda, recent research efforts focused on CBSV detection and determination of incidence, severity and whitefly counts by conducting diagnostic surveys. However, the Rwandan isolates of CBSVs were unknown, representing a big gap in knowledge of epidemiology and management of CBSD in Rwanda. Also, there have been no reports on the potential roles of non-cassava plant species acting as virus reservoirs or alternative hosts in the perpetuation of CBSVs in Rwanda and at region level. Increased availability of sequences of isolates from wild species may provide more information on the evolution of CBSV and UCBSV and thus improve our awareness of the adaptation of these viruses to cassava as a new host. It is therefore very important to know the different isolates of CBSD causal agents in cassava and identify the alternative hosts for CBSV and UCBSV, and then develop appropriate diagnostic tools for proper management of CBSD in Rwanda. This work was addressed by one of our MSc students, Mrs Jeanine Umfuyisoni.

Based on 2015 cassava disease survey data from young cassava fields (3–6 MAP), the study established that CBSD incidence and severity had increased from 18.8% and 2.1 in 2012, respectively, to 27.39% and 2.4 in 2015. The disease occurred at a moderate severity score that had increased by 0.3 (using a scale of 1–5) during the three years. The study also established the diversity of CBSVs affecting cassava crops in Rwanda and at least five different isolates were confirmed to be the main CBSD causal agents and indicated a greater genetic variability among UCBSV than CBSV isolates. This fact, coupled with the much wider distribution of UCBSV than CBSV, suggests that UCBSV is likely to be the endemic species associated with cassava in Rwanda. Five non-cassava plant species were identified as CBSV hosts in Rwanda. This is an important factor in designing proper management strategies for cassava viral diseases.

## The relationship between CBSV presence and disease development

The main objective of the study contributes to the knowledge of CBSV biology and epidemiology. This work was part of the PhD research of Ms Espérance Munganyinka (Jomo Kenyatta University of Agriculture and Technology, Kenya), and the findings are published in Munganyinka et al. (2017).

# Characterization of disease vectors

Whitefly samples were collected and characterized using the *mtCO1* gene. The whitefly species was identified as SSA1.

# SECTION TWO: Integrated pest management

## Conventional breeding support

### Breeders' material monitored for disease

After harvesting the advanced yield trial crop (AYT), 11 clones were tested for uniformity yield trials (UYT) in different locations in 2016. The results at 6 MAP showed that CMD and CBSD incidence and severity had different levels on improved varieties. The incidence and severity varied among locations: high at Karama and Rubona but relatively low at Nyagatare. At Karama Research Station, the highest CBSD incidence was 36.4% on leaves and the highest severity score was 3 on leaves. The highest incidence of CMD was 28.4% and the highest severity score was 2.3 (Table 3). At Nyagatare Research Station, the clone with the highest CBSD incidence had 25.8% on leaves and mean severity of 2; the highest incidence of CMD was 3.1% and the highest severity score was 2 (Table 4). At Rubona Research Station, the highest incidence was 8.1% with severity score of 2.5 for CMD and the high incidence was 26.6% with severity score of 2 for CBSD (Table 5).

**Table 3 Incidence and severity of CMD and CBSD at Karama Research Station at 6 MAP (UYT)**

| No. | Names of clones | CMD incidence (%) | CMD severity | CBSD incidence (%) | CBSD severity |
|---|---|---|---|---|---|
| 1 | 01/1371-5 | 0 | 1 | 2.9 | 2 |
| 2 | TME 419/60 | 1 | 2 | 0 | 1 |
| 3 | 05/0099/17 | 0 | 1 | 13.8 | 2.7 |
| 4 | UNKNOWN 1 | 8.3 | 2.3 | 36.4 | 3 |
| 5 | UNKNOWN 2 | 0 | 1 | 11.5 | 2.5 |
| 6 | 06/2357-2 | 0.8 | 2 | 1.9 | 2.5 |
| 7 | 05/0127/35 | 8.1 | 2 | 8.2 | 2 |
| 8 | 01/1206/75 | 0 | 1 | 0 | 1 |
| 9 | 06/1630-1 | 0 | 1 | 4.3 | 2 |
| 10 | GARUKUNSUBIRE | 2.9 | 2 | 21.8 | 2.3 |
| 11 | 05/1814-4 | 28.4 | 2.5 | 15.8 | 2 |
| 12 | 01/1412/63 | 4.4 | 2 | 2.9 | 2 |

**Table 4 Incidence and severity of CMD and CBSD at Nyagatare Research Station at 6 MAP (UYT)**

| No. | Names of clones | CMD incidence (%) | CMD severity | CBSD incidence (%) | CBSD severity |
|---|---|---|---|---|---|
| 1 | 01/1371-5 | 0 | 1 | 0 | 1 |
| 2 | TME 419/60 | 0 | 1 | 0 | 1 |
| 3 | 05/0099/17 | 0 | 1 | 0 | 1 |
| 4 | UNKNOWN 1 | 0 | 1 | 0 | 1 |
| 5 | UNKNOWN 2 | 0 | 1 | 4.5 | 2 |
| 6 | 06/2357-2 | 0 | 1 | 4 | 2 |
| 7 | 05/0127/35 | 0 | 1 | 0 | 1 |
| 8 | 01/1206/75 | 0 | 1 | 25.8 | 2 |
| 9 | 06/1630-1 | 0 | 1 | 0 | 1 |

| No. | Names of clones | CMD incidence (%) | CMD severity | CBSD incidence (%) | CBSD severity |
|---|---|---|---|---|---|
| 10 | GARUKUNSUBIRE | 3.1 | 2 | 0 | 1 |
| 11 | 05/1814-4 | 0 | 1 | 3.8 | 2 |
| 12 | 01/1412/63 | 0 | 1 | 0 | 1 |

**Table 5 Incidence and severity of CMD and CBSD at Rubona Research Station at 6 MAP (UYT)**

| No. | Names of clones | CMD incidence (%) | CMD severity | CBSD incidence (%) | CBSD severity |
|---|---|---|---|---|---|
| 1 | 01/1412/63 | 0 | 1 | 9 | 2.3 |
| 2 | TME 419/60 | 0 | 1 | 11.3 | 3.3 |
| 3 | Unknown 1 | 2.4 | 2.1 | 11 | 3 |
| 4 | Unknown 2 | 0 | 1 | 4.6 | 2.1 |
| 5 | 05/0127/35 | 0 | 1 | 13.7 | 2.6 |
| 6 | 01/1371-5 | 0 | 1 | 2 | 4 |
| 7 | 06/1630-1 | 0 | 1 | 19 | 4.6 |
| 8 | 05/0099/17 | 0 | 1 | 26.6 | 2.6 |
| 9 | CYIZERE | 8.1 | 2.5 | 11 | 2.8 |
| 10 | 01/1206/75 | 0 | 1 | 6.5 | 2 |
| 11 | 06/2357-2 | 3 | 2 | 7.4 | 2.5 |
| 12 | 05/1814-4 | 0 | 1 | 9.8 | 2.8 |

After harvesting CET, 11 clones were advanced at PYT for further testing in different locations in 2017. At 6 MAP, CMD and CBSD incidence and severity showed different levels on improved varieties. The incidence and severity varied between locations: high at Karama and relatively low at Rubona. The following clones were evaluated: MM06/0090-OP/12, MM06/0128-OP/1, MM06/0128-OP/4, MM06/0128-OP/3, MM06/0128-OP/10, Bulk/35, Bulk/16, NASE14 (Check), MH05/0091-OP/11, Bulk/13, MH05/0091-OP/12 and NAROCASS1. At Karama, two clones (MM06/0128/1 and Bulk/35) out of 11 showed no CMD or CBSD leaf symptoms at 6 MAP. Three clones showed CBSD symptoms on leaves. The clone with highest CBSD incidence had 50% on leaves and the clone with the highest CBSD severity had a score of 3. The highest incidence of CMD was 93% and the highest severity score was 3 (Table 6). At Rubona, two clones (MM06/0090-OP/12 and MM06/0128-OP/3) out of 12 showed CMD leaf symptoms with severity score 3. For CBSD, three clones (MM06/0128-OP/4, MH05/0091-OP/11 and MH05/0091-OP/12) showed CBSD leaf symptoms at 6 MAP with severity score 3 (Table 7).

Table 6 Incidence and severity of CMD and CBSD at Karama Research Station at 6 MAP (PYT)

| No. | Names of clones | CMD incidence (%) | CMD severity | CBSD incidence (%) | CBSD severity |
|---|---|---|---|---|---|
| 1 | Bulk/13 | 44.8 | 3 | 0 | 1 |
| 2 | MM06/0128/4 | 48.0 | 3 | 0 | 1 |
| 3 | Bulk/16 | 37.9 | 3 | 0 | 1 |
| 4 | MM06/0128/1 | 0 | 1 | 0 | 1 |
| 5 | MH05/0091/12 | 12.5 | 3 | 0 | 1 |
| 6 | MM06/0128/3 | 93.3 | 3 | 33.3 | 2 |
| 7 | MM06/0128/10 | 50.0 | 3 | 50 | 3 |
| 8 | MH05/0091/11 | 5.7 | 2 | 28.6 | 3 |
| 9 | Bulk/35 | 0 | 1 | 0 | 1 |
| 10 | MH97/0105 (Check) | 8.8 | 2 | 100 | 3 |
| 11 | MM06/0090/12 | 69.2 | 2.5 | 0 | 1 |

Table 7 Incidence and severity of CMD and CBSD at Rubona Research Station at 6 MAP (PYT)

| No. | Names of clones | CMD incidence (%) | CMD severity | CBSD incidence (%) | CBSD severity |
|---|---|---|---|---|---|
| 1 | Bulk/13 | 1.0 | 3 | 0 | 1 |
| 2 | MM06/0128/4 | 1.5 | 3 | 2 | 3 |
| 3 | Bulk/16 | 4.0 | 3 | 0 | 1 |
| 4 | MM06/0128/1 | 0 | 1 | 0 | 1 |
| 5 | MH05/0091/12 | 1 | 3 | 1 | 3 |
| 6 | MM06/0128/3 | 5.5 | 3 | 0 | 1 |
| 7 | MM06/0128/10 | 1 | 3 | 0 | 1 |
| 8 | MH05/0091/11 | 0 | 1 | 4.5 | 3 |
| 9 | Bulk/35 | 1 | 3 | 0 | 1 |
| 10 | NASE14 (Check) | 0 | 1 | 0 | 1 |
| 11 | MM06/0090/12 | 4.3 | 3 | 0 | 1 |

## Reaching farmers directly and through partners

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

Thirty farmers from Bugesera and Ruhango Districts were trained on diagnosis of cassava viral diseases through observation of symptoms, pest and disease scoring, and management options (Figure 10 and Figure 11).


**Figure 10 Assessing performance of demonstration plots at Bugesera site (A), farmer weighing NASE14 (B) and CBSD symptoms on variety Ndamirabana used as check (C) in 2017**


**Figure 11 Assessing performance of demonstration plots at Ruhango site (A), farmer weighing NASE14 (B) and CBSD symptoms on variety Rutanihisha used as check (C) in 2017**

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

The demonstration plots were established in Bugesera and Ruhango Districts. At harvesting time in December 2015, data were collected on yield (Table 8 and Table 9). At Bugesera site, farmers appreciated the performance of improved variety, MM98/0105, with yield of 31.6 t/ha compared to the local variety with 9.2 t/ha.

**Table 8 Demonstration plot harvest in Bugesera (80 $m^2$)**

| Year | Varieties | No. plants harvested | No. roots marketable | No. roots non-marketable | Weight marketable | Weight non-marketable | Total roots | Weight (kg) | Yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | MH98/0105 | 71 | 310 | 160 | 232 | 21 | 470 | 253 | 31.6 |
| | Garukunsubire | 44 | 172 | 100 | 62 | 12 | 272 | 74 | 9.2 |
| 2017 | NASE14 | 40 | 174 | 57 | 38 | 4.4 | 231 | 42.4 | 5.3 |
| | Ndamirabana | 36 | 121 | 145 | 42.6 | 14 | 266 | 56.6 | 7.1 |

**Table 9 Demonstration plot harvest in in Ruhango (80m$^2$)**

| Year | Varieties | No. plants harvested | No. roots marketable | No. roots non-marketable | Weight marketable | Weight non-marketable | Total roots | Weight (kg) | Yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | MH98/0105 | 65 | 210 | 60 | 69 | 27 | 270 | 96 | 13.7 |
| | Cyizere | 25 | 72 | 50 | 22 | 8 | 122 | 30 | 6.3 |
| 2017 | NASE 14 | 64 | 270 | 135 | 135 | 13.5 | 405 | 148.5 | 18.5 |
| | Rutanihisha | 34 | 81 | 60 | 41 | 7.5 | 141 | 48.5 | 6.1 |

After harvesting, we disseminated the improved variety to 14 farmers from two sites, Nemba and Batima, in Rweru Sector of Bugesera District with 100 cuttings per farmer (Table 10). A total of 1400 cuttings were disseminated. Eight women and six men participated in this event. At Ruhango site, the performance of improved variety MM98/0105 was not good due to susceptibility to CBSD. Its yield was 13.7 t/ha and the local variety was 6.3 t/ha. Due to CBSD susceptibility of the improved variety, the planting materials were not disseminated.

**Table 10 Dissemination of cuttings in Rweru Sector of Bugesera District in Rwanda**

| Sector | Sites | Villages | No. of male | No. of female | No. of cuttings received |
|---|---|---|---|---|---|
| **Rweru** | Nemba | 10 | 6 | 4 | 1000 |
| | Batima | 4 | 0 | 4 | 400 |
| | **Total** | **14** | **6** | **8** | **1400** |

## Information materials developed and disseminated

### Training

There were 150 leaflets developed, printed and disseminated to farmers.

### Awareness

Two radio talks were done on cassava virus diseases and farmers were free to ask questions about cassava virus diseases.

### Participation in agriculture show

To disseminate project information on project activities to different stakeholders promoting cassava production in Rwanda, the team participated in the agriculture show held at Mulindi in June 2016. The stand was visited by farmers, students and agricultural extension agents. During the 10-day period, about 793 show-goers interacted with the team on various subjects including insect pests and diseases affecting cassava, cassava varieties and yields (Figure 12).

Figure 12 CDP-Rwanda team at the agriculture show in Mulindi, June 2016

# Build sustainable regional capacity

## Project inception and consultative meeting with stakeholders

Two Rwanda Agricultural Board staff including the Country Team Leader (CTL), Ms Marie C. Kanyange, and the Assistant CTL, Mr Gervais Gashaka, participated in the development of the country-specific milestones during the project inception and consultative meeting with stakeholders.

## Stakeholder engagement

A number of stakeholders were approached and contact maintained throughout the project. These interested parties ranged from University departments to research institutions and to government departments (see Table 11).

**Table 11 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) |
|---|---|---|---|---|---|
| Rwanda Agricultural Board | Rubona, (Southern Province) | NARS (Project partner) | Ms Marie C. Kanyange (CTL) and Mr Gervais Gashaka, (Assis. CTL/Cassava Breeder) | Hosting the project, breeding for resistance to CMD and CBSD and disease diagnostics | Ms Marie C. Kanyange, Mr Gervais Gashaka |

| Institution | Location | Partnership/ Type of stakeholder | Respondent(s) | Role | Contact person(s) |
|---|---|---|---|---|---|
| | | NARS (Non-project staff) | Mr Jean Lambert Rurangwa (Quality Seed Control Officer), Mr Jervais Ngererwa (Coordinator of Seed Production Services), Ms Concilie Nyirahorana (Social Economist) and Mr Felix Gatunzi (Research Officer) | Social economics, seed certification and tissue culture | Mr Jean Lambert Rurangwa, Mr Jervais Ngererwa, Ms Concilie Nyirahorana |
| University of Rwanda | Butare | Universities (stakeholders) | Dr Solange Uwituze (Dean of Faculty of Agriculture), Dr Charles Bucagy (Head of Department, Crop and Horticulture) | Training and supervision of students | Dr Solange Uwituze |
| NGO-INGABO | | NGO | Mr Ntehomvukiye Frav (Agronomist) | Seed multiplication and distribution | Mr Ntehomvukiye Frav |
| Ituze Farmers' Cooperative | Ituze | Farmers' Cooperative | Mr Sibomana Pascal, (Ituze Cooperative Leader) | Cultivation and processing of cassava | Mr Sibomana Pascal |
| Kinazi Cassava Processing Plant | Kinazi | Cassava processing facility | Mr Robert Runazi, (Director General) | Processing | Mr Robert Runazi |

## Exchange visits between scientists in the project countries

Ms Marie C. Kanyange (CTL) and Mr Gervais Gashaka (Assistant CTL) participated in the first exchange visit to Zambia Agriculture Research Institute during 15–21 May 2016. They visited the Cassava Diagnostics Project (CDP) research activities in Zambia including the new screenhouse and laboratories, and farmers' fields to assess the disease situation.

## Outreach to regional virologists in non-project countries

Ms Jeanine Umfuyisoni accompanied the TARI–Mikocheni CDP team (Dr J. Ndunguru, Dr P. Sseruwagi and Dr F. Tairo) and Dr Laura Boykin on a fact-finding mission to Madagascar in January 2017. She was instrumental in helping the visiting team in translation of French and English with the hosts in Madagascar. The visit aimed to establish collaboration and exchange experiences on cassava virus diagnostics, field disease assessments and management.

# Strengthening human capacity and infrastructure

## Human capacity staff in Rwanda

### Project staff recruited

| Name | Position |
|---|---|
| Marie C. Kanyange | CTL |
| Gervais Gashaka | Assistant CTL |
| Ghislain Niyonteze | Research Assistant |
| Esperance Munganyinka | PhD student |
| Jeanine Umfuyisoni | MSc student |
| Ildephonse Hakizimana | Driver |

PhD and MSc training on different aspects of cassava virus diseases:

- One MSc student – Jeanine Umfuyisoni
- Support to MSc research – Concilie Nyirahorana
- One PhD student – Esperance Munganyinka.

Advanced specialized training and visits for project scientists (1–2 months) conducted. During 1–30 June 2015, Marie C. Kanyange and Nurbibi Cossa, Mozambique CTL, visited the Department of Ecology and Evolution and Natural Resources, School of Environmental and Biological Sciences Rutgers University, USA, under the supervision of Professor Siobian Duffy.

The objectives of the visit were:

1. To understand fundamentals of nucleotide sequence alignment
2. To explore phylogenetic relationships as a tool in molecular evolution
3. To go through recombination analysis.

| Training | Participants | Number |
|---|---|---|
| Training on Disease Diagnostic and Survey Methodologies, 17–24 August 2014 | Research assistant and students | 3 |
| IP Rights and Communications Nairobi, 26–31 October 2014 | CTL and Assistant CTL | 2 |
| Data Management, 17–19 February 2015 | CTL | 1 |
| Rutgers University, for one month (Bioinformatics), 1–30 June 2015 | CTL | 1 |
| Training of farmers | Farmers | 30 |
| Plant and Animal Genome Conference (PAG), AgShare.Today, 9–16 January 2016 | CTL and PhD student | 2 |
| Financial management training, Mango, Kigali, 2016 | CTL and accountant | |
| Bioinformatics training, MARI, 22–24 February 2016 | PhD and MSc students | 2 |
| Bioinformatics data analysis, University of Western Australia, 4 July–5 August 2016 | MSc student | 1 |
| Training on manuscript development and writing by AgShare.Today, Zambia, 3–9 October 2016 | PhD and MSc students | 2 |

## Infrastructure strengthening

1. Diagnostic and virus-indexing laboratories refurbished
2. CDP project supported cassava program with laboratory equipment including gel documentation, PCR machine and centrifuge
3. Greenhouses constructed/renovated
4. A car was purchased for facilitating project activities.

# SECTION THREE: Impacts, success stories and learning outcomes

## Impacts

This information was not available at the time of writing.

## Success stories

This information was not available at the time of writing.

## Learning outcomes

We learned more about team spirit within the region to solve common issues in the agriculture sector, especially concerning cassava viral diseases and networking among regional and international research institutions.

We were able to exchange information on cassava varieties tolerant to both CMD and CBSD that are available in the region.

# List of manuscripts

Munganyinka, E., Ateka, E.M., Kihurani, A.W., Kanyange, M.C., Tairo, F., Sseruwagi, P. and Ndunguru, J. (2017) Cassava brown streak disease in Rwanda, the associated viruses and disease phenotypes. *Plant Pathology*, 67:377–387.

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