Cassava Brown Streak Disease: An evidence note on impacts and management strategies for Zambia

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Abstract

In Zambia, cassava is the second most important economic staple crop after maize, and a mainstay for an estimated 30% of Zambians. The invasive Cassava Brown Streak Disease, which can cause yield losses of up to 100% in susceptible cassava varieties has emerged as a serious threat with the potential to collapse the cassava subsector in Zambia. The effects of CBSD impacts and management strategies were assessed through a combination of a household survey of 516 households and secondary data. Farmer survey results across the three surveyed districts indicated annual average yield losses of 1.4 t/ha. Early indications of the economic damage due to CBSD in Zambia is estimated to be 55% of total annual cassava production, which corresponds to monetary losses of over US $500,000, annually. CBSD being new in Zambia, management of CBSD symptoms on farmers' fields include plucking infected leaves, owing to lack of knowledge of effective control or management measures against CBSD. Stringent cross-border sanitary and phytosanitary measures will most likely impede the growth of Zambia's cassava export market if deliberate remedial actions are not taken as the whitefly vector, *Bemisia tabaci* that causes CBSD is classified an A2 quarantine pest by the European and Mediterranean Plant Protection Organization and the Caribbean Plant Protection Commission. CBSD is spreading throughout Zambia, underscoring the need to reinforce sanitary and phytosanitary measures, in addition to educating farmers on how to manage the disease.

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Acronyms

AEZ	Agro-Ecological Zone
CABI	Centre for Agriculture and Bioscience International
CBSD	Cassava Brown Streak Disease
CBSV	Cassava Brown Streak Virus
CMD	Cassava Mosaic Disease
DACO	District Agricultural Co-ordinating Office
DoA	Department of Agriculture
DRC	Democratic Republic of Congo
ELISA	Enzyme-Linked Immunosorbent Assay
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FGD	Focus Group Discussion
IITA	International Institute of Tropical Agriculture
PCR	Polymerase Chain Reaction
PQPS	Plant Quarantine and Phytosanitary Services
SCCI	Seed Control and Certification Institute
SSA	Sub-Saharan Africa
UCBSV	Ugandan Cassava Brown Streak Virus
ZARI	Zambia Agriculture Research Institute
ZMW	Zambian Kwacha

Executive summary

Background

Cassava (*Manihot esculenta* Crantz) is an important perennial crop originating from the Americas and cultivated in the tropical regions of Africa, Asia and the Americas. In Africa, cassava is the main staple for about 500 million people, who cultivate it for its roots and leaves. About 70 million people depend on cassava as their primary source of food and derive from it over 500 kcal per capita of their dietary calories. In Zambia, cassava is the second most important staple crop after maize and a mainstay for about 30% of Zambians.

Over the past decade, Zambia's cassava subsector has grown markedly, following the introduction of new industrial uses for the crop. However, several abiotic, biotic and socioeconomic challenges affect cassava production in Zambia. Among the biotic challenges is Cassava Brown Streak Disease (CBSD), which has emerged as a serious threat with the potential to collapse the cassava sub-sector if actions are not taken to tackle it. This evidence note presents information about the current incidences and effects of CBSD in Zambia, while highlighting the factors exacerbating its spread and the various stakeholder-specific measures that contribute towards its mitigation. Primary data for study were obtained from a household survey conducted in October 2021 involving face-to-face interviews and focus group discussions (FGDs) in Northern, Luapula and North-Western provinces of Zambia. We complemented this with secondary data and supplementary information from literature.

Cassava Brown Streak Disease

It is caused by two types of virus, Cassava Brown Streak Virus (CBSV) and Ugandan Cassava Brown Streak Virus (UCBSV), transmitted by the vector *Bemisia tabaci* Gennadius, which is also responsible for transmitting many of the viruses responsible for Cassava Mosaic Disease (CMD). Although the symptoms caused by CBSV and UCBSV are similar, UCBSV is suspected to cause milder symptoms in cassava. In Zambia, CBSD was first diagnosed in cassava samples collected from North-Western province during a routine disease surveillance exercise, and its prevalence was subsequently confirmed in selected districts of the Northern and Luapula provinces at 32.3% incidence.

CBSD bioecology and damage

The presence of UCBSV has been confirmed in Zambia and, although CBSV has not been detected, scientists continue to monitor for both viruses. The typical symptoms of CBSD in cassava that have been observed in the affected regions of Zambia include; feathery chlorotic veins; chlorotic blotches and mottling on the leaves; brown streaks on the stems; and hard rots on the roots caused by necrosis. These symptoms do not always occur simultaneously, making it difficult to identify CBSD in the fields, particularly in cases where leaf and stem symptoms are absent but root symptoms are present.

CBSD-associated yield, economic losses and impacts on cassava production

CBSD, which can cause yield losses of up to 100% in susceptible varieties, has become the leading constraint to cassava production in sub-Saharan Africa (SSA), where the average yield is 11 t/ha, lower than the average yields for South America (13 t/ha) and for Asia (12 t/ha). CBSD causes production losses through reduced root growth, reduced weight of up to 70%, low quality and spoilage of harvested roots due to necrotic rot, pitting and constrictions. Farmer survey results across the three surveyed districts reported an average yield loss of 1.4 t/ha, with district-level losses of 1.9, 1.5 and 0.7 t/ha for Chienge, Kaputa and Kabompo, respectively.

The economic damage due to CBSD has been estimated at about 1.6m tonnes of fresh roots valued at between US $75m and US $750m per year across Kenya, Tanzania, Uganda and Malawi. In Zambia, CBSD is estimated to cause losses of about 55% of annual total cassava production, equivalent to monetary losses of over US $500,000, annually.

Origin, spread and current distribution

CBSD was first identified in Africa in the coastal region of East Africa close to the mid-20th century. It is known to spread in a sporadic “hotspot” pattern, rather than in a radiative manner from a central source. CBSD’s presence has now been confirmed in several eastern, central and southern African countries, including Tanzania, Uganda, Kenya, Rwanda, Burundi, Congo, the DRC, South Sudan, Malawi and now Zambia. Potential pathways of entry suggest it may have originated from the DRC, owing to the current localized distribution of CBSD in the northern regions of the country and the porous border between Zambia and the DRC (which enables the free movement of cassava planting materials). On the other hand, the relative genetic closeness between CBSD’s causal virus in Zambia, and those in Malawi and Tanzania suggests that CBSD could have spread into Zambia from those two countries.

Environmental suitability modelling for CBSD from literature

Model-based predictions have demonstrated that cassava could moderately benefit from climate change, with average increases in production and minimal decreases in cassava climatic suitability in most areas in Africa, indicating its beneficial characteristics and resilience. As such, cassava may be an important substitute crop for other staples, implying that increased drought tolerance could bring benefits to nearly 30% of the cassava-producing regions in eastern and southern African countries, and that cassava might remain a viable crop in most areas of SSA at the end of the century.

Predictions indicate that climate change could result in increased incidences of cassava pests, further exacerbating economic losses and vulnerability. Models evaluating potential whitefly distribution at different temperatures show that climatic changes might modify whitefly distribution and abundance. Evidence shows that climatic conditions for the whitefly *B. tabaci* improved significantly in the areas where the pandemics had been reported in eastern and central Africa, which could have contributed to the increased incidences of CBSD.

Management of CBSD symptoms on farmer fields

Nearly 67% of the surveyed farmers indicated that they monitored their cassava fields regularly for abnormal changes and for the presence of insect and disease pests. Information from the FGDs and survey interviews revealed that farmers had limited or no knowledge of effective control or management measures against CBSD, owing to limited understanding of CBSD as a viral disease, as it is fairly new in Zambia. Across all three districts, farmers expressed the need for information on effective and science-based methods to manage CBSD.

Potential impacts of CBSD on trade

Zambia's exports of fresh cassava roots and starch are low compared to the volume of cassava production. For example, between 2010 and 2020, the country exported a total of 188,000 tonnes of fresh cassava and 394,000 tonnes of starch, valued at US $47,000 and US $400,000 respectively.

CBSD is spreading across districts in Zambia, underscoring the need to reinforce sanitary and phytosanitary measures. Stringent cross-border sanitary and phytosanitary measures will most likely impede the growth of Zambia's cassava export market if deliberate remedial actions are not taken. This follows from the classification of the whitefly vector, *Bemisia tabaci* (which transmits CBSD), as an A2 quarantine pest by the European and Mediterranean Plant Protection Organization (EPPO) and the Caribbean Plant Protection Commission.

Recommendations

Despite the short time during which CBSD has existed in Zambia, lessons from the experience thus far, and examples from other countries that have had CBSD for years, suggest actionable steps that are applicable to different stakeholder groups. The multi-faceted nature of the CBSD problem in Zambia requires farmers, high-level policymakers, regulators, researchers and extension service providers to engage in dialogue and collaborate to tackle CBSD.

High-level policymakers

- Investment by various stakeholders in coordinated cassava breeding programmes are critical to the development of CBSD-resistant varieties for use by farmers
- Cassava for industrial use can improve the livelihoods of farmers and the economy as a whole through income generation and creation of jobs. The Cassava Sector Development Strategy for Zambia requires updating to include explicit strategic actions to address CBSD.

Regulators (Seed Control and Certification Institute (SCCI) and the Plant Quarantine and Phytosanitary Services (PQPS))

- Joint efforts should be promoted between the SCCI and the PQPS to influence compliance with cassava seed multiplication standards
- Strengthen the surveillance of border points and institute stringent quarantine regulations to prevent the movement of CBSD-infected cassava cuttings and to implement rigorous phytosanitary standards during the multiplication and distribution of cassava planting material
- Introduce effective diagnostic techniques for surveillance, monitoring and forecasting CBSD outbreak to enable the timely application of management and containment measures

- Track changes in local whitefly populations, especially in new outbreaks and threatened areas, to enable timely response in mitigating the aggravating factors of whitefly population increase

Researchers

- Ensure the movement of cassava germplasm between countries adheres to all prescribed export procedures, including pre-export inspections, and that all necessary documentation is present, such as virus-indexed tissue culture forms
- Regularly inspect cassava multiplication plots/blocks from pre-planting to post-harvest for the presence of CBSD or CBSD-related symptoms
- Collaborate in developing and deploying CBSD-resistant cassava varieties and ensure that efforts in advancing CBSD research are properly co-ordinated
- Encourage research on the identification of natural enemies of the CBSD transmission vector

Farmer advisers and advisory services

- Educate farmers on the role they play in exacerbating CBSD spread through the practices of sharing and moving planting material from one field to the next, or from one farmer to another
- Develop various communication materials on CBSD and devise innovative ways of sharing information with farmers to enable them to learn about the disease and its symptoms, causes, effects and mitigation measures
- Farmers contracted to multiply cassava planting materials should be well trained and equipped with the necessary knowledge and skills on identification of CBSD to avoid disease spread through the distribution of diseased planting material to other farmers
- Agricultural extension personnel should familiarize themselves with the performance of various cassava varieties in terms of CBSD and farmer-preferred traits to enable them to make recommendations to farmers and breeders on the varieties that are suitable for current production and breeding

Farmers

- Cassava farmers should ensure they use planting materials with no CBSD symptoms and that they obtain cuttings from CBSD-free sources
- Farmers contracted as cassava seed multipliers should ensure that all infected cassava plants in their seed fields are uprooted and destroyed to avoid distributing infected propagative material to recipient farmers
- Institute collective community-level actions among farmers growing cassava to instigate the implementation of sanitary and phytosanitary measures, including sourcing and maintaining CBSD-free planting material and the subsequent selection of clean cuttings for propagating new fields of cassava
- Farmers should consult extension service providers on recommended cassava varieties for planting to minimize damage and losses due to the combination of CBSD and other conditions

1. Cassava production and the CBSD problem

1.1 Cassava commodity context

Cassava (*Manihot esculenta* Crantz) is an important perennial crop belonging to the family Euphorbiaceae and cultivated in the tropical regions of Africa, Asia and the Americas (Chikoti et al. 2015). It originated from the Americas and was introduced to Africa around the 16th century (Okigbo 1980; Barratt et al. 2006). Over 50% of current global cassava production is grown in SSA, with Nigeria, the DRC and Tanzania collectively accounting for nearly 70% of the region's total production (Bennett 2015).

In Africa, cassava is the main staple food for over 500 million people who cultivate it for its roots and leaves (Tembo et al. 2017). An estimated 70 million people solely depend on cassava as the primary source of their dietary caloric intake, estimated at 500 kcal per capita, or 30% of daily caloric needs. Storage cassava roots are eaten fresh, used to make cassava chips or processed into flour for household consumption. Cassava flour has many uses, from confectionery to industry, including the preparation of bread, biscuits, pasta, couscous-like products, adhesives, animal feed, beer, paper and starch for the mining industry (Hillocks et al. 2002). Cassava starch is also used in the textile and paper industries, as well as in the manufacture of plywood glucose and dextrin syrups. Cassava can be used as a raw material in the production of pharmaceutical products, biofuels and biopolymers (Balat and Balat 2009; Hillocks et al. 2002). It is a particularly attractive crop for bioethanol production because it requires less energy input to generate a profit of close to 100% (Jansson et al. 2009). In some parts of Africa, cassava leaves are consumed for their vitamin content (Vitamins A and B) (Tomlinson et al. 2018). In the main cassava-producing countries in Africa (including Nigeria, the DRC, Ghana, Angola and Tanzania), the crop is also an important source of cash income for farmers.

In Zambia, cassava is the second most important economic staple crop after maize. It was introduced into the country from the Congo Basin over 300 years ago, at the same time as maize (*Zea mays*). For a long time, cassava was not as popular as maize among farmers because of the absence of government subsidies to support its production (Chikoti et al. 2019). Nevertheless, cassava is the mainstay for an estimated 30% of Zambians (Chiona et al. 2014). It is regarded as the main staple crop in four of the country’s 10 provinces, including Luapula, Northern, North-Western, Copperbelt and Western, the provinces, where it is mostly produced (Tembo et al. 2017).

Over the years, and due to the growing manifestations of climate change (such as recurrent droughts and invasive pests), cassava has gained importance as a potential food security crop that promises drought insurance and higher yields compared to maize (Barratt et al. 2006; Alamu et al. 2019). Following this renewed interest, there have been deliberate efforts to promote the crop by various stakeholders in Zambia, especially in drought and hunger-prone regions that are most vulnerable to food insecurity during years of famine (Barratt et al. 2006; Kaluba et al. 2021). The promotion of cassava production in non-traditional cassava growing regions of Zambia forms part of the country’s crop diversification efforts for mitigating the impacts of climate change (Szyniszewska et al. 2021; Phiri 2011). The crop plays a key role in food security, as a result of which less than 10% of production is sold for income (Sitko et al. 2013). Cassava acts as a food reserve in cases of general failure of other staple crops because the roots can be harvested in a piecemeal manner, as the need arises (FAO 2000; Nweke 2004; Bennett 2015).

Biotic factors affecting cassava productivity in Zambia have assumed greater importance over both abiotic and socioeconomic factors, which is largely attributed to the arrival of the invasive CBSD. This has considerably heightened the effects of biotic constraints. Prior to 2018, the single most challenging viral disease affecting cassava was CMD, which has prevailed in epidemic proportions in many of Zambia's neighbouring countries (including Tanzania, Malawi, the DRC, Zimbabwe, Mozambique and Angola). At present, CMD is the most widespread viral disease of economic importance in cassava in Zambia, with a higher incidence than Cassava Anthracnose Disease and Cassava Bacterial Blight (Chikoti et al. 2019). Cassava yield losses due to CMD were estimated in 1997 at 50%–70% (Muimba–Kankolongo et al. 1997). In 2016, Tembo et al. (2016) reported a mean percentage of marketable roots from CMD-infected cassava of 23.6%. The arrival of the new invasive CBSD and its rapid rate of spread is a source of major concern for Zambia's cassava subsector because it is a more aggressive viral disease that is difficult to detect – especially by smallholder farmers – owing to its subtle symptoms, which mostly manifest at later stages of plant growth (Mulenga et al. 2018). Cassava, a clonal crop, is most commonly propagated through stem cuttings and is therefore prone to adverse damage by pathogens, especially viruses (Chikoti et al. 2019). Unlike CMD, CBSD is not yet widespread in Zambia, but occurs severely in most of the historical cassava growing areas of Luapula, Northern, North-Western and Western provinces of the country. In 2018, Mulenga et al. (2018) reported a CBSD prevalence of 79%, with an average incidence of 32.2% across sampled fields in two representative districts located in the traditional cassava-producing provinces of Northern and Luapula. CBSD severity was over 50% for the sampled farmers' fields in these districts. Since its first detection in Zambia, CBSD has continued to spread rapidly to the more southerly parts of the country and is exacerbated by many identified production constraints that span biotic, abiotic and socioeconomic factors.

1.2 Cassava production trends in Zambia

Cassava is mostly produced by smallholder farmers on marginal and submarginal lands in the humid and semi-humid tropics. This is because, unlike other staple crops in SSA, cassava is believed to exhibit high adaptability to variable farming environments, including drought, acidic soils and minimal input use (Hillocks et al. 2002). Cassava production in Zambia involves little use of commercial fertilizer or pesticides, and currently stands at 4m tonnes (FAOSTAT 2022).

A 15-year historical trend of land area under cassava production in Zambia shows a fairly stagnant area of 190,000–205,000 ha between 2008 and 2013, followed by a sharp decline to 56,000 ha in 2015. Similarly, the trend for total cassava production remained in the range of 1.1m–1.2m tonnes, with a corresponding stagnant yield of 5.8 t/ha^{-1}, in the same period. Between 2016 and 2020, total cassava production more than tripled from 0.95m tonnes to 3.9m tonnes, which can be attributed to the withdrawal of maize subsidies (Chikoti et al. 2019). Between 2008 and 2015, the area under production declined by more than 250% (from 205 ha to 56,000 ha). However, the trend later reversed, with the area under production rising by 148% to 139,000 ha in 2020. Conversely, yield increased by over 200% from an average of 10 t/ha^{1} in 2014 to 35 t/ha^{-1} in 2018, and declined marginally to 28 t/ha^{-1} in 2020 (Figure 1).

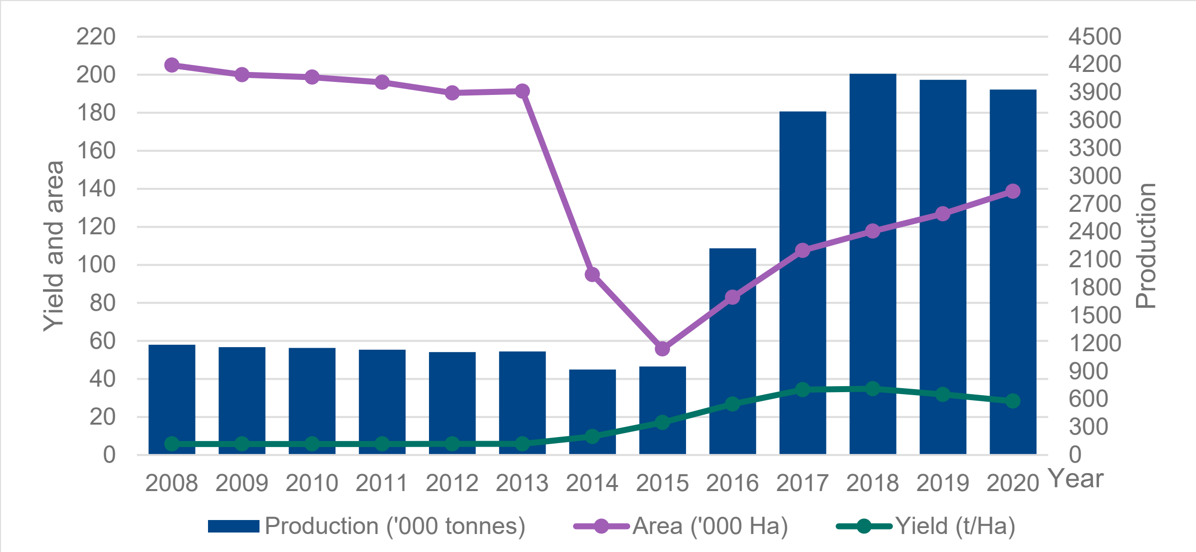

Figure 1: Cassava area under production, total production and yield in 2008–2020 in Zambia

Source: FAOSTAT 2022

Overall, although the area under production generally declined between 2008 and 2020, productivity increased and gains in cassava yields were observed. Besides the removal of subsidies on maize, additional contributing factors for the observed increase in productivity included the activities in the North-Western and Western provinces of Zambia involving the introduction of out-grower schemes for cassava farmers aimed at supporting cassava production and marketing (Government of Zambia 2020). In addition, efforts by several stakeholders (and led by the government-supported Zambia National Cassava Association) culminated in the development of a National Cassava Sector Development Strategy for 2020–2024, which was intended to oversee the subsector development and spur it into vibrancy.

As in most SSA countries, the current average cassava yields in Zambia are considerably lower than the potential yield. This is because of the many abiotic, biotic and socioeconomic challenges associated with cassava production that contribute to losses in the crop yields. Among the most notable constraints affecting cassava production in Zambia are poor soil fertility, viral pests, limited farmer knowledge regarding cassava diseases of importance, poor implementation of phytosanitary regulations and the use of susceptible cassava varieties (Chikoti et al. 2015; Chikoti et al. 2019; Mwamba et al. 2021). Chikoti et al. (2019) and Kaluba et al. (2021) attribute Zambia's low cassava yields to low adoption of improved varieties by farmers and poor agronomic practices, including poor weeding and limited use of fertilizers. Viral diseases, especially CMD and the more recent CBSD, are currently the most challenging factors affecting cassava production in Zambia's traditional cassava growing areas.

1.3 CBSD

CBSD was first detected in Africa in the low-altitude regions of Tanzania as far back as 1936 (Storey 1936). It is caused by two types of virus that are both ribonucleic in nature and are made up of positive single-stranded nucleotide chains. The two types of virus – CBSV and UCBSV – are similar in their genome organization; both belong to the genus Ipomovirus and the family Potyviridae (Mbanzibwa et al. 2009; Winter et al. 2010). CBSV and UCBSV are transmitted by the small, white vector *Bemisia tabaci* Gennadius, which is also responsible for transmitting many of the viruses responsible for causing CMD. Although the symptoms of CBSD caused by CBSV and UCBSV are similar, UCBSV is suspected to cause milder symptoms in cassava. CBSV also seems to have more variants than UCBSV, suggesting a higher rate of evolution (Mulenga et al. 2018).

Diagnosing can be a challenge, especially if relying solely on physical symptoms (Chikoti et al. 2019). This is because CBSD symptoms on cassava are less prominent than the symptoms of other viral diseases, including CMD. The relatively mild symptoms of CBSD, coupled with limited knowledge among farmers about the existence of the disease, often render the identification of CBSD symptoms in the field more difficult. This poses a great challenge to effective management strategies for CBSD and could lead to spread to further parts of the country. Fortunately, advances in agricultural biotechnology have enabled robust and high throughput techniques of disease diagnosis that are increasingly applied worldwide. The triple antibody sandwich, enzyme-linked immunosorbent assay and an immunosorbent electron microscope were among the initial advanced diagnostic techniques (Mkuyuamba et al. 1995). Later, Mulenga et al. (2015) used polymerase chain reaction (PCR) to detect the East African Cassava Mosaic Malawi Virus in field-collected samples of cassava. More recently, genome isolation and blast search have been used to ascertain the type of virus responsible for observed CBSD symptoms in Zambian cassava fields (Mulenga et al. 2018).

In Zambia, CBSD was first was reported in selected districts of the Northern and Luapula provinces (Mulenga et al. 2018). It has since spread to other districts, and its progression is being closely monitored by scientists from the Zambia Agriculture Research Institute (ZARI). Evidence in the literature has shown that the spread of CBSD and its development is enhanced by high disease pressure, the use of susceptible genotypes, the use of infected cassava cuttings for planting and high whitefly populations (Katono et al. 2015). The common practice among farmers of sharing and exchanging cassava stems for planting, including across borders, contributes to the spread of CBSD to areas where it was previously absent (Legg et al. 2011). Whiteflies, which can thrive even at altitudes above 1000 metres above sea level, can also disperse and amplify CBSD prevalence locally (Alicai et al. 2007; Jeremiah et al. 2015; McQuaid et al. 2017).

1.4 CBSD bioecology, damage and associated yield losses

UCBSV presence has been confirmed in Zambia, although CBSV has not been detected (Mulenga et al. 2018). Scientists continue to monitor both viruses, and further research is required to determine the differential existence of the two. There is speculation that CBSV prevalence is attributable to the altitude of a given ecological region, or that the whitefly vector possesses differential capability in acquiring and transmitting the two types of virus. The genetic closeness between the specific variant of UCBSV found in Zambia and the Tanzanian and Malawian variants has implications for possible pathways of spread (Mulenga et al. 2018). Comparative epidemiological investigations are required to substantiate these theories and devise appropriate strategies for mitigating CBSD spread to other areas.

The typical symptoms of CBSD in cassava that have been observed in the affected regions of Zambia include feathery chlorotic veins; chlorotic blotches and mottling on the leaves; brown streaks on the stems; and hard rots on roots caused by necrosis (Mulenga et al. 2018). These symptoms do not always occur simultaneously, which exacerbates the difficulty of identifying CBSD in the field. This is particularly the case where both leaf and stem symptoms are absent, and only root symptoms are present. Leaf symptoms of CBSD predominantly occur on the lower leaves of the plant, which makes it difficult for farmers to identify them promptly before leaf senescence (Legg et al. 2011).

The average yield of cassava in Africa is 11 t/ha^{-1}, lower than the average yields for South America (13 t/ha^{-1}) and for Asia (12 t/ha^{-1}) (Kaluba et al. 2021). CBSD has become the leading constraint to cassava production in SSA and can cause yield losses of up to 100% in highly susceptible varieties (FAO 2010; Alicai et al. 2007; Legg et al. 2011; Hillocks and Maruthi 2015). Typical symptoms of the disease include distinct yellowing along the veins, brown streaks on stems and corky necrosis of roots. These render cassava roots unusable for food or as feed (FAO 2010; Hillocks 2004; Patil et al. 2015; Hillocks et al. 2016). CBSD also causes a reduction in the number of roots per plant (Ndyetabula et al. 2016). Farmers therefore desire cassava varieties that are less prone to CBSD (Hillocks et al. 2015).

Since the early 1950s, it has been noted that CBSD causes losses in production through reduced growth and spoilage of harvested roots (Nichols 1950). The quality of roots is affected by pitting, constrictions and root necrosis, resulting in lower plant productivity through reductions in the number and weight of the roots. Hillcocks et al. (2001) reported the development of necrotic symptoms six months after planting, resulting in a 70% reduction in root weight. Root symptoms become increasingly severe as plants grow and farmers resort to early harvesting of the tubers before they are fully mature, which compromises their full yield potential (Muhindo et al. 2020).

The main challenge in estimating the economic damage due to CBSD remains the lack of data beyond the limited data from experimental plots (Manyong et al. 2012). Past estimates considering eight countries of east and central Africa indicated overall losses of about 1.6m tonnes of fresh roots valued at US $75m (Manyong et al. 2012). Estimated losses for Kenya, Tanzania, Uganda and Malawi amounted to US $750m per year (Hillocks and Maruthi 2015). Ndyetabula et al. (2016) report a value of US $51m, corresponding to US $73 per hectare, in field economic losses due to CBSD in Tanzania. Other economic costs involve the additional labour cost of separating necrotic from non-necrotic portions of affected cassava roots (Alicai et al. 2007; Legg et al. 2011) and the deleterious effects on the starch quality of non-necrotic portions of affected roots (Jeremiah and Legg 2008; Manyong et al. 2012). CBSD attack on cassava roots can reduce cassava starch yields by about 55%–65% because it also affects starch deposition within the storage roots (Nuwamanya et al. 2015).

1.5 Potential impacts of CBSD on trade

As the fourth most important source of plant-based starch in the world after wheat, maize and potato, cassava is considered a highly valuable industrial crop (Sharma et al. 2016; Amelework et al. 2021). Market forecasts indicate that the demand for cassava starch will reach over 10m tonnes by 2024, largely driven by advancements in technology in the starch and manufacturing industries, which have made cassava an attractive source of modified starch for food-grade starch, adhesive, paper and textile grade starches (Adelekan 2010; Business wire 2019). Despite Africa being the leading global producer of cassava, most cassava production is consumed domestically, with little access to global markets. This reinforces the fact that cassava is a food security crop in Africa, more importantly for resource-constrained households.

Zambia’s export of cassava in the form of fresh roots and starch is low compared to the volumes produced. For example, between 2010 and 2020, the country exported a total of about 188,000 tonnes of fresh cassava (worth US $47,000) and 394,000 tonnes of starch (valued at US $400,000), which is minimal compared to the over 20m tonnes of cassava produced in the country over the same period (FAOSTAT 2022) (Figure 2).

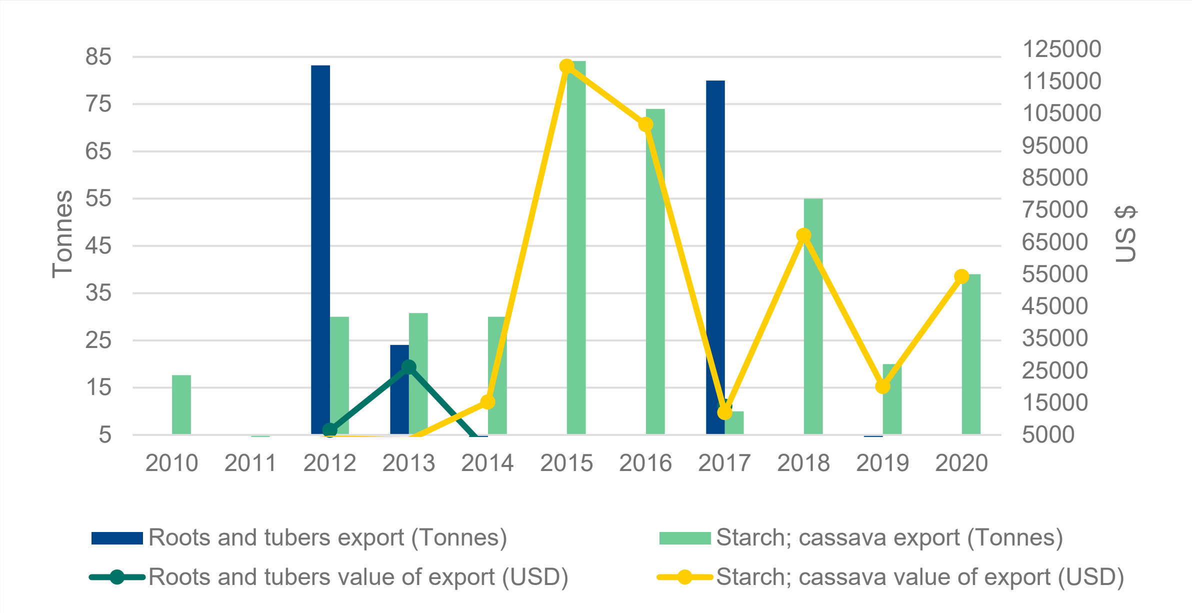

Figure 2: Export and value of export of fresh cassava and starch 2010–2020

Source: Comtrade 2022.

The CBSD-causing viruses are transmitted by the whitefly, *Bemisia tabaci* (Mbanzibwa et al. 2009; Mbanzibwa et al. 2011; Winter et al. 2010; Maruthi et al. 2017), which has been listed as an A2 quarantine pest by EPPO (OEPP/EPPO 1989) and the Caribbean Plant Protection Commission. Due to the quarantine status, plants and plant products containing the pest are intercepted, and their presence in a given country can hinder trade with other countries. Over the years, *B. tabaci* has been among the leading causes of interceptions in plants imported into the European Union Member States and Switzerland. A case in point is the 2018 interception of *Solidago* imported from Zambia to Europe due to the detection of *B. tabaci* (EUROPHYT 2018). This interception provides a classic example of the ramifications invasive pests or diseases like CBSD can have on an important staple such as cassava.

1.6 Origin, pathways of entry and establishment

Although it is well established that CBSD originated from the coastal regions of East Africa close to the mid-20th century, the exact origin of CBSD in Zambia is uncertain. Zambia is a landlocked country with eight neighbouring countries. Five of Zambia's neighbours – the DRC (to the north), Tanzania (to the north-east), Malawi and Mozambique (to the east) and Angola (to the west) – have all confirmed the presence of CBSD for at least three years (Nichols 1950; Hillocks et al. 2002; Mulimbi et al. 2012; Tomlinson et al. 2018; Bakelena et al. 2019). There is speculation that CBSD spread into Zambia from the DRC, owing to the current localized distribution of the disease in the northern regions and the porous border between the two countries, which allows free movement of cassava planting materials. However, the relative genetic closeness between the causal virus of CBSD symptoms in Zambia and those of Malawi and Tanzania suggests otherwise (Mulenga et al. 2018). Targeted studies are required to establish the precise pathway of CBSD spread into Zambia more reliably.

Considering that some of Zambia's immediate neighbours were already grappling with CBSD years before it was detected in Zambia, it was only a matter of time before the disease arrived in the country. Awareness of CBSD presence in Zambia's neighbouring countries by scientists in Zambia helped strengthen routine monitoring and early detection (Chikoti et al. 2019; Tembo et al. 2017). However, the benefits of these efforts could be lost if they are not capitalized upon to curb further spread of CBSD through proven multi-pronged approaches. Szyniszewska et al. (2019) reported that 94% of farmers in Zambia sourced their cassava planting material from their fields or from nearby family and friends. Mostly of these farmers do this without careful inspection to ensure selection of disease-free propagating material. This practice fuels the spread of CBSD from field to field, from farm to farm and eventually across the districts. If CBSD spread is to be effectively controlled in Zambia, the source of propagative material should be one of the priority interventions. The widespread distribution and establishment of CBSD in Zambia is capable of collapsing the country's cassava subsector and impeding the current progress evident in the number of growing investments and the favourable political will that has been associated with the subsector over the last decade (Alamu et al. 2019).

1.7 Current spread and distribution of CBSD in Africa

The presence of CBSD has now been confirmed in several east and central African countries, including Burundi, Congo, the DRC, Kenya, Malawi, Rwanda, South Sudan, Uganda and Zambia (Mulenga et al. 2018; Muhindo et al. 2020). The invasive CBSD is likely to spread westwards via central Africa. West Africa is not yet affected, but presents a high chance of devastation from CBSD if it spreads to the region owing to its widespread cultivation of cassava (Muhindo et al 2020.). Unlike CMD, which spreads outwards from a central point, the spread of CBSD is characterized by a sporadic "hotspot" pattern. In addition, CBSD prevalence is not always consistent with whitefly vector populations (Legg et al. 2011). These factors confound the development of reliable models for predicting CBSD spread, establishment and associated damage.

Prior to 2004, CBSD was confined to the low coastal regions in altitudes lower than 1000m above sea level. Since then, the disease has begun to spread to areas with higher altitudes, and has been reported in other East African countries (Tomlinson et al. 2018). To provide more predictive models for CBSD spread in Africa, innovative approaches that simultaneously harness the synergistic effect of several factors associated with the disease are important. Factors such as the biology of the two causal viruses, whitefly population dynamics, farmer behaviour and weather conditions are essential. Additionally, there is a need to encourage more sharing of pest status-related information among countries to strengthen surveillance and preparedness for countries that have not yet detected the disease.

One of SSA's major challenges in facing a viral disease like CBSD is existing barriers in communication compounded by farmers' low levels of literacy (Henriksson et al. 2021). Achieving understanding among farmers that CBSD is viral in nature and cannot be addressed by the spraying of chemical pesticides is a milestone that requires deliberate efforts in the delivery of extension services (Szyniszewska et al. 2019).

1.8 Environmental suitability for further CBSD invasive spread: a literature review

Model-based prediction studies have quantified the impacts or responses of cassava to climate change, and most have found cassava to be the least affected crop compared with other major staples (including maize, sorghum and millets). Through statistical modelling, Lobell et al. (2008) demonstrated that cassava will moderately benefit from climate change by 2030 with an average increase of 1.1% in production. Further predictions indicate that major decreases in cassava climatic suitability are not expected for the majority of areas in Africa and that increases in suitability could occur, indicating the beneficial characteristics and resilience of the crop in the context of climate change. Thus, cassava may be an important substitute crop for other staples in areas where these suffer greatly. This implies that increased drought tolerance could bring benefits to nearly 30% of cassava-producing regions in eastern and southern African countries (Jarvis et al. 2012) and that it may remain a viable crop in most areas of SSA at the end of the century (Chapman et al. 2020). However, according to Schlenker and Lobell (2010), cassava production will decrease by 8% by mid-century, compared with steeper decreases for maize (by 22%) and for sorghum and millets (by 17%).

Although a dearth of information exists on the distribution of cassava pests and diseases within the context of climate change (Herrera Campo et al. 2011), climate change could result in increased incidences of these pests, further exacerbating economic losses and vulnerability (Ceballos et al. 2011). At present, cassava is experiencing significant crop losses due to biotic constraints. Future projections indicate that pest and disease pressures are likely to rise in many regions of Africa, moving into some new regions, even though the pressure could reduce in other regions (Herrera Campo et al. 2011; Jarvis et al. 2012). The whitefly is the most widely distributed cassava pest potentially covering over 23m km^2. Although this distribution is predicted to shrink by 2030, other predictions show that it could expand into 600m km^2 of new areas in the Central African Republic, Ethiopia and Cameroon. However, models looking at potential whitefly distribution at different temperatures (Aregbesola et al. 2019; Aregbesola et al. 2020) indicate that, even though climatic stress negatively affects the life-history traits of whiteflies, these effects differ due to tolerance levels and the potential that climatic changes might modify whitefly distribution and abundance in addition to the environmental suitability for plant viruses (Alonso Chavez et al. 2021). Further evidence shows that climatic conditions for the whitefly *B. tabaci* improved significantly in the areas where the pandemics of CMD and CBSD had been reported, providing some evidence that the same climatic changes attributed to the increase of whitefly abundance in east and central Africa have contributed to the increase, in part, of CBSD (Kriticos et al. 2020).

2. Effects of CBSD on cassava production in Kabompo, Kaputa and Chienge districts of Zambia

2.1 Study methodology

Study sites and sampling

A household survey about CBSD was implemented in three provinces in the agro-ecological zone (AEZ) III of Zambia where CBSD was first detected. AEZ III represents the region with the highest rainfall (above 1000m/year). Chienge, Kabompo and Kaputa districts – located in the provinces of Luapula, North-Western and Northern respectively – were selected for the survey. Cassava production in the three districts was characterized by low input systems predominantly practiced by smallholder farmers, some of whom were out-grower producers contracted by local cassava companies. Besides the similarities in production systems, Kabompo district is relatively more developed in terms of infrastructure than both Chienge and Kaputa districts. With assistance from extension service providers from the local district agricultural co-ordinating offices, six, five and three agricultural camps in Chienge, Kabompo and Kaputa districts respectively were selected (Table 1). In each of the three districts, between 165 and 178 respondent farmers were purposively sampled, targeting farmers who had a current cassava crop in the field and who had encountered hard rots on cassava harvested from either their current or their previous field. Between October and November 2021, 516 face-to-face farmer interviews were conducted across the three districts, using a structured questionnaire in digital form on Open Data Kit data collection app.

The questionnaire contained key questions on cassava production and productivity, the nature of the cassava germplasm used by farmers, crop management practices, farmer knowledge of CBSD, CBSD-associated losses and farmer coping strategies. The questionnaire also sought to collect sociodemographic data pertaining to each sampled household. Prior to questionnaire administration in the districts, a team of enumerators was identified and trained on CBSD and household data collection. The trained enumerator team pre-tested the questionnaire in the cassava growing community of Rufunsa district of Lusaka province to ensure the questions were clear, consistent and unambiguous. The survey was conducted with strict adherence to all necessary ethical guidelines, including prior permission from the office of the Department of Agriculture (DoA) in all three targeted provinces. Further, informed consent was sought from each participant before the interview was conducted, while adhering to CABI’s data protection policy to keep respondent personal data confidential and to aggregate all individual responses to generate average study statistics. In accordance with COVID-19 regulations, recommended measures were taken, including social distancing, hand sanitizing and wearing face masks for both interviewer and respondent.

Table 1: Survey provinces and districts used in data collection on CBSD in Zambia

Province	District	Camps	Number of respondent farmers
Luapula	Chienge	Mwabu, Lambwe Chomba, Lambwe, Chikwama, Kalungwishi, Mununga, Kaseke,	173
North-Western	Kabompo	Nkulushi, Kamafwafwa, Kamashila, Katuva, Mumbeji	178
Northern	Kaputa	Nkosha, Kasepa, Kaputa central	165
Total farmer respondents			**516**

Quantitative data from face-to-face questionnaire interviews with farmers were supplemented by qualitative data from FGDs. A desk study, involving the review of pertinent literature on CBSD in Zambia and neighbouring regions, was also conducted to complement the information from the farmer interviews and FGDs.

The FGDs

The FGDs were held in a single camp in each of the three districts. They took the form of situational analyses aimed at understanding the sociocultural environment of the three farming communities and generating gender-responsive information on their cassava production practices. The participating farmers were asked to identify and name the distinct gender groups they recognized within their community. A “gender group” was defined as a cluster of individuals who were assigned specific roles and responsibilities within the community based on their sex. Four, five and three distinct gender groups emerged from Chienge, Kabompo and Kaputa respondent farmers respectively. The highest and lowest numbers of farmers who participated in the FGDs were 98 (in Kabompo district) and 38 (in Chienge district) (Table 2). During the FGDs, participants sat according to the gender group they each identified with. This was to enable collective representation of the views of a particular gender group when responding to the various discussion questions. Each gender group was assigned differently coloured cards for ease of identification during scoring. Each gender group selected scoring objects, such as sticks, seeds, flowers, mango fruits, maize grains or stones, to indicate their collective ratings in response to discussion topics. Several questions under four thematic profiles were posed for each of the gender groups to discuss between themselves, and using their scoring object to indicate their agreed response. The four thematic profiles were household, community, production and resource-level profiles. The data collected from the FGDs were used to support the quantitative data from the questionnaires.

Table 2: Farmer gender groups involved in FGDs on CBSD in Kabompo, Chienge and Kaputa districts

District	Gender groups	Number of participant farmers
Chienge	Old men, old women, young women, young men	38
Kabompo	Men, women, young women, elderly men, young men	98
Kaputa	Men, women, youth	50
Total participant farmers		**186**

2.2 Household characteristics

Out of 516 interviewed farmers, Chienge and Kabompo districts each accounted for 34% of respondents, while Kaputa district accounted for 32% (Table 3). About 60% of respondent farmers were men, while 40% were women. The largest farmer age bracket was aged 50 and above, represented by 38% of the respondents. Farmers aged 40–49 and 30–39 each constituted 26% of the total number of interviewed farmers and were the second-largest age group in the study. The smallest age group was represented by 11% of respondents and was made up of young farmers aged 20–29. Over half of respondents (57%) had attained a primary education, 27% had reached secondary school, 15% had no schooling and less than 1% had a tertiary level education. About 78% of respondents were household heads. Farming was the primary activity and main source of income for 99% of respondents. The average landholding size was approximately 5 ha, of which the average land dedicated to cassava production per farmer across the three survey districts was 1.2 ha. Nearly 22% of the respondent farmers earned a monthly average income of less than 1000 Zambian Kwacha (ZMW) (US $57), and (cumulatively) more than two-thirds earned less than US $1.5 per capita per day.

Table 3: Profiles of Households heads in Chienge, Kabompo and Kaputa districts

Variable	District			Total (%)
	Chienge (%)	Kaputa (%)	Kabompo (%)	
District	34	32	34	
Gender				
Women	11.0	24.0	22.0	19.0
Men	89.0	76.0	78.0	81.0
Average age	46 years	49 years	48 years	48 years
Highest level of education	25.4	11.4	5.7	14.2
No schooling	50.9	54.5	54.6	53.3
Primary	23.1	32.9	39.2	31.8
Secondary school	0.6	1.2	0.6	0.8
Tertiary	25.4	11.4	5.7	14.2
Average household size	8	8	7	7
Primary source of income				
Farming	99.4	98.8	95.5	97.8
Salaried employment	0.6	–	2.3	1.0
Business	–	0.6	1.7	0.8
Other sources	–	0.6	0.6	0.4
Average land owned in ha (2019–2021)				
a) Land owned by household	5.2	4.2	5.2	4.9
Owned and cultivated	1.8	2.0	1.7	1.8
Owned and fallowed	0.8	0.9	1.4	1.0
Owned and wood lot	1.2	1.2	2.2	1.5
b) Land rented in for cultivation	–	0.1	–	0.1
Monthly household income (ZMW*)				
<1000	33	24.6	7.4	21.5
1000–3000	26	31.7	22.2	26.6
3001–5000	16.2	18.6	23.9	19.6
5001–10,000	16.8	13.8	27.3	19.4
10,001–15,000	4.1	7.2	10.2	7.2
>15,000	2.9	3.0	8.0	5.9

Farmers utilized cassava in various forms: in preparing flour for making *Nsima*, for boiling or roasting cut roots or for frying chipped ones. Production of cassava flour for Nsima (92% of the respondent farmers) was the most common form of cassava utilization, while preparation of animal feed (2.8% of the farmers) was the least common (Table 4).

Table 4: Cassava production and resource utilization

Variable	District			Total (%)
	Chienge (%)	Kaputa (%)	Kabompo (%)	
District	34	32	34	
Farming system				
Mono cropping	7.0	21.6	18.8	15.7
Mixed cropping	93.0	78.4	81.2	84.3
Households' cassava utilization				
Flour	24.4	32.7	34.5	91.7
Boiled cassava	19.4	22.0	32.7	74.2
Cassava chips	9.9	12.3	29.4	51.6
Roasted	2.6	11.3	–	13.9
Mashed cassava	0.4	3.6	6.0	9.9
Feed to animals	0.2	0.4	2.2	2.8
Raw	0.4	2.0	0.0	2.4
Key decision maker on cassava field management				
Head	43.9	59.9	59.1	54.3
Spouse	1.7	3.6	21.6	9.1
Both head and spouse	52	36.5	18.8	35.7
Child	1.2	–	–	0.4
Other household members	1.2	–	0.6	0.6
Key decision maker on resource utilization				
Head	32.4	51.5	49.4	44.4
Spouse	1.7	2.4	11.4	5.2
Both head and spouse	64.2	46.1	38.6	49.6
Other household members	1.7	–	0.6	0.8

*1 ZMW = US $0.05675 (15 November 2021)

2.3 Perceptions of CBSD infestation levels among farmers

Knowledge and perception of CBSD among farmers

Respondents were asked to indicate if they could identify symptoms of cassava diseases presented on eight different photo images (Annex 1) displayed by interviewers. A follow-up question sought to establish whether farmers had a name for the symptoms or diseases depicted in the images. Almost 98% were able to recognize CBSD symptoms in Image 4, which depicted severe necrotic rot on cassava roots. Image 6, showing brown streaks on the stems of a cassava plant, was the least recognized, with 82% of the interviewed farmers explaining the correct symptoms depicted by the image. Although farmers recognized some of the symptoms in the images and were able to describe their own experiences of grappling with the effects, they were mostly unable to provide actual names for the diseases in question.

When shown Image 9 (of the whitefly), approximately 70% of farmers indicated they had encountered whiteflies on cassava leaves and stems in their fields. However, Chikoti et al. (2015) reported a low prevalence of whiteflies in the three districts. Therefore, farmers may have mistaken the cassava mealybug – which produces a white substance on cassava stems and is widespread in the survey areas – to be the whitefly. On the other hand, it is possible that whitefly populations may have increased considerably since 2015. About 40% of the farmers who recognized the symptoms of CBSD mentioned they had first observed them on cassava plants several seasons prior to the survey period. About 51% of farmers indicated that the part of the cassava plant where they commonly observed CBSD symptoms was the roots, followed by the leaves (reported by 42% of respondents). The stem was where farmers least observed CBSD symptoms (reported by 36% of respondents). When the farmers were asked if they had previously used cassava cuttings exhibiting any of the symptoms associated with CBSD for planting new cassava fields, nearly 30% responded affirmatively. On the other hand, 44% of farmers indicated they had not previously planted cassava cuttings exhibiting CBSD-associated symptoms, and 27% were not certain. The majority of farmers in all survey districts stated they were unaware of the cause of CBSD and the factors aggravating its spread. About 66% and 70% of respondent farmers from Chienge and Kaputa districts respectively were the highest proportion of surveyed farmers that indicated limited awareness of the cause and the aggravating factors associated with CBSD spread (Figure 3.)

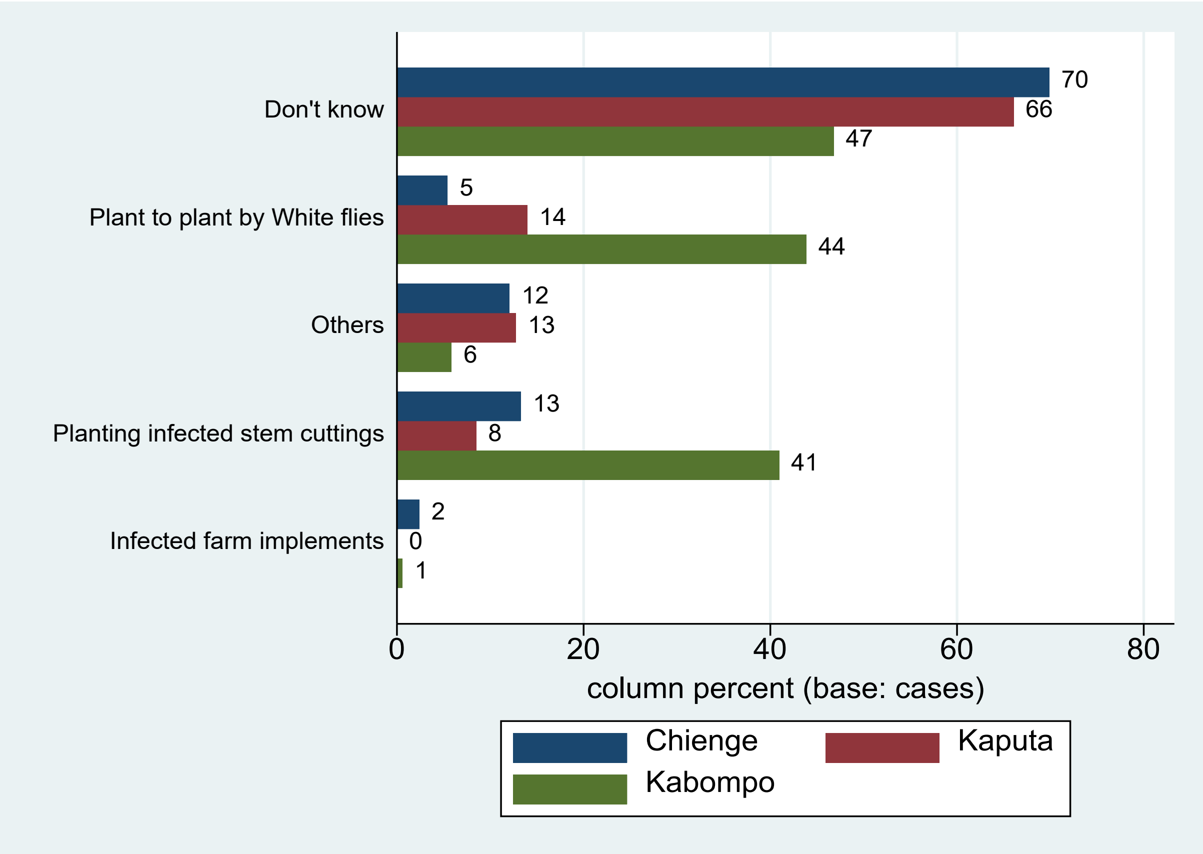

Figure 3: Farmer knowledge of the causes of CBSD spread in Zambia

Farmer descriptions of their experience of hard rots in cassava – depicted in Images 3, 7 and 8 – indicates that CBSD is likely present and spreading in all three survey districts. This corroborates the findings of Mulenga et al. (2018), who confirmed CBSD presence in the survey regions. Farmers expressed a dire need for more information on CBSD and requested assistance on how they could recognize the factors causing hard rot on their cassava roots.

Infestation by CBSD on cassava fields

At least one of the displayed symptoms related to CBSD had been encountered by 98% of respondent farmers from the survey districts. Overall, nearly, 80% of farmers mentioned the infestations were on the increase compared to previous seasons. The severity of infestation on cassava fields was minimal in Kabompo, where the majority of the fields (79%) had 0%–20% CBSD infestation, while most (37%) farmers in Chienge district reported 41%–60% infestation levels. Kaputa district had the highest infestation with most (48%) surveyed farmers reporting infestation levels of 41–60% (Table 5).

Table 5: The proportion of cassava fields affected by varying levels of CBSD

The proportion of cassava fields infested with CBSD	Districts			Overall
0%–20%	4%	8%	79%	31%
21%–40%	7%	17%	13%	12%
41%–60%	37%	48%	7%	30%
61%–80%	30%	22%	1%	18%
81%–100%	22%	4%	0%	9%

2.4 Farmer-based estimates of production and economic losses due to CBSD

The study sought to obtain estimates of cassava production from the farmers' fields considering the years 2016, 2017 and 2018. Cassava production data for the years 2019, 2020 and 2021 were obtained for comparison. This period covered a full cassava production cycle in the survey regions and also encompassed a period representing one year prior to two years after the first detection of CBSD in Zambia. Kaputa district had the highest average area under cassava cultivation (1.3 ha per farmer), while Kapombo district had the lowest (1.1 ha per farmer). In order to standardize the estimates, only the main harvest at the end of a cropping cycle was considered in the estimation of cassava production. Incorporating farmers' practice of piecemeal harvesting confounds production estimates because it is done on a variable needs basis dictated by the household's food security status, and recalling all minor harvests from three to five years before was challenging for the respondent farmers. The average production per hectare was between 0.7 and 1.0 tonnes in 2016 and below 1.0 tonnes in the subsequent two years. Over the entire three years considered in this study, farmers expected to harvest quantities of over 1.5 t/ha^{-1}.

Overall, the farmers reported an estimated average yield of 1.1 t/ha, constituting individual mean yields of 0.6 t/ha^{-1}, 1.0 t/ha^{-1} and 1.8 t/ha^{-1} for Chienge, Kaputa and Kabompo districts respectively. The expected average yield in the absence of CBSD symptoms across the three districts was 2.5 ha^{-1}. Respondent farmers in Chienge, Kabompo and Kaputa districts expected average yields of 2.1 t/ha^{-1}, 3.2 t/ha^{-1} and 2.0 t/ha^{-1}ha respectively. The estimated average yield loss due to CBSD for the 2019 to 2021 cropping seasons for Chienge, Kabompo and Kaputa districts were 1.49, 1.02 and 1.39 ha^{-1} respectively (Figure 4). The values for cassava production and productivity obtained by this study are indicative because accurate cassava yield estimates are difficult to make (especially in retrospect), largely because of piecemeal harvesting practices. Piecemeal harvesting is confounded by varying quantities and frequency of harvests, which in turn depend on specific household requirements. Moreover, farmer estimates of their own harvested quantities are often not expressed in standard units of measurement. A designed study to scientifically determine yield losses due to CBSD is recommended.

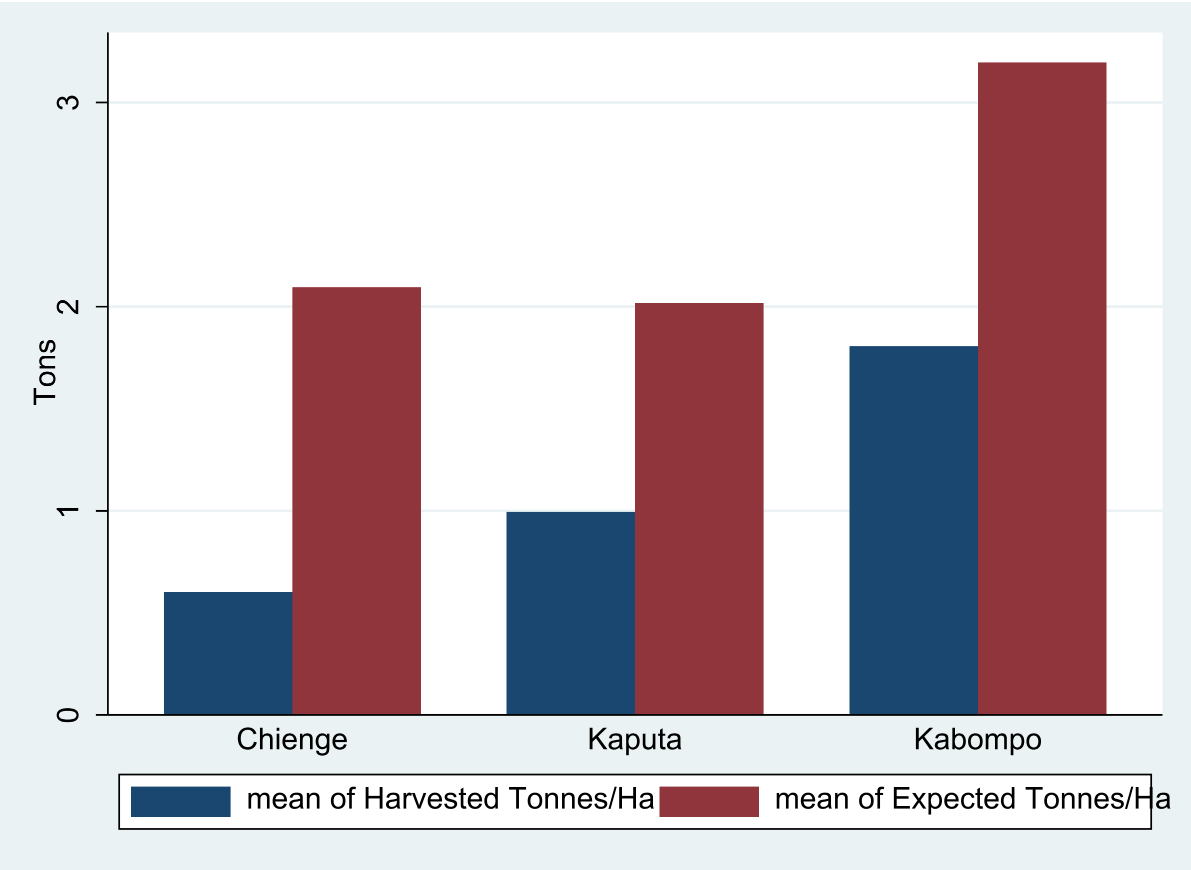

Figure 4: Cassava harvested from one hectare in 2019–2021 against expected harvest in the absence of CBSD

Farmers provided estimates of mean percentage cassava production losses due to CBSD between 2016 and 2018. According to Table 6, the estimated mean losses were 55%, with a minimum of 2% and a maximum of 99%. Figure 5 illustrate the estimate production losses trends on a district scale in 2016, 2017 and 2018. The production loss trends for Kaputa and Chienge districts are relatively higher than those of Kabompo. Notably, all three districts had higher projected cassava losses in 2018 than previous years, which could be attributed to CBSD.

Table 6: The mean (%) loss due to CBSD in 2016 – 2018

Percentage loss	Obs	Mean (%)	Min	Max
Chienge	118	72.7	7.4	99.0
Kaputa	111	51.1	5.4	98.0
Kabompo	122	40.4	2.0	98.3
Overall	351	55.4	2.0	99.0

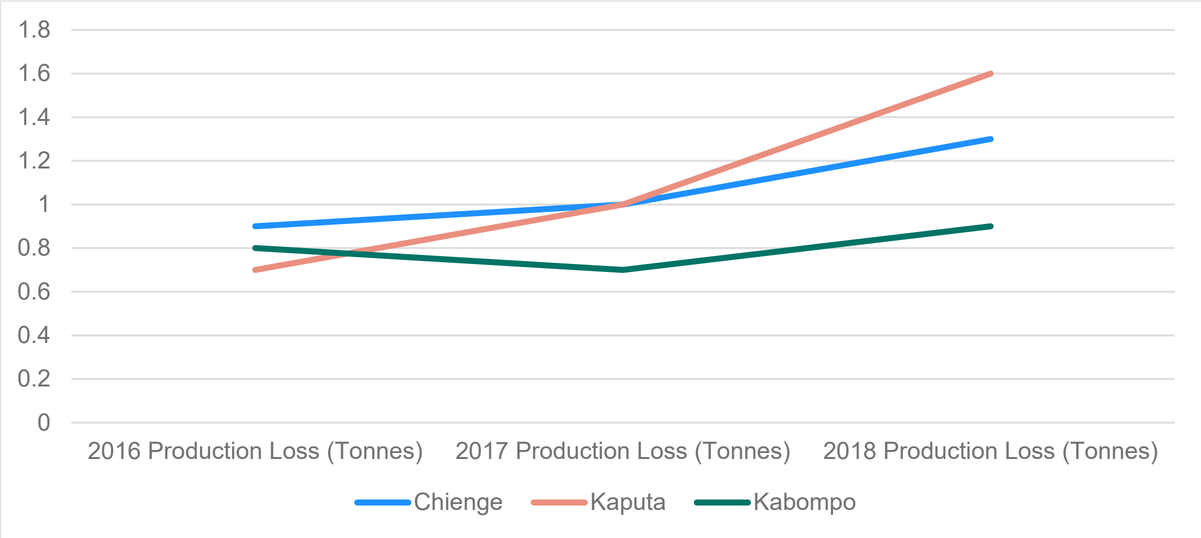

Figure 5: Cassava mean losses from one hectare in 2016, 2017 and 2018 due to CBSD

The average cassava yield loss estimates from the farmers' fields were used through extrapolation to estimate national production losses and their associated monetary value in US dollars. The national cassava production and corresponding prices of cassava per tonne were obtained from the Food and Agriculture Organization (FAO) Corporate Statistical Database (FAOSTAT) for 2015–2020. To compute the estimated national production losses, the yearly national yield losses were multiplied by the corresponding hectarage under production to obtain average production losses. The value of production losses was computed by multiplying the annual yield losses by the corresponding price per tonne. However, it was not possible to obtain the prices for 2016, 2017 and 2020 to enable the computation of the value of production and, subsequently, their corresponding yield losses. Production losses amounted to 0.5m tonnes in 2015 and 2.2m tonnes in 2018 and 2019. These losses in production were equivalent to US $340,000 in 2015, US $711,000 in 2018 and US $611,000 in 2019 (Figure 6). The trends in production losses for 2016–2019 suggest that losses were lower prior to the detection of CBSD in the survey districts. The years 2017–2018 indicate an increase in estimated cassava production losses, which is possibly attributable to the onset of CBSD in Zambia.

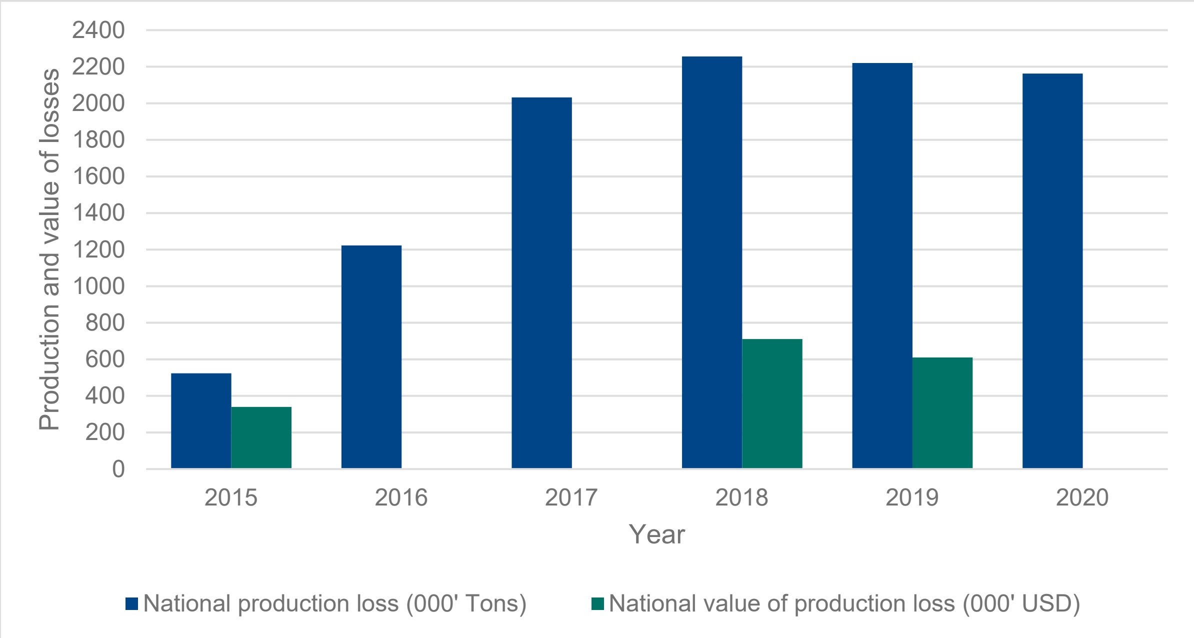

Figure 6: Cassava production losses and value of losses 2015–2020 in Zambia

Source: FAOSTAT 2022

2.5 Methods used by farmers to manage CBSD symptoms

CBSD management in Zambia

Farmer interviews, complemented by information from the FGDs, revealed that farmers had little or no knowledge of CBSD and of subsequent effective control or management measures for the disease. Over 55% of respondent farmers did not provide any options for CBSD management because of limited knowledge and understanding of the disease. About 67% of the farmers indicated that they monitored their cassava fields regularly, checking for abnormal changes (such as the presence of pests, discolouration and deformity of plant parts). This suggests the potential for timely detection of CBSD symptoms if the disease were to occur in these farmers' fields. The use of chemical pesticides, followed by resistant varieties, were the CBSD management methods least mentioned by farmers. The current low use of chemical pesticides for CBSD management by farmers provides an opportunity to demonstrate eco-friendly options for general pest management and to divert farmers' over-dependence on chemical control methods. The low use of resistant varieties affirms that there are currently no cassava varieties with validated resistance to CBSD. Kabompo district had the highest percentage of farmers using disease-free cuttings, which is attributable to the existence of a centre for the distribution of CBSD-free cassava cuttings in a neighbouring district. Although the centre is located in Lumwana district, some farmers from Kabompo were able to benefit from the disease-free cuttings distributed there. These farmers seem also to have received some form of training on CBSD management, as evidenced by the equal percentage (38%) of farmers who indicated the use of disease-free cuttings and of roguing as their management method. Roguing is a method of CBSD management recommended for farmers who produce cassava as seed and is therefore practised by contracted seed growers, who receive specialized prior training. Figure 7 summarizes the CBSD management actions taken by farmers.

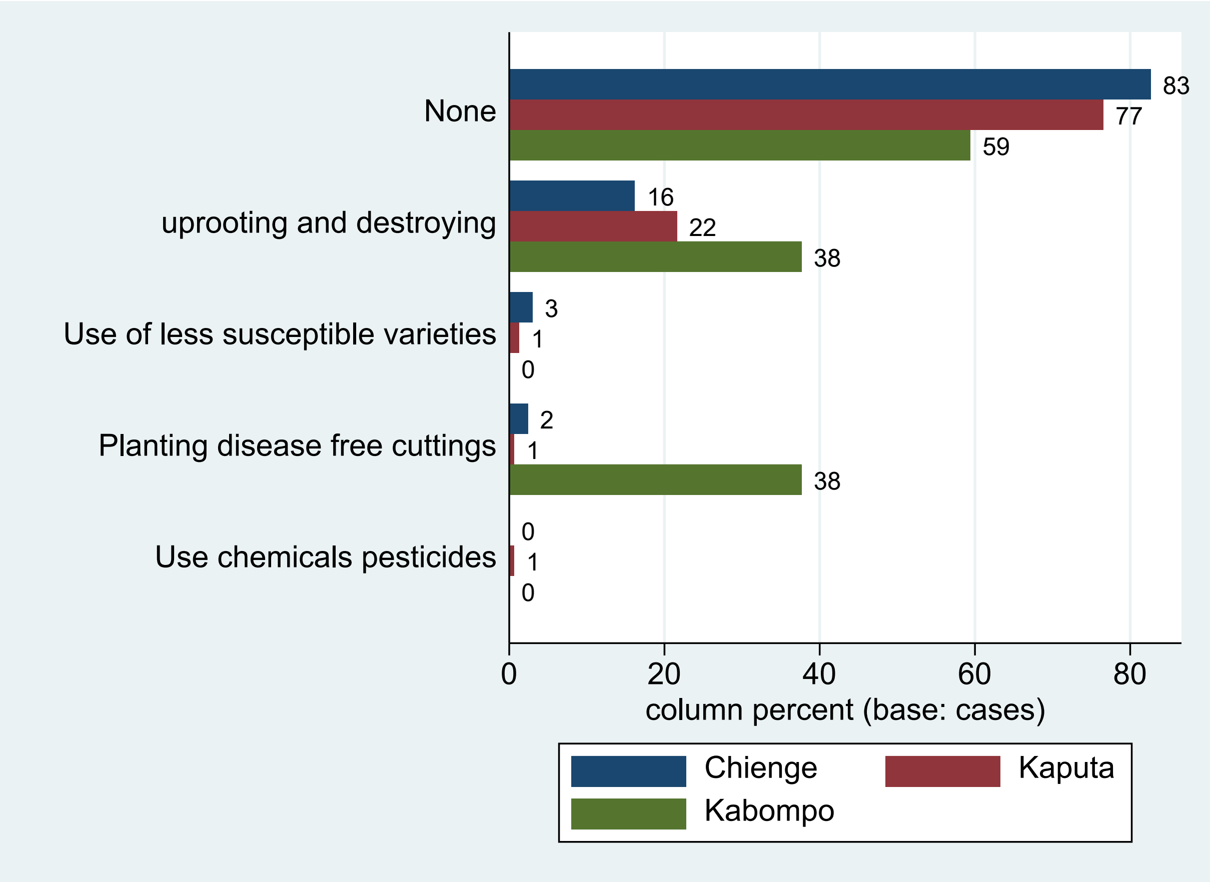

Figure 7: Control actions taken by farmers to manage symptoms of CBSD

Gender considerations in CBSD management

Integrating gender factors into the CBSD management practices mentioned by the respondent farmers showed gender-responsive trends for methods used by men and women in the survey districts (Table 7). In Kaputa district, a small proportion of men indicated that they planted clean cassava cuttings, used comparatively less susceptible varieties and sprayed chemicals in an effort to prevent CBSD, while the women did not use any of these three methods.

Table 7: Control actions taken by farmers (%)

	Chienge		Kaputa		Kabompo	
Control actions	Women	Men	Women	Men	Women	Men
None	84.2	82.4	79.0	75.8	61.1	59.0
Uprooting and destroying	15.8	16.2	21.1	21.8	38.9	37.3
Planting of clean cassava cuttings	0.0	2.7	0.0	0.8	38.9	37.3
Use of less susceptible varieties	5.3	2.7	0.0	1.6	0.0	0.0
Chemicals to prevent CBSD	0.0	0.0	0.0	0.8	0.0	0.0

Source of cassava cuttings for planting

Although farmers obtained cassava planting material from multiple sources, the most common sources were from their own older fields or from their neighbours' fields. In Kaputa district, 68% of farmers obtained propagative cuttings from their own fields, while 41% obtained them from their neighbours. In Chienge and Kabompo districts, 60% and 48% of farmers respectively obtained cuttings for planting new cassava fields from their neighbours' fields. The farmers who obtained propagative cassava cuttings from their own fields were 51% and 65% for Chienge and Kabompo districts respectively (Figure 8).

Overall, about 10% of the farmers had obtained cassava cuttings from outside their districts (Kabompo, Chienge and Kaputa). Kaputa district had the highest proportion of farmers who had obtained cassava cuttings from other districts (17%), including Nchelenge, while Chienge had the smallest proportion of farmers that sourced cuttings from outside the district (4%).

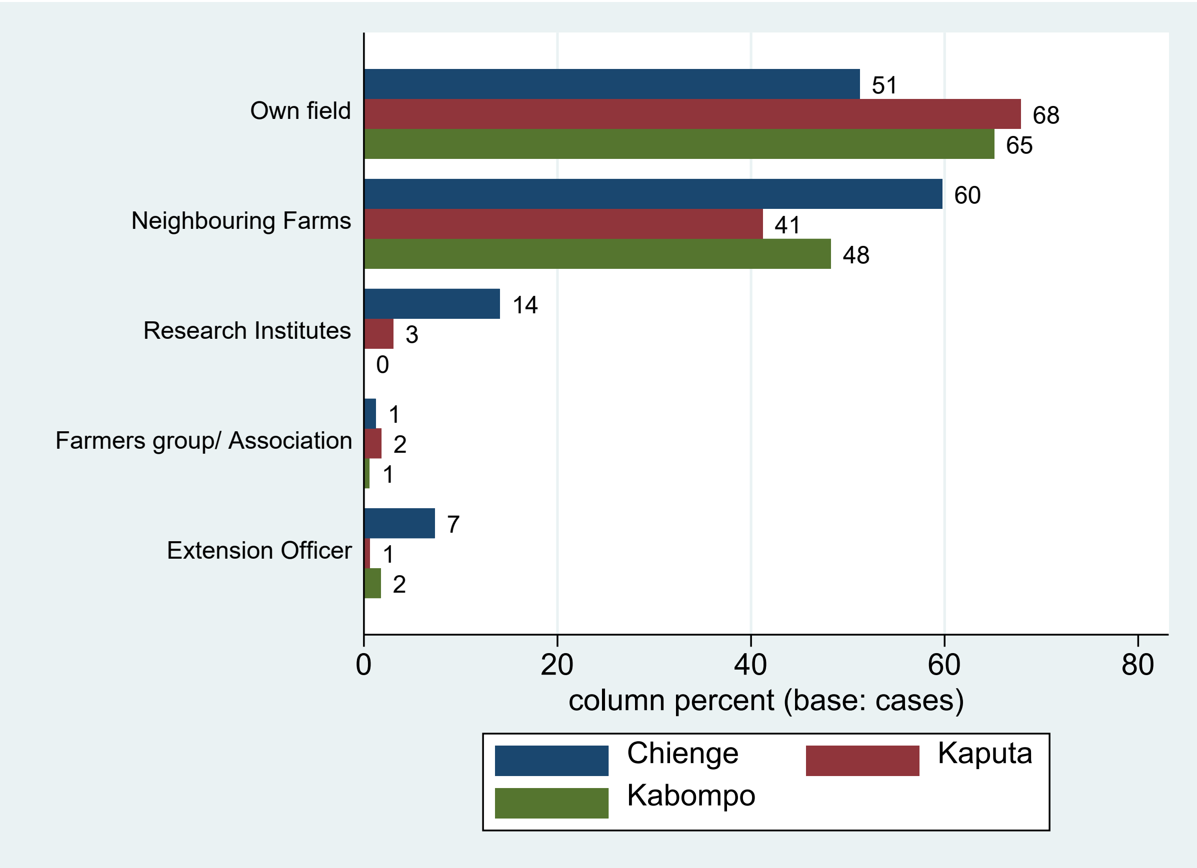

Figure 8: Sources of planting cassava cuttings

The farmer-to-farmer exchange of contaminated cassava planting material was identified as the major pathway through which CBSD is potentially spreading in Zambia. Farmers attributed this practice to variety preference and to the availability of the planting material (Szyniszewska et al. 2019). In addition, long-distance spread of whitefly-transmitted CBSD viruses is largely driven by human movement of infected planting material from regions where the disease exists to disease-free regions (Mulenga et al. 2018; Maruthi et al. 2017; Mbewe et al. 2015).

CBSD management methods in other countries and their implications for Zambia

In other countries where CBSD has existed for many years, such as Uganda, Kenya and Tanzania, several approaches – including crop hygiene, phytosanitary regulations and the use of resistant cultivars – have been used in an effort to manage CBSD. Crop hygiene or phytosanitation represents a strategy that can be employed more readily than resistant cultivars, provided a facility for the mass generation of disease-free cuttings is established. In many SSA countries, cassava planting material comes either from a farmer's field, from neighbours or from marketing middlemen, who seldom bother about the disease status of the planting material. The provision of a credible source for obtaining certified disease-free cuttings is therefore a promising strategy (Chikoti 2011). It is even more promising when coupled with additional crop hygiene practices, such as the removal of volunteer cassava plants and crop debris that may serve as carriers of inoculum from the previous season's crop (Fargette et al. 1990). Comprehensive phytosanitation thus emphasizes the use of both disease-free planting material and field hygiene, and has been shown to be effective in the case of CMD control. For instance, careful selection of clean planting material from CMD-susceptible cultivars in western Kenya resulted in cassava yields that were similar to those of CMD-resistant ones (Mallowa et al. 2014). In Tanzania, cassava yields have been enhanced through the use of disease-free cuttings (IITA 2017).

The use of disease-free cuttings has not yet been extensively adopted in Zambia, despite the demonstrated impact of the practice: a 2002–2004 study on CMD targeting Mansa and Lusaka revealed a yield improvement of 21% over the control (Alene et al. 2013). Currently, farmers are using few methods, if any, to manage CBSD spread, partly because they have only recently become aware of the existence of the disease and also partly because of limited access to alternative control options. Moreover, there is a growing tendency among farmers to resort to chemical spraying in response to any pathological problem they encounter in their fields. Thus, yet another hurdle to overcome is the need to persuade farmers to see CBSD as a viral disease for which chemical pesticides are ineffective. Presently, the most readily applicable strategies for CBSD management in Zambia involve recommended phytosanitation practices and the implementation of more stringent phytosanitary regulations. In the long term, the development and deployment of CBSD-resistant cassava cultivars will provide the most sustainable management strategy for the disease.

There are currently no CBSD-resistant cultivars for use by farmers in Zambia. Breeding efforts by scientists from ZARI and the International Institute of Tropical Agriculture (IITA) are underway. Given the devasting impacts already experienced by farmers on account of CBSD, the stage has been adequately set for the deployment of resistant cultivars once they are available. Farmers seem more than willing to use resistant cultivars in the affected areas. Nonetheless, a participatory breeding approach that involves farmers' inputs through the main stages of the breeding process will ensure greater capture of farmers' preferred traits, which will in turn lead to the more sustainable use of new cultivars.

Borrowing from the trend observed prior to CMD establishment in Zambia, it is most likely that concerted multi-sectoral and multidisciplinary efforts are needed for the effective management of CBSD. Approaches for managing CMD in Zambia – including improved diagnostics and monitoring; the use of disease-free stem cuttings; the use of CMD-resistant cassava cultivars; and stakeholder training – have focused on the principles of phytosanitation and host-plant resistance.

3. Advice, information and communication

3.1 Sources of information on CBSD control

Farmers indicated three main sources of general information on cassava production, involving both informal and formal sources. The most common sources of information on cassava production were informal and included indigenous knowledge (represented by 39% of farmers), neighbours (29%) and friends and family (29%). Farmers' formal sources of information on cassava production mainly came from government extension officers (as alluded to by 5% of respondent farmers) (Figure 9).

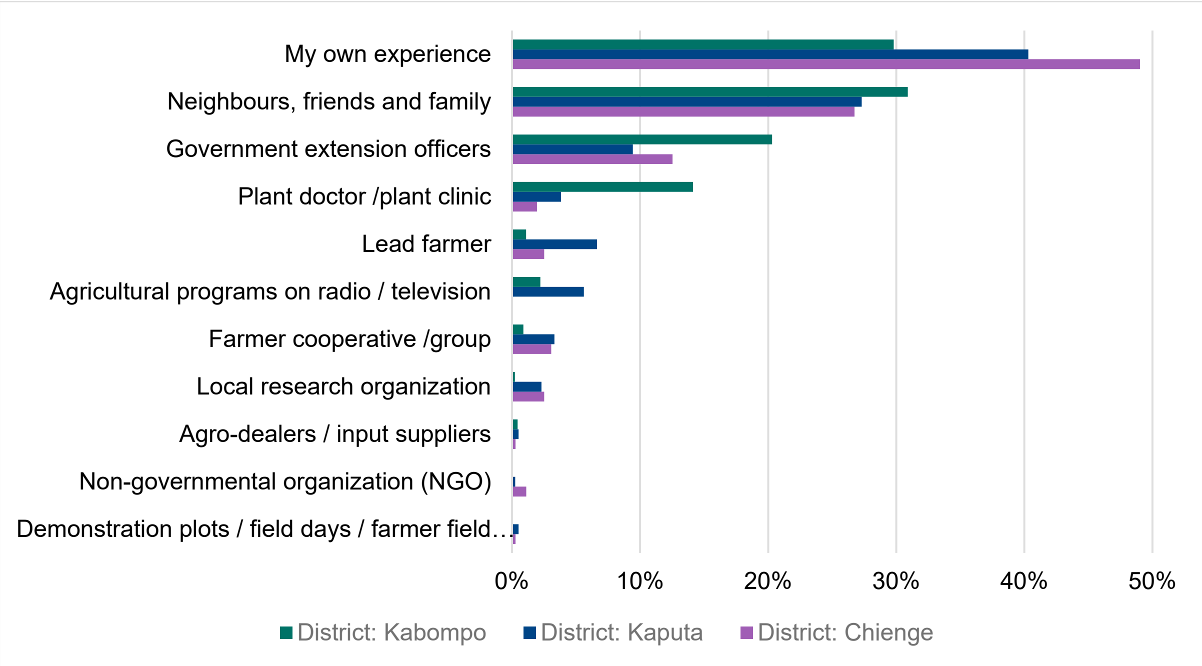

Figure 9: Sources of general information on cassava production

The pattern of information sources regarding cassava production was similar across the three survey districts. For Chienge, Kaputa and Kabompo districts, 49%, 40% and 30% of farmers respectively obtained information on cassava production from indigenous knowledge. Cassava production information from neighbours, friends and family was the second most important information source, accounting for 27% for both Chienge and Kaputa districts and 31% for Kabompo district. Government extension officers ranked last as a source of information on cassava production and was represented by 13%, 9% and 20% from Chienge, Kaputa and Kabompo districts respectively. The least mentioned sources were demonstration plots, non-governmental organizations and agro-dealers, each constituting less than 1%.

About 40% of respondent farmers in the survey were aware of CBSD occurrence in Zambia. Of this proportion, 62% indicated that their most common sources of information on CBSD management were agricultural extension agents and 26% indicated it was other farmers. In Kabompo district, 94% of farmers indicated that agricultural extension officers were the most common source of information on CBSD management, while in Chienge and Kaputa districts other farmers were the most common information source represented (by 55% and 44%

respectively). Other sources of CBSD-related information included radio programmes (represented by 7% of farmers) and ZARI (represented by 3%) (Figure 10).

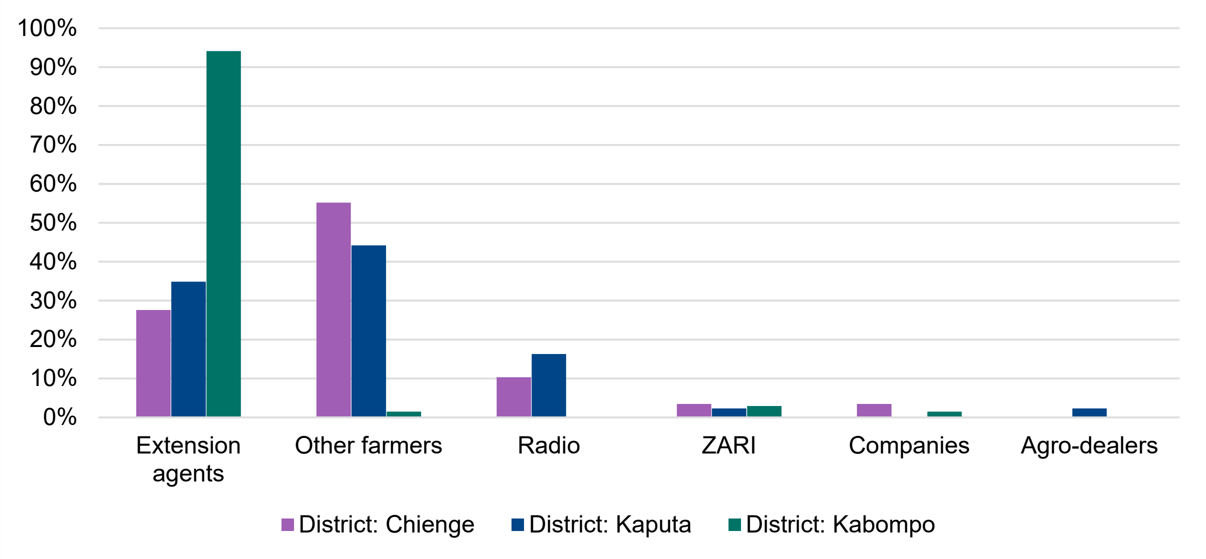

Figure 10: Sources of information for the control measures and methods for managing CBSD in cassava (n = 208)

Generally, few farmers indicated awareness of CBSD and were seeking information on how to effectively manage it to mitigate the losses incurred in their fields. This is mostly attributable to the recency in detecting CBSD in Zambia, and implies the inadequate spread of information on management due to the novelty of the disease.

At the time of the survey, only 6% of respondent farmers in the three districts had received some form of training on how to identify and manage CBSD. They indicated that their training had involved topics on uprooting and burning infected plants (32%), removing crop residues and damaged crops showing symptoms of pests (23%), crop rotation (15%) and frequent weeding (11%). The DoA provided the training through camp extension officers and research organizations, lead farmers and commercial cassava producers.

3.2 Information resources and tools

Limited farmer knowledge of CBSD existence, symptoms and aggravating factors prompted the interest of CABI to partner with ZARI and the DoA in Zambia to conduct communication campaigns in the traditional cassava growing districts of Zambia. The campaigns were aimed at awakening nationwide interest in CBSD to spur concerted efforts in devising effective management strategies. So far, CBSD communication campaigns have focused on closing knowledge gaps by increasing farmer awareness of the existence of the disease, its symptoms, the aggravating effect of sharing cuttings among farmers and the negative impact of low phytosanitation practices. Several districts across four provinces (Northern, Luapula, North-Western and Western) have currently been covered by various communication activities including farmer sensitization gatherings, plant health rallies, radio programmes, SMS campaigns and the distribution of information, education and communication materials (including posters and factsheets). These efforts have reached a considerable number of farmers who have become aware of the existence of CBSD, its main symptoms and where to obtain further information. CABI continues to conduct communication campaigns with targeted messages for various stakeholders in order to actualize the necessary concerted efforts to curb CBSD in Zambia.

4. Recommendations

Despite the limited period during which CBSD has been encountered in Zambia, lessons from the experience thus far and examples from other countries that have had it for years suggest actionable steps applicable to different stakeholder groups. The multi-faceted nature of the CBSD problem in Zambia invites farmers, high-level policymakers, regulators, researchers and farmer extensionists to a engage in dialogue platform where each stakeholder's pledge in mitigating CBSD is most critical.

High-level policymakers

- CBSD is a policy problem because it affects the survival of a very promising sub-sector of Zambia's agriculture. Policymakers should therefore be equipped with the correct and latest information on CBSD as the current major biotic challenge capable of collapsing the subsector
- Invest in coordinated cassava breeding programmes through collaboration with the research department to develop CBSD-resistant varieties among the various stakeholders across the country
- The Cassava Sector Development Strategy for Zambia requires updating to include explicit strategic actions on addressing the most devasting cassava diseases, key among them being CBSD. The generalized information currently contained in the strategic document compromises efforts towards tackling the disease at a national scale because it is currently the main guiding document for interventions in the cassava subsector

Regulators (SCCI and PQPS)

- Promote joint efforts between the SCCI and the PQPS to influence compliance with cassava seed multiplication standards
- Educate and create awareness, especially among farmers living close to the border areas between Zambia and other countries, about the importance of adhering to quarantine requirements and avoiding the movement of uncertified cassava cuttings within and across borders
- Strengthen the surveillance of border points to prevent crossing of cassava materials to minimize CBSD
- Institute stringent quarantine regulations to prevent the movement of CBSD-infected cassava cuttings and implement rigorous phytosanitary standards during the multiplication and distribution of cassava planting material

- Introduce effective diagnostic techniques for the surveillance, monitoring and forecasting of CBSD spread to enable timely application of management and containment measures
- Track changes in local whitefly populations, especially in new outbreaks and threatened areas, to enable timely response in mitigating the aggravating factors associated with whitefly population increases

Researchers

- Ensure the movement of cassava germplasm between countries adheres to all prescribed export procedures, including pre-export inspections, and that all necessary documentation is present, such as virus-indexed tissue culture forms
- Regularly inspect cassava multiplication plots/blocks from pre-planting to post-harvest for the presence of CBSD or CBSD-related symptoms
- Collaborate with other stakeholders in developing and deploying CBSD-resistant cassava varieties, ensuring that efforts in advancing CBSD research are properly co-ordinated
- Encourage research on the identification of natural enemies of the CBSD vector.

Farmer advisers and advisory services

- Educate farmers on their role in exacerbating CBSD spread through the practices of sharing and moving planting material from one field to the next and from one farmer to another
- Develop various communication materials on CBSD and devise innovative ways of sharing information with farmers to enable them to learn about the disease and its symptoms, causes, effects and mitigation measures
- Farmers contracted to multiply cassava planting materials should be well trained and equipped with the necessary knowledge and skills on proper identification of CBSD to avoid disease spread through the distribution of diseased planting material to other farmers
- Work in close collaboration with farmers contracted as seed multipliers to oversee their seed multiplication activities, and provide information and guidance on CBSD identification and management to other farmers sourcing planting materials from contracted farmers
- Agricultural extension personnel should familiarize themselves with the performance of various cassava varieties in terms of CBSD and farmer-preferred traits to enable them to make recommendations to farmers and breeders on suitable varieties for current production and breeding.

Farmers

- Cassava farmers should ensure they use planting materials with no CBSD symptoms and should obtain cuttings from CBSD-free sources
- Farmers contracted as cassava seed multipliers should ensure that all infected cassava plants in their seed fields are uprooted and destroyed to avoid distributing infected propagative material to recipient farmers' fields
- Institute collective community-level actions among farmers growing cassava to instigate the implementation of sanitary and phytosanitary measures, including sourcing and maintenance of CBSD-free planting material and the subsequent selection of clean cuttings for propagating new fields of cassava
- Farmers should consult extension service providers on recommended cassava varieties for planting to minimize damage and losses due to the combination of CBSD and other conditions.

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Annex 1: CBSD farmers' knowledge of disease photos

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Photo 8

Photo 9

Description of image symptoms

Photo 1: Chlorotic lesions on cassava leaf. *Photo Credit; CABI*

Photo 2: Closer view: feathery veins and chlorotic patches on cassava leaf. *Photo Credit; CABI*

Image Photo 3: Shrivelling and hard rots forming on cassava roots. *Photo Credit; CABI*

Photo 4: Closer view: root necrosis – cassava roots damaged by CBSD-inflicted hard rots. *Photo Credit; CABI*

Photo 5: CBSD affected cassava field. *Photo Credit; CABI*

Photo 6: Streaks forming on a young stem of the cassava plant. *Photo Credit; CABI*

Photo 7: Shrivelled cassava roots and hard rots. *Photo Credit; CABI*

Photo 8: Combination of CBSD symptoms on leaves stems and roots. Chlorosis on leaves, necrosis on roots and brown streaks on stems of the cassava plant. *Photo Credit; CABI*

Photo 9: Whiteflies on a leaf. *Photo Credit; Suwilanji Sichilima from ZARI*

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